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United States Air Force Academy

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Falcon Sat-3
2nd Structural Engineering Model (SEM2)
Vibration Test and Mass Properties Measurement
Test Report

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Revisions

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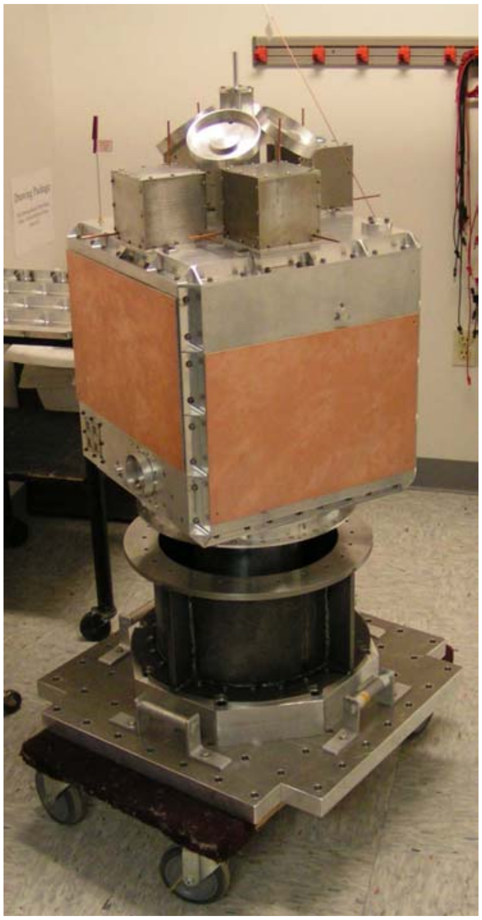
1 Executive summary



The FalconSAT-3 (FS3) 2nd Structural Engineering Model 2 (SEM2) is the second iteration on the campaign to launch for FS3. This test will be a stepping stone in its progress.

The SEM2 test is a development test to support the design of the FS3 spacecraft, which is fourth in a series developed for educational purposes in the Small Satellite Program at the United States Air Force Academy (USAFA). FS3 will be launched on a Lockheed-Martin Atlas-V ESPA, currently scheduled for October 2006. The SEM2 testing is the second of three planned phases of testing, with testing of the Qualification Model (QM) planned for the spring of 2004 and acceptance testing of the Flight Model (FM) planned for the spring of 2005.

The purpose of the SEM2 test is to build confidence in the structural design and to acquire information that will help improve that design. The SEM2 consists of copies of the primary and secondary structures of the flight spacecraft, with detailed avionics and payload mass dummies designed and built to have the key characteristics of the preliminary structural configuration for the flight model. Mass simulators represent and replace the spacecraft's operating equipment, distributed in such a way as to give the SEM2 flight-like mass properties.

All tests and measurements will be performed at the Aerospace Engineering Facility (AEF) at Kirtland Air Force Base (KAFB), New Mexico. Testing took place 19-22 January 2004.

SEM2 was tested for low-level sine sweep to determine the fundamental and other natural frequencies, and random vibration and sine burst to confirm strength and structural integrity. Testing was done to qualification levels, with test environments conservatively defined, recognizing that the launch vehicle is relatively new and that this will be the first flight of the ESPA. We expect environments defined by the LV program to change throughout the FS3 development program, and the SEM2 was tested at least as severely as the qualification model will be tested.

The mass properties of the SEM2 test were measured to verify the design data.

This test report provides the details of the tests that were performed.

2 Scope

2.1 Introduction

This test report describes the Structural Engineering Model 2 (SEM2) testing for FalconSAT-3. The FS3 program will use these results to verify the design of both the primary and secondary structures, including some of the payloads. The SEM2 was vibrated to qualification levels to demonstrate appropriate margins in the design.

2.2 Vibration tests

The following tests were performed separately in the X, Y and Z-axes:

- Low-level sine sweep
- Sine burst (with and without the Shock Ring)
- Random vibration (with and without the Shock Ring)

2.3 Mass Properties

The following mass properties were measured for various spacecraft configurations:

- Mass
- Center of Gravity in X, Y & Z
- Moments of Inertia in X, Y & Z

3 Test objectives and summary results

3.1 Introduction

The main purpose of SEM 2 was to validate the detailed structural design of FalconSat-3 and develop procedures for the assembly of the structure. This information will be used for the qualification and flights models.

Specific objectives and corresponding results were as follows:

- Objective: Give cadets hands on experience with spacecraft
    - Result: All cadets were active in the planning and execution of the tests for the SEM2. Everyone involved gained a deeper understanding of the testing procedures and the mechanics principles behind the FalconSAT program.
- Objective: Validate assembly procedures

  - Result: The procedures for assembling the satellite were completed successfully. Alterations in the plan were made in order to improve facilitate a better assembly of the qualification and flight models.
- Validate structural modifications from SEM1
  - Result: All alterations of the design were made in accordance to the Rev B design specifications.
- Validate the computer based structural FEM
  - Result: The satellite matches the design that have been specified in the drawing package.
- Determine system response to mechanical vibration loads
  - Result: System was characterized according to its response to given inputs.
- Measure satellite mass properties
  - Result: The mass properties match the predicted properties.
- Determine the functionality of the Shock Ring
  - Result: The shock ring functions as it should in reducing the first mode of the satellite when attached to the testing stand and in turn the launch vehicle. This occurs in all configurations of the satellite.
- Train in the use of the mounting interfaces to be used with the QM and FM spacecraft
  - Result: Mount devices for the QM and FM will have to be modified in order treat the satellite with more care to protect the flight hardware that will be attached at stages in the design.

All test configurations and set-ups were photographed and described in relevant detail during the tests. Detailed sketches with dimensions were made where appropriate to include in the test report.

3.2 Safety

Mechanical tests are inherently dangerous, with heavy lifting and maneuvering required. During the actual tests a lot of energy was imparted into the SEM2, with risk of items breaking off and moving at speed. All personnel were briefed on test facility safety by Mr. Dale Stottlemeyer, the AEF safety officer prior to the start of the test campaign. Hard Hats and Safety glasses were used when dealing with the satellite.

3.3 Tests

3.3.1 Sine Sweep

The objective of the Sine sweep was to determine the fundamental and further natural frequencies, modal shapes and modal gain of the structure in the three main axis, and, by repeating this test after the high-level sine burst and random vibration, to determine whether anything in the satellite changed or broke as a result of the tests by comparing the responses pre- and post-test. The fundamental frequency must meet launch vehicle requirements. This information will also be used to validate and further develop the computer based structural FEM of the spacecraft, and it will aid in analysis of any design changes that may be made.

3.3.2 Random Vibration

The objective of this test was to verify the capability of the satellite structure and components to withstand the fatigue introduced during the launch vibrations

3.3.3 Sine Burst

The objective of this test was to check the static strength of the spacecraft structure to determine whether it could withstand the launch acceleration loads. This test was performed both with and without the Shock Ring, as the Shock Ring was not designed to withstand the loads defined for design and test of the FS-3 SEM2. The difference in design loads is because of geometry; the Shock Ring is cylindrical, whereas the FS-3 has a square cross section. To ensure that testing in one axis at a time would adequately stress the FS-3 structure, encompassing the multi-axis design loads specified for ESPA payloads, the single axis acceleration had to be higher than needed to adequately test the cylindrical shock ring. The test with the Shock Ring therefore was performed with a reduced acceleration.

3.3.4 Mass

The mass of the satellite was measured to determine its launch weight and will be used for attitude control purposes. This value was also required to calculate the Center of Gravity and Moments of Inertia from the output values of the mass properties table. The mass must also meet launch vehicle requirements. The measured mass will be used to update the computer based FEM, and it should be close to the calculated mass to validate the method of predicting mass.

3.3.5 Moments of Inertia

The Moments of Inertia were measured in three axes. These values are required to analyze the satellite tip-off during deployment in space from the launch vehicle, and for the attitude control algorithms that are used while in space. The measured MoI will be used to update the computer based FEM. Also, the measured MoI will be compared to the calculated MoI in order to validate the method used for predicting MoIs.

3.3.6 Center of Gravity

The Center of Gravity was measured in three axes. This value is required to analyze the satellite tip-off during deployment in space from the launch vehicle and for the attitude control algorithms. This value must also meet launch vehicle requirements. The measured CoG will be used to update the computer based FEM. Also, the measured CoG will be compared to the calculated CoG in order to validate the method used for predicting CoGs.

3.4 Test success criteria

3.4.1 General

The structure was visually inspected from the outside, without disassembly, between tests.

For bolt-torque checks, locking features were considered effective if fasteners did not rotate at a torque of 80% of the initial installation torque. If rotation was detected in any fasteners at a torque below 90% of the installation torque, all fasteners of that type were re-torqued to the installation torque where accessible without disassembly. Only those fasteners that were easily accessible were inspected between tests. All others will be checked during inspection disassembly upon return to USAFA.

Test anomalies required partial disassembly of the SEM2 to enable inspection and/or repair, or replacement e.g. of accelerometers. This was performed with the agreement of the Responsible Test Engineer.

3.4.2 Sine sweep

- The fundamental frequency of the spacecraft with the Shock Ring attached was expected to be approximately 30 Hz; without the Shock Ring it was expected to be higher
- Peak acceleration at fundamental frequency was not to shift by more than +/- 20% (TBD by Responsible Test Engineer) during tests, as determined by the low-level sine sweeps before and after the high-level tests
- Fundamental frequency was not to shift by more than +/- 5% (TBD by Responsible Test Engineer) during tests, as determined by the low-level sine sweeps before and after the high-level tests

3.4.3 Random vibration

- No damage to the spacecraft
- No fasteners losing more than 20% of original torque

3.4.4 Sine Burst

- No damage to the spacecraft

3.4.5 Mass

- Mass <55 kg (nominal maximum allowed value)

3.4.6 Moments of Inertia

- Measurement only, Ixx should have been close to Iyy, within 10%

3.4.7 Center of Gravity

- Lateral CoG (X-Y plane) must have been within 0.25" radius of the line centered on the center of the separation ring
- Axial CoG (Z axis) must have been within 10.25" of the separation plane (9.00" from the bottom surface of the base plate)

4 Test article

4.1 Introduction

The test article is the second Structural Engineering Model of FalconSat-3 (SEM2). The primary structure consists of an 18" cube made of six machined aluminum panels and an aluminum adapter ring attached to the Lightband separation mechanism and the Shock Ring.

The test article includes the mechanical avionics stack with mass simulators for the electronics and simulators for the payloads and the boom (stowed simulator) to provide for realistic structural loading of the structure while being tested.

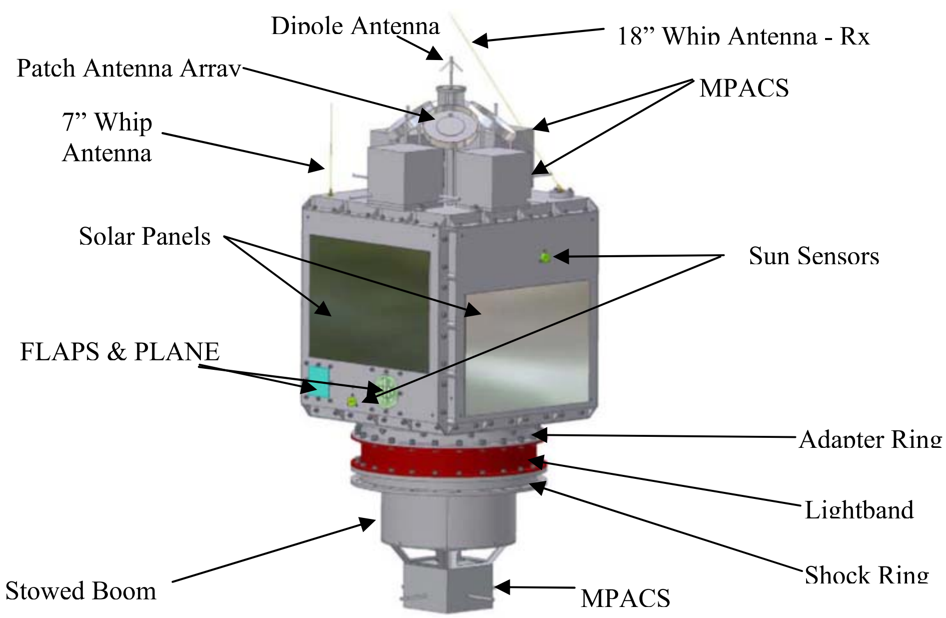


Figure 1 FalconSat-3 external configuration

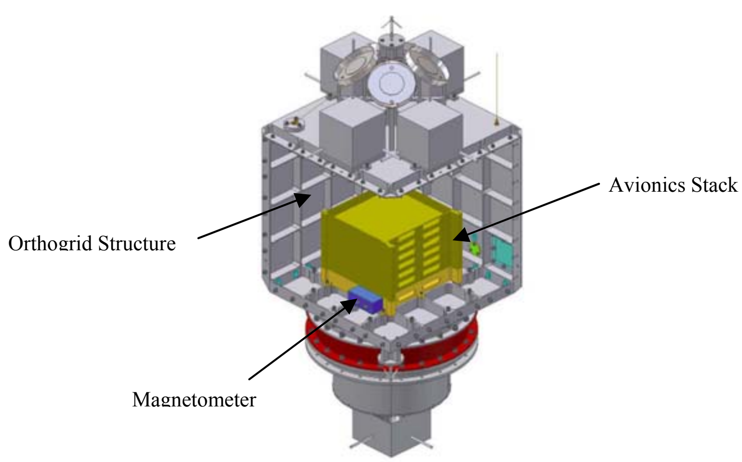


Figure 2 Internal view of FalconSat-3

4.2 Spacecraft axis

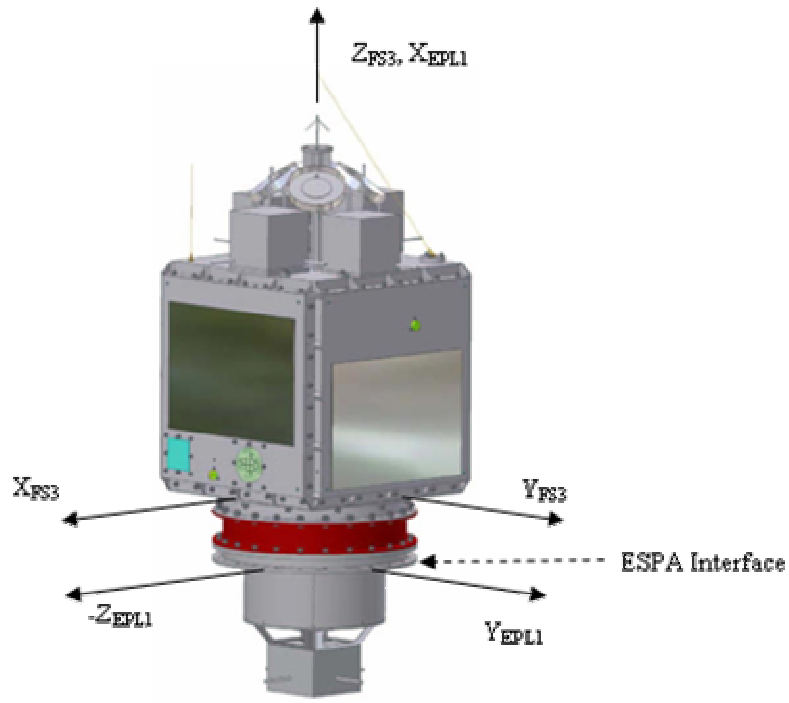


Figure 3 FalconSat-3 axis diagram

4.2.1 ESPA local coordinate system

- X_{EPL1}, Y_{EPL1}, Z_{EPL1}
- Origin at center of ESPA mechanical interface

4.2.2 FalconSAT-3 (FS3) / Space Vehicle (SV) coordinate system

- X_{FS3}, Y_{FS3}, Z_{FS3}
- Origin at center of bottom surface of the satellite's base plate

4.2.3 Relationship of FalconSAT-3 to ESPA Local Coordinate System

- $X_{EPL1} = Z_{FS3} + 5.38$ inch
- $Y_{EPL1} = Y_{FS3}$
- $Z_{EPL1} = -X_{FS3}$

4.3 Estimated mass properties

The mass properties of SEM2 have been estimated from the computer model as shown in Table 1and Table 2.

MOI	kg-m^2	lbm-in^2	lbf-ft-s^2	lbf-in-s^2

Ixx	3.9	1.31E4	2.83	33.99
Iyy	3.9	1.33E4	2.87	34.46
Izz	1.4	4.51E3	0.97	11.68
Products	~0	~0	~0	~0

Table 1 Calculated Moments of Inertia

Coordinate	in	m
X	0.13	0.003
Y	0.04	0.001
Z	5.19	0.13181

Table 2 Calculated Center of Gravity

These mass properties include the complete Lightband, the Shock Ring and the stowed boom. The origin for the MoI is the Center of Gravity, the origin for the Center of Gravity is the Bottom Center of the spacecraft baseplate, where it interfaces to the Interface Ring.

The mass is estimated to be 49.6 kg (109.12 lb).

4.4 Mechanical dimensions of test article

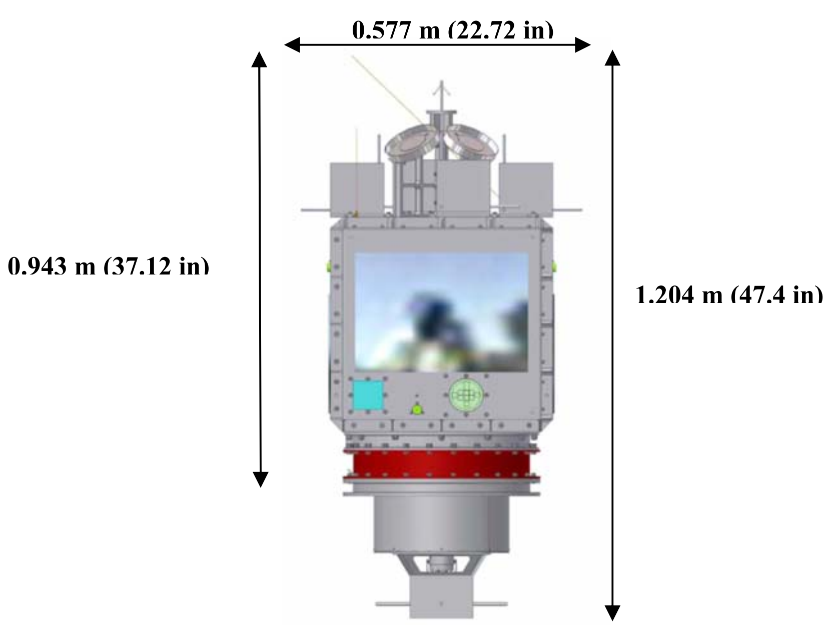


Figure 4 SEM2 overall dimensions

4.5 Mechanical interface to vibration table

The test article was mounted on the vibration table using a USAFA supplied extender and interface plate. The interface plate bolts to both the vibration slip table and directly to the head.

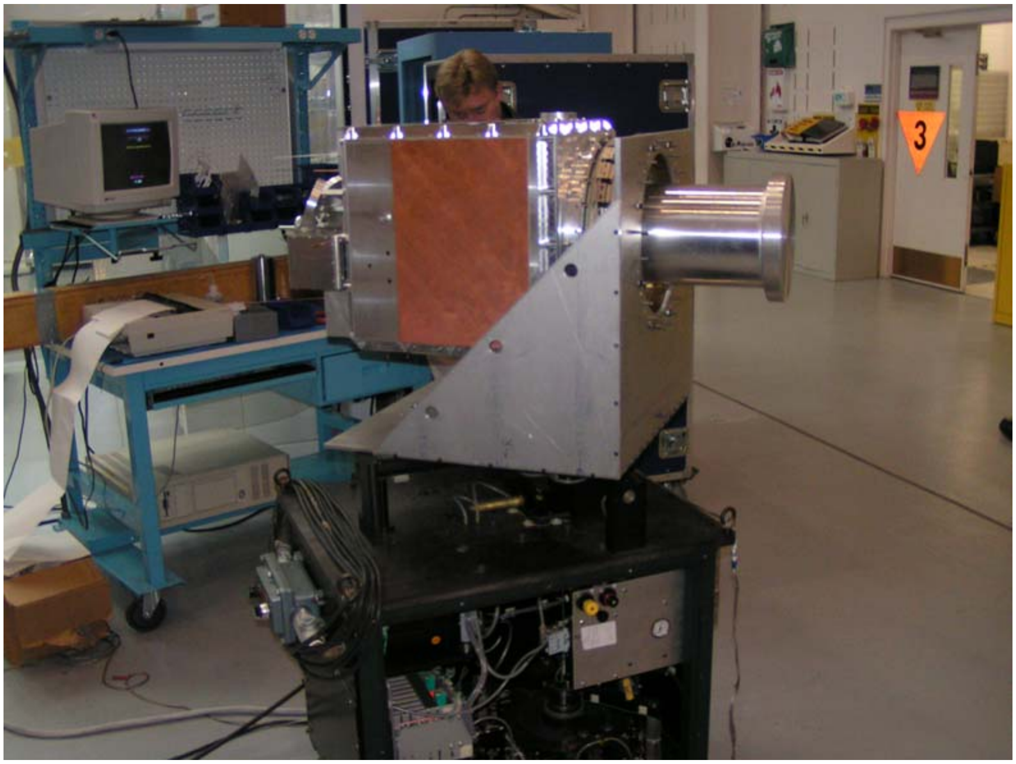


Figure 5 SEM2 mounted on the Mechanical properties table

4.6 Mechanical interfaces to Mass Properties table

For the mass properties test, the SEM2 was mounted in both the horizontal and vertical direction. Two mounting brackets were available for this test, both interfaced to the table. The interfaces were compatible with FS3 SEM2, QM and FM. The interfaces were measured separately using the mass properties table to enable the final SEM2 properties to be calculated from the combined measurements.

4.6.1 Vertical mounting

The vertical mounting bracket supported the spacecraft onto the mass properties table to measure the following:

- Moment of Inertia around Z from SC origin (Izz)
- Center of Gravity in the X axis from SC origin
- Center of Gravity in the Y axis from SC origin

The vertical mounting interface was also used to support the horizontal interface during spacecraft assembly.

Figure 6 Vertical stand (shown mounted under Horizontal stand)

4.6.2 Horizontal mounting

The horizontal mounting bracket allowed the spacecraft to be mounted onto the mass properties table to measure the following:

- Moment of Inertia around X from CoG (Ixx)
- Moment of Inertia around Y from CoG (Iyy)
- Center of Gravity in the Z axis from SC origin

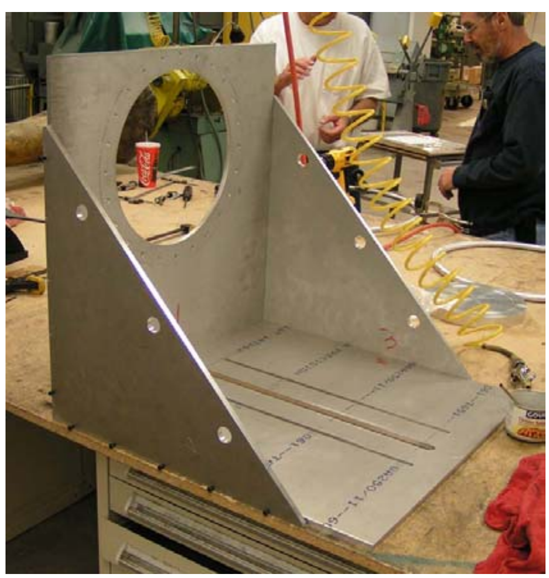


Figure 7 Horizontal mounting interface

The horizontal mounting bracket facilitated the rotation of SEM2 between horizontal and vertical positions. The composite was held at all times when lifted, to prevent any unwanted rotation; and no personnel stood under a suspended load at any time. The interface was mounted onto the vertical interface for support and to clear the spacecraft boom when assembled. The horizontal mount had an additional leg to support it: this was assembled before the interface was positioned onto the vertical stand. The satellite was then lowered onto the interface, and eight nuts were assembled onto the studs that were cleared by the vertical stand. Two long (6-10 feet) straps were connected to the highest side holes. The composite was then lifted while personnel held onto the interfaces. When the assembly was lifted several feet off the ground it was rotated to the horizontal position and then moved over to the Mass Properties table. The interface had slotted mounting holes to allow the satellite to be mounted at is CoG over the rotation axis of the table. When the composite had been mounted and bolted onto the table the vertical support and the additional leg were removed. The lifting straps were not removed before the composite was securely bolted on the table.

To measure the inertia in the cross axis the procedure was reversed, the satellite rotated 90 degrees on the stand, and the composite re-mounted onto the table.

Figure 8 Horizontal stand on Vertical stand ready for spacecraft to be assembled to it

4.7 Lifting gear

The spacecraft was supplied with a lifting system that allowed support in various axes for handling during the vibration test. The lifting gear consisted of a set of steel cables that attached through holes in the side panels of the spacecraft with shackles. It was ensured that the shackles were screwed shut during lifting. Loads were stable before land during lifting and moving operations. The crane operators confirmed that spacecraft and interfaces were safe to lift and not bolted to any fixed support before lifting. Crane operators and the Responsible Test Engineer confirmed that the spacecraft was stable and safe before releasing lifting gear from the spacecraft.

The spacecraft was not lifted through its lifting points with either the vibration interface or the horizontal mass properties interface attached. Only the vertical mass properties interface was light enough to be lifted through the spacecraft. The other interfaces have lifting points themselves that allowed lifting with or without the spacecraft attached.

Figure 9 Lifting cables used for assembling spacecraft on L-bracket

Figure 10 Spacecraft turned sideways for mass properties

4.8 Test configurations

The SEM2 was tested in two configurations:

- Satellite with Shock Ring (A)
- Satellite without Shock Ring (B)

For vibration testing, the SEM2 was mounted to the shaker fixture with an USAFA supplied extender tube, as the boom protrudes below the mounting interface of the Shock Ring. This extender fixture allowed mounting of the SEM2 with and without the Shock Ring. The interface plate bolts to both the vibration slip table and directly to the head. The bolts between the interface and the vibration table were assembled and torqued by AEF staff. The interface has attachment points for straps to facilitate lifting.

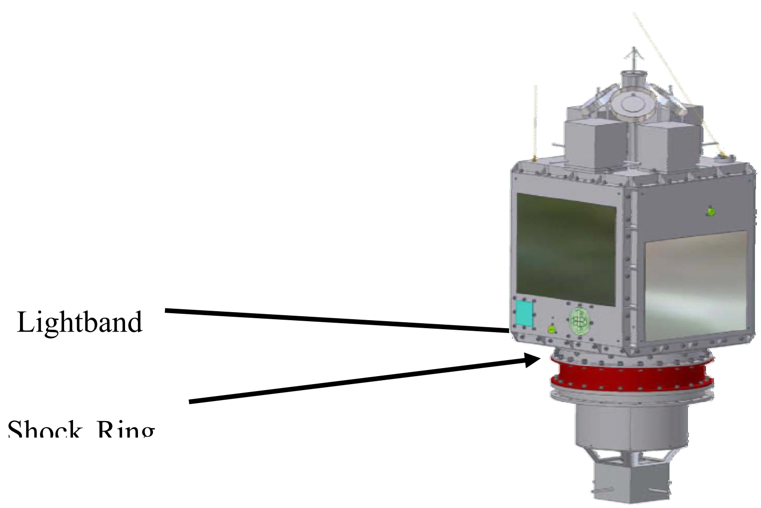


Figure 11 Lightband and Shock Ring location

4.9 Accelerometers

The positions of the accelerometers were as follows:

Output Number	Serial Number	Sensitivity	Channel Label
1	2346	10.2	Adapter Plate Front Left (SE)
2	2341	10.1	Adapter Plate Front Right (NE)
3	AD808 X	9.3202	Top Center X
4	AD808 Y	10.46	Top Center Y
5	AD808 Z	9.406	Top Center Z
6	11457	104.1	-Y Panel Y
7	21522	10.39	Bottom Corner Z
8	AAM32 X	10.30	Stack Top X
9	AAM32 Y	9.651	Stack Top Y
10	AAM32 Z	9.346	Stack Top Z
11	30818	9.70	Boom Tip X
12	30816	9.83	Boom Tip Y
13	30819	9.60	MPACS Y
14	21523	9.95	Antenna Bracket Y
15	13228	9.42	FLAPS Outside X
16	30817	10.07	Interface Ring Y

Table 3 Accelerometer locations

4.10 Spacecraft shipping

The SEM2 spacecraft model was shipped between USAFA and AEF by mounting it on the Horizontal Mass properties interface. This provided the shortest height, which made it simpler to handle and put in a van. The horizontal bracket also provided protection to SEM2 by partially surrounding it, and it provided convenient lifting points for handling and restraining. The Horizontal stand was mounted on a sheet of plywood sized to be larger than the spacecraft footprint. Caster were then attached to this piece of plywood in order to assist in transportation and handling.

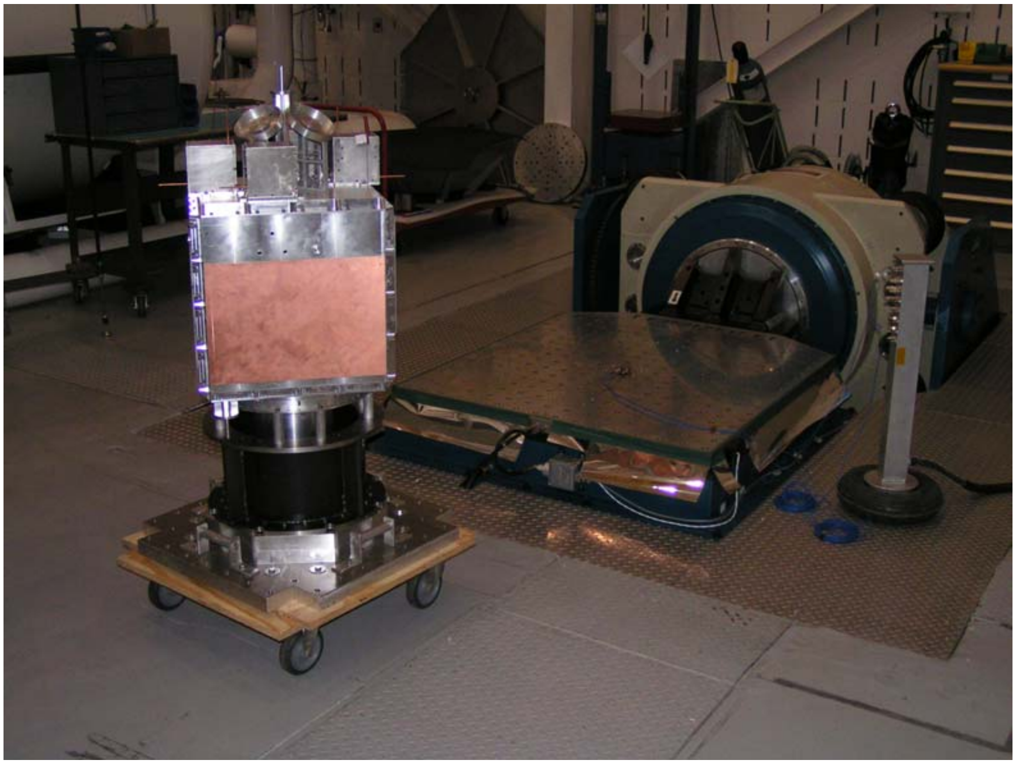


Figure 12: S/C attached to mounting bracket and plywood cart.

USAFA supplied items

The following test and support articles were supplied by USAFA for the SEM2 test at AEF:

Item	Notes
SEM2	Assembled FS-3 Structural Engineering Model
SEM2 shipping support	Allows SEM2 to be transported
Vibration interface	Mounts between SEM2 and the shaker table
Bolts between vibration I/F and SEM2	Not the bolts between vibration i/f and shaker!
Horizontal mass properties stand	Mounts between SEM2 and Mass properties table
Bolts to mount SEM2 onto Hor. stand	Not the bolts between Horizontal Stand and table
Vertical mass properties stand	Mounts between SEM2 and Mass properties table
Bolts to mount SEM2 onto Vert. stand	Not the bolts between Vertical Stand and table
Lifting cables to lift SEM2	Connects to AEF crane hook
Tools to assemble USAFA supplied bolts	No tools to assemble bolts into AEF tables and shakers

Table 4 USAFA supplied items

5 Mass properties measurements

5.1 Introduction

The mass properties were measured using adaptor fixtures for attachment and tilting of the satellite. The mass properties of the fixtures will be measured separately to enable the values for the spacecraft to be calculated from the measurements taken with the composite.

5.2 Test Configuration

5.2.1 Y-axis

Figure 13: SEM-2 on MOI test table in Y Config.

5.2.2 Y-axis

Figure 14: Pictures of Z Axis MOI Testing

5.3 Test Results

5.3.1 Mass Results

Estimated	Measured
49.6 kg (109.12 lb)	43.29 kg (95.23 lb)

Difference: -12.7%

5.3.2 Center of Gravity Results

5.3.2.1 X and Y Predicted Values

Table X shows the predicted values for C.G. in the FalconSAT-3 Coordinate Frame.

Coordinate	in (m)
X	0.13 +/- 0.125 (0.003 +/- 0.003175)
Y	0.04 +/- 0.125 (0.001 +/- 0.003175)
Z	5.19 +/- 1.000 (0.13181 +/- 0.0254)

Table 5 Predicted Center of Gravity

5.3.2.2 X and Y Measured Values

The first measurements were for the X and Y axis only as shown in Table X. As the geometric center of the satellite was directly over the geometric center of the test table, no translation is needed. Thus, the spacecraft X and Y coordinates, in FalconSAT-3 coordinates, are shown in Table X.

Coordinate	Measured location in (m)	Predicted in (m)	Note
X	-0.0194 (-0.00049)	0.13 +/- 0.125 (0.003 +/- 0.003175)	Within ESPA requirement. Within error band
Y	-0.0379 (-0.00096)	0.04 +/- 0.125 (0.001 +/- 0.003175)	Within ESPA requirement. Within error band

5.3.2.3 Z Predicted Values

Coordinate	in (m)
Z	5.19 +/- 1.000 (0.13181 +/- 0.0254)

5.3.2.4 Z Measured Values

To translate from the test fixture to the FalconSAT-3 coordinates we took dimensions of the test fixture as shown in Figure X.

Coordinate	Raw Measured location in (m)	Translated to S/C coordinates in (m)	Predicted in (m)	Note
Machine X (satellite Z)	-1.1754 (-0.02985)	3.902	5.19 +/- 1.000 (0.13181 +/- 0.0254)	Within ESPA requirement. Difference of 1.288" (0.0325 m), 0.288 inches greater than predicted error band
Machine Y (satellite Y)	-0.0121 (-0.031)	-0.0121 (-0.031)	0.04 +/- 0.125 (0.001 +/- 0.003175)	Within ESPA requirement. Confirms above results, within error band

5.3.3 Moment of Inertia

5.3.3.1 Predicted Values

MOI	kg-m^2	lbm-in^2	lbf-ft-s^2	lbf-in-s^2
Ixx	3.84	1.31E4	2.83	33.99
Iyy	3.89	1.33E4	2.87	34.46
Izz	1.32	4.51E3	0.97	11.68
Products	~0	~0	~0	~0

Table 6 Predicted Moments of Inertia

5.3.3.2 Measured Values

No adjustment is required to the machine measured MOI due to minor differences in center of gravity.

MOI	Predicted lbm-in^2 (kg-m^2)	Measured lbm-in^2 (kg-m^2)	Difference %	Notes

Ixx	1.31E4 (3.84)	1.2336E4 (3.6099)	-6.2	Within expected error bound
Iyy	1.33E4 (3.89)	N/A	N/A	Within expected error bound No direct measurement made, assumed = Ixx
Izz	4.51E3 (1.32)	4.632E3 (1.3556)	+2.6	Within expected error bound

Table 7 Measured Moments of Inertia

5.3.4 Reason for Error

There were two main differences between the SEM-2 structure and the predicted mass model. First, a 2.27 kg or 5 lbs harness was uniformly distributed about the center of gravity in the predicted measurements. This was not present in FS-3 SEM-2. Secondly, the four MPACS modules located on the top plate of the satellite have a specified NTE weight of 1.8 kg. This NTE weight was used for all predicted measurements. However, the mass models built for the SEM-2 weighed 0.935 kg each. They were made to mimic the most current data received on the MPACS modules and not to their full envelope weight. This created an extra -3.461 kg difference on the SEM-2. In total, SEM-2 was built 5.731 kg lighter than reported in Rev B calculations. This mass difference has a domino effect on the predicted center of gravity and moments of inertia. In order to define an accurate predicted value to compare our measured data to, the following equations were used:

$$z_{cg} = \frac{m_{system} \cdot \overline{z_{\mathrm{Re}vB}} - m_{mis\sin g} \cdot \overline{z_{mis\sin g}}}{m_{total}}$$

$$I_{xx} = I_{xx\,\mathrm{Re}vB} - m_{mis\sin g} \cdot d_{mis\sin g}^{\;2}$$

To correct the center of gravity value, the missing mass of the harness and MPACS (multiplied by the distance from the FS-3 coordinate frame origin to the missing mass) was subtracted from the initial Rev B data. The moment of inertia value was corrected by subtracting the missing masses times their distance from the new center of gravity squared. The results of this transformation are shown in Table 7 below.

	Rev B Prediction	**Kirtland Results**	**Rev B Prediction Corrected For Missing Mass in SEM2**
Mass (kg)	49.6 ± 10%	43.2	43.869 ± 10%
Center of Gravity (m)			
X	0.003 ± 0.003175	-0.00049	0.003 ± 0.003175
Y	0.001 ± 0.003175	-0.00096	0.001 ± 0.003175
Z	0.13181 ± 0.0254	0.09911	0.103 ± 0.0254

Moment of Inertia (kg-m^2)			
Ixx	3.84 ± 15%	3.6099	3.69 ± 15%
Iyy	3.89 ± 15%	n/a	3.74 ± 15%
Izz	1.32 ± 15%	1.3556	1.31 ± 15%
Product of Inertia (kg-m^2)			
Pxy	~ 0		~ 0
Pyz	~ 0		~ 0
Pxz	~ 0		~ 0

Table 7 Measured Value Corrections

After this simple correction for the missing masses of the harness and MPACS, the predicted values match the measured results within all of the defined tolerances.

6 Test Fixture Characterization +/- Y & Facility Check-out

6.1 Test Set-up

First, the entire shaker table was cleaned with alcohol and rags. The test fixture, which was cleaned with Simple Green before leaving USAFA, consists of two parts. The fixture was removed from FalconSat3, and all hardware (bolts, washers, etc.) was separated for inventory and inspection. Four people carried the fixture to the vibration table, where ½ in. shaker table bolts (2 ½ in. length) were used to bolt the fixture to the table. The team used as many bolts as possible to secure the fixture. The bolts were torqued to 44 ft-lbs using a 3/8" hex head socket. The torque was double-checked by a second person, and two loose bolts were discovered. The error was corrected.

Next, the bolts securing the two parts of the test fixture together were checked for proper torque (100 in-lbs). The first torque wrench used for this procedure was improperly calibrated, and one of the bolts was broken. As a result, all the bolts had to be removed and the two parts of the test fixture had to be separated. The broken bolt was extracted and the two parts were reassembled. When inserting the bolts for reassembly, each one had to be tightened by hand first, and then tightened with the torque wrench one at a time, alternating sides in a star pattern.

6.2 Test Objectives & Success Criteria

Test objectives for this portion of the test campaign are summarized in Table 8. To save time, all tests were conducted in only one axis with the assumption that if they are successful in the X-axis, they will be successful in all axis.

Table 8: Test Fixture Test Objectives and Success Criteria.

Test	Objective	Success Criteria
Sine Sweep	Characterize natural frequency of the test fixture	First mode natural frequency of the test fixture >~2x highest mode natural frequency of the spacecraft (>400 Hz)
Sine Sweep, sine	Verify data and test control from test	Data input from all available

burst and random vibe	facility	channels
Sine Sweep, sine burst and random vibe	Verify ability of test facility to conduct all planned tests	Facility successfully executed planned test profiles

6.3 Sine Sweep

6.3.1 Test Levels

A sine sweep of the test fixture was performed with the frequency and acceleration specification shown in Table 9.

Table 9: Sine Sweep levels for test fixture testing.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-2000	0.1 g	2

6.3.2 Test Results

During the first sine sweep the test computer hung up and aborted at ~1800 Hz. The test controllers spent the rest of the first day and half of the second day resolving the problem. In the mean time, CG/MOI tests were conducted.

Once the vibe table was returned to service, the sine sweep was repeated. Results indicated the first mode natural frequency of the test fixture was ~750 Hz.

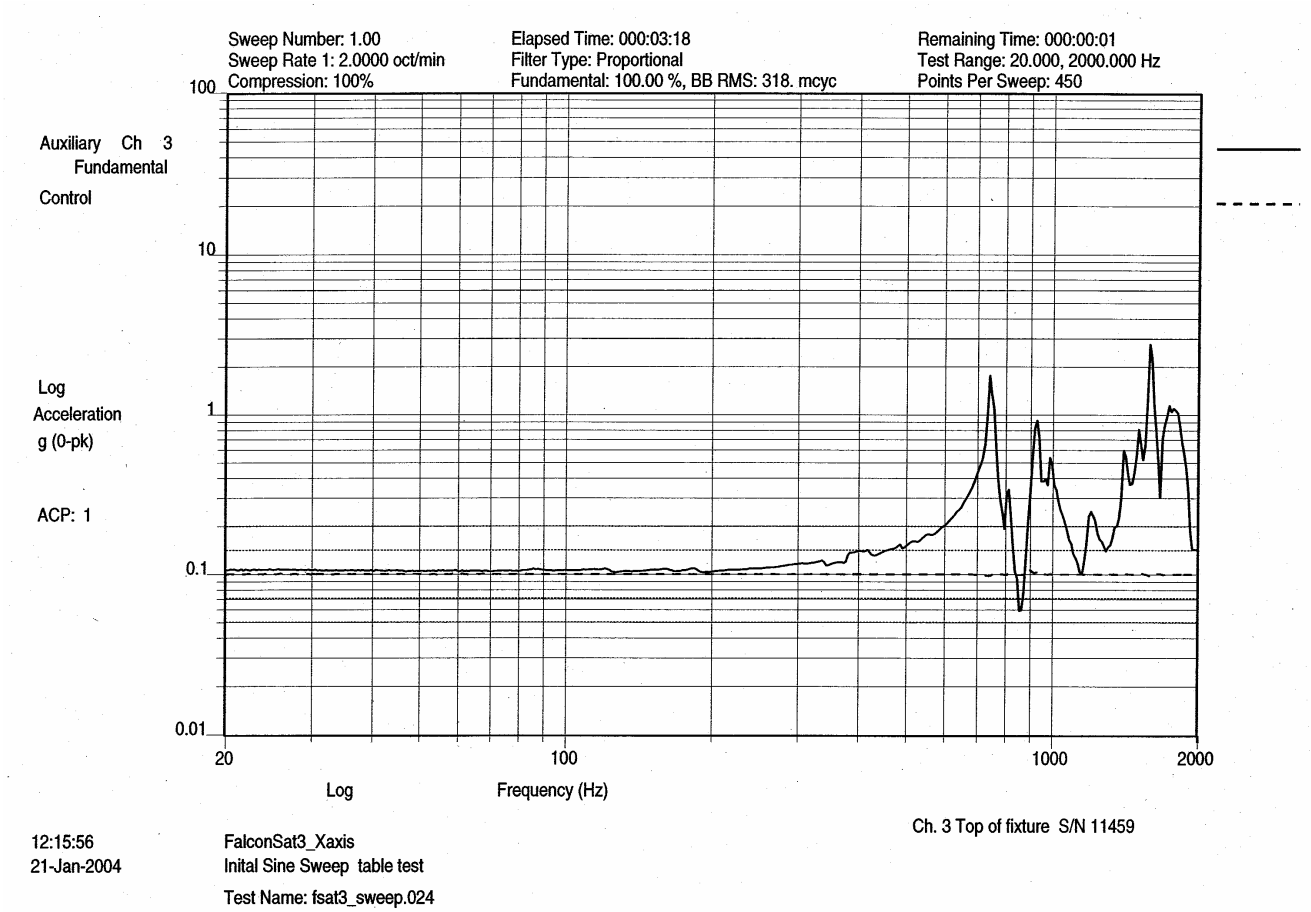


Figure 15: Initial Sine Sweep of Test Fixture

6.4 Random Vibration

6.4.1 Test Levels

6.4.1.1 Without Shockring qualification levels

The random vibration test was conducted at the highest planned level only with the assumption that if it is successful, then all lower levels will be successful. The levels are shown Table 10.

Table 10: Test Fixture Random Vibration Levels.

Frequency (Hz)	Acceleration PSD (g^2/Hz)
20	0.04
20-50	+6 dB/octave
50-600	0.24
600-2000	-4.5 dB/octave
2000	0.04

Duration	**2 minute per axis**
Overall g rms	**16.3**

6.4.2 Test Results

The test facility was able to perform this test at the required levels. No malfunctioned occurred during the test and no failure was observed.

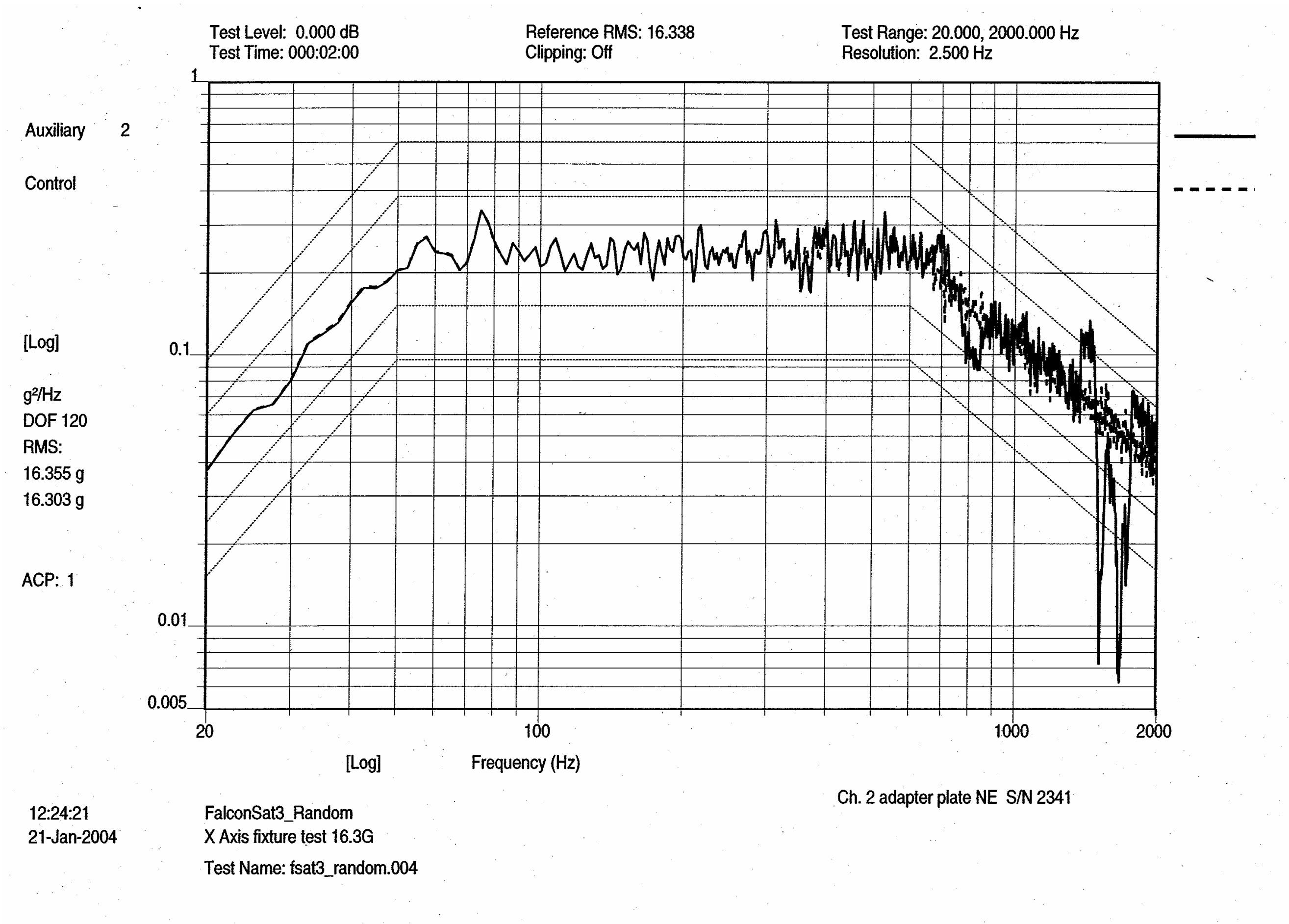


Figure 16: Random Vibe plot from the Adapter Plate

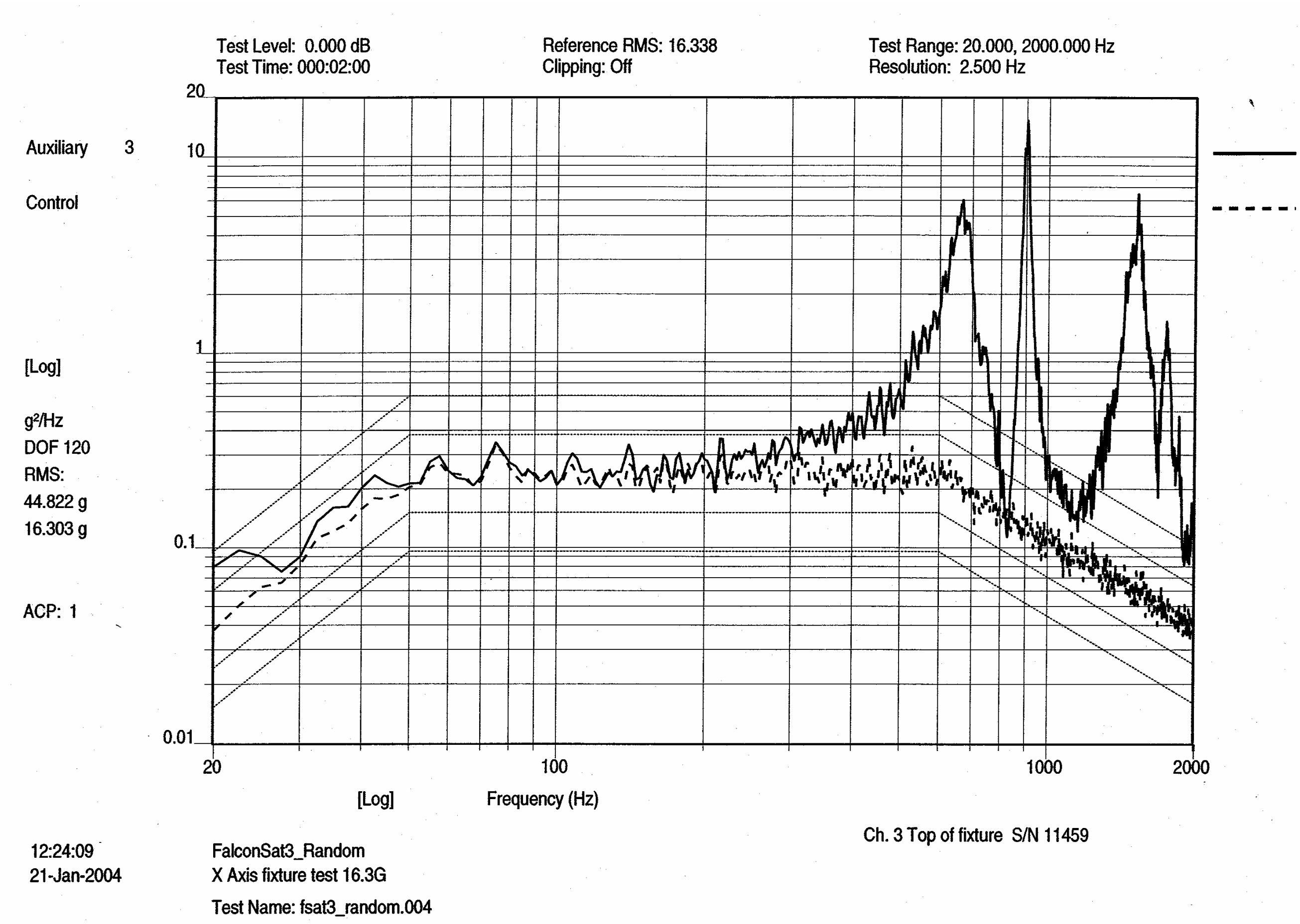


Figure 17: Random vibe results from test fixture

6.5 Sine Burst

6.5.1 Test Levels

Sine burst test was conducted at the highest planned levels with the assumption that if it were successful, all lower levels would be successful. The sine burst level used is shown in Table 11.

Table 11: Test Fixture Sine Burst Level.

Frequency (Hz)	Acceleration (g)
22 Hz	21.3

6.5.2 Test Results

The test facility was able to perform this test at the required levels.

6.6 Summary of Results

Results of all tests conducted on the test fixture are shown in Table 12.

Table 12: Summary of Test Fixture Results.

Test	Objective	Success Criteria	Result
Sine Sweep	Characterize natural frequency of the test fixture in Y axis	First mode natural frequency of the test fixture >~2x highest mode natural frequency of the spacecraft (>400 Hz)	Natural frequency in Y axis is ~750Hz
Sine Sweep, sine burst and random vibe	Verify data and test control from test facility	Data input from all available channels	Pass
Sine Sweep, sine burst and random vibe	Verify ability of test facility to conduct all planned tests	Facility successfully executes planned test profiles	Pass

7 Structural Tests Results—Config A (w/ShockRing) +/-Y

7.1 Test Configuration

7.1.1 Test Set-up

The test article consisted of the SEM-2 with both the shockring and lightband attached. The SEM-2 was bolted to the FalconSAT-3 test fixture. The test fixture was bolted to the table in the same configuration as described in Section 5. The test configuration is shown in Figure 18: Configuration for +/- Y-axis test with Shockring and lightband

(shown attached to test table)..

Figure 18: Configuration for +/- Y-axis test with Shockring and lightband

(shown attached to test table).

7.1.2 Accelerometer Locations

Accelerometers for this portion of the test were placed as shown in Table 13.

Output Number	Serial Number	Sensitivity	Channel Label
1	2346	10.2	Adapter Plate Front Left (SE)
2	2341	10.1	Adapter Plate Front Right (NE)
3	AD808 X	9.3202	Top Center X
4	AD808 Y	10.46	Top Center Y
5	AD808 Z	9.406	Top Center Z
6	11457	104.1	-Y Panel Y
7	21522	10.39	Bottom Corner Z
8	AAM32 X	10.30	Stack Top X
9	AAM32 Y	9.651	Stack Top Y
10	AAM32 Z	9.346	Stack Top Z
11	30818	9.70	Boom Tip X
12	30816	9.83	Boom Tip Y
13	30819	9.60	MPACS Y
14	21523	9.95	Antenna Bracket Y
15	13228	9.42	FLAPS Outside X
16	30817	10.07	Interface Ring Y

Table 13: +/- Y-axis test accelerometer locations.

7.2 Summary of Test Objectives, Success Criteria & Results

Test	Objectives	Success Criteria	Result
Initial Sine Sweep	1. Characterize natural frequencies of the SEM-2 flight configuration in the Y axis. 2. Verify primary mode is >35Hz ESPA requirement. 3. Capture performance data on the shockring to validate its benefits and help to refine its final flight design. 4. Capture transfer function data on dynamic response of different parts of the spacecraft.	1. Successful measurements 2. Primary mode > 35 Hz 3. Data collected 4. Data collected	1. Primary mode is at about 33 Hz, 2nd mode is at about 150 Hz. 2. Mode is less than ESPA requirement. This likelihood was briefed at the CDR and will be contained in the FalconSAT-3 ICD to ESPA. 3. Pass 4. Pass
Sine Burst	1. Verify spacecraft meets the ESPA static load requirement of 10.6 g limit load in axial	1. Spacecraft maintains structural integrity following RSS of 10.6 g's	1. Verified up to 12.82 g's due to limitations of test

	and lateral axes simultaneously. 2. Collect data on dynamic response of spacecraft components.	in two axes (15 g's) sine burst. 2. Data collected	equipment. 2. Pass
Subsequent Sine Sweep (after each test)	1. Verify structural integrity following major test.	1a. Peak acceleration at fundamental frequency does not shift by more than +/- 20% during tests, as determined by the low-level sine sweeps before and after the high-level tests. 1b. Fundamental frequency does not shift by more than +/- 5% during tests, as determined by the low-level sine sweeps before and after the high-level tests	1. Pass
Shockring Characterization Random Vibration	1. Collect data on low-level dynamic response of spacecraft with shockring to characterize performance and aid in final flight design.	1. Data collected	1. Pass
Acceptance Random Vibration	1. Collect data on medium-level dynamic response of spacecraft with shockring to characterize performance and aid in final flight design.	1. Data collected	1. Pass
Qualification Random Vibration	1. Verify the capability of the satellite structure and components to withstand the fatigue introduced during the launch vibrations per ESPA interface requirement. 2. Collect data on dynamic response of spacecraft components. 3. Collect data on high-level dynamic response of	1a. Representative sample of fasteners do not lose more than 20% of original torque 1b. Post Random Vibration Sine sweep meets above criteria. 2. Data collected 3. Data collected	1a. Pass 1b. Pass 2. Pass 3. Pass

	spacecraft with shockring to characterize performance and aid in final flight design.		

7.3 Test data

The tests produced output graphs from the various accelerometers. From these graphs the response of the structure was determined. In the cases when the only output available was hardcopy plots, the main values were captured off the recording equipment before they were cleared off the system and noted on the copies by hand when they could not be printed directly.

7.4 Initial Sine Sweep

7.4.1 Objective

The initial sine sweep was conducted to determine the fundamental and further natural frequencies, modal shapes, and modal gain of the structure. The sine sweep also provided a baseline from which subsequent tests were judged. Additional sine sweeps were conducted following each test to ensure that no damage was done to the spacecraft (indicated by no change in the fundamental frequency).

7.4.2 Success Criteria

The success criteria for the sine sweep were to characterize the natural frequencies of the SEM-2 flight configuration in the Y axis and to find a primary mode greater than 35 Hz in accordance with the ESPA requirement.

7.4.3 Test Levels

The following table outlines the frequencies and accelerations that were used for all sine sweeps completed during testing in this particular configuration.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-2000	0.1 g	2

Table 14 Sine sweep vibration specification

7.4.4 Results

From this initial sine sweep, we determined the following fundamental and secondary frequencies.

Mode	Frequency (Hz)
First	33
Stack Rocking, with outer structure rocking opposite	235
Boom Rocking, resulting in second mode	140

Table 15 Initial sine sweep frequency results

These frequencies are illustrated in the following figure which depicts the initial sine sweep response of the top panel with the shockring. As you can see, the primary mode is not greater than the 35 Hz ESPA requirement. However, this likelihood was briefed at the CDR and will be contained in the FalconSAT-3 ICD to ESPA. In the Y panel Y axis there was suspected saturation or other problem resulting in skewed results. The pre and post test sine sweep varied in the fundamental frequency. This was due to the temperature change in the visco elastic material (VEM) that shifted the fundamental frequency. In the future a second post test sine sweep should be conducted after the VEM has cooled in order to get a better feel for the result on the structure from the test.

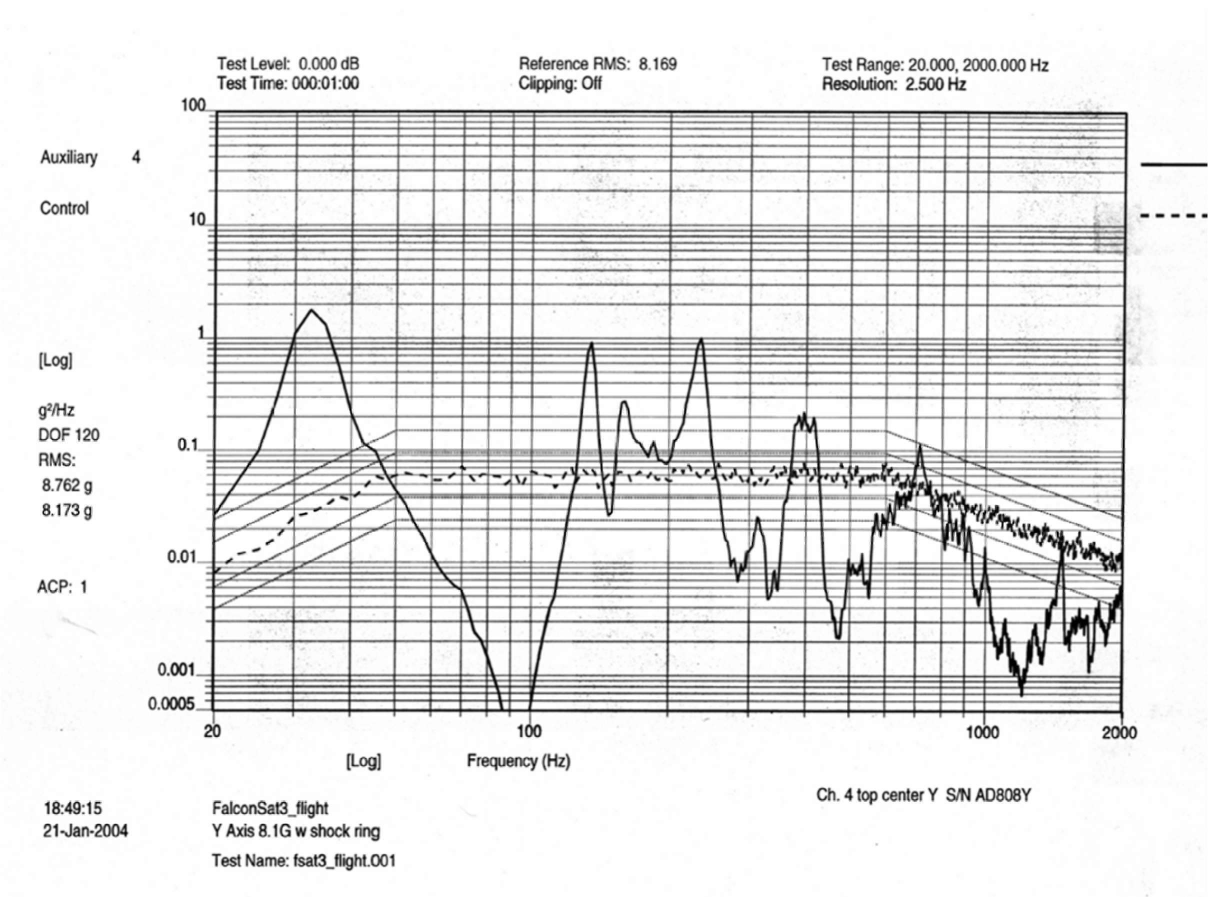


Figure 19: Initial Sine Sweep, Top Center Y

7.5 Characterization-Level Random Vibration Test

7.5.1 Objective

The characterization-level random vibration test was completed to collect data on low-level dynamic response of spacecraft with shockring to characterize performance and aid in design. The random vibration tests were also conducted in order to verify the capability of the satellite structure and components to withstand the fatigue introduced during launch vibrations. For this reason, the loads introduced during this test should mirror the loads that will be applied to the Flight model in low level dynamic loads.

7.5.2 Success Criteria

The success criterion for this test was simply to collect the data referred to above.

7.5.3 Test Level

The tests were performed on the satellite using the following levels.

Frequency (Hz)	Acceleration PSD (g^2/Hz)
20	0.005 (for information only)
20-50	+6 dB/octave
50-600	0.03
600-2000	-4.5 dB/octave
2000	0.005 (for information only)
Duration	**1 minute per axis**
Overall g rms	**5.78**

Table 16: Shockring characterization random vibration levels

7.5.4 Results

Following this random vibration test, a swine sweep was conducted to the levels indicated in Table 14 Sine sweep vibration specification. In order to verify structural integrity after the SEM-2 was subjected to the above environment, we checked the torques of the fasteners following the post-testing sine sweep. After a reasonable sample of the bolts were checked for the proper torque it was determined that less than 20% of the torque had been lost on any one bolt. The plot below illustrates the sine sweep results for the top panel following this test. As you can see, the fundamental frequency following this test remained almost unchanged. Plots remain unchanged, for the most part, from one accelerometer to the next.

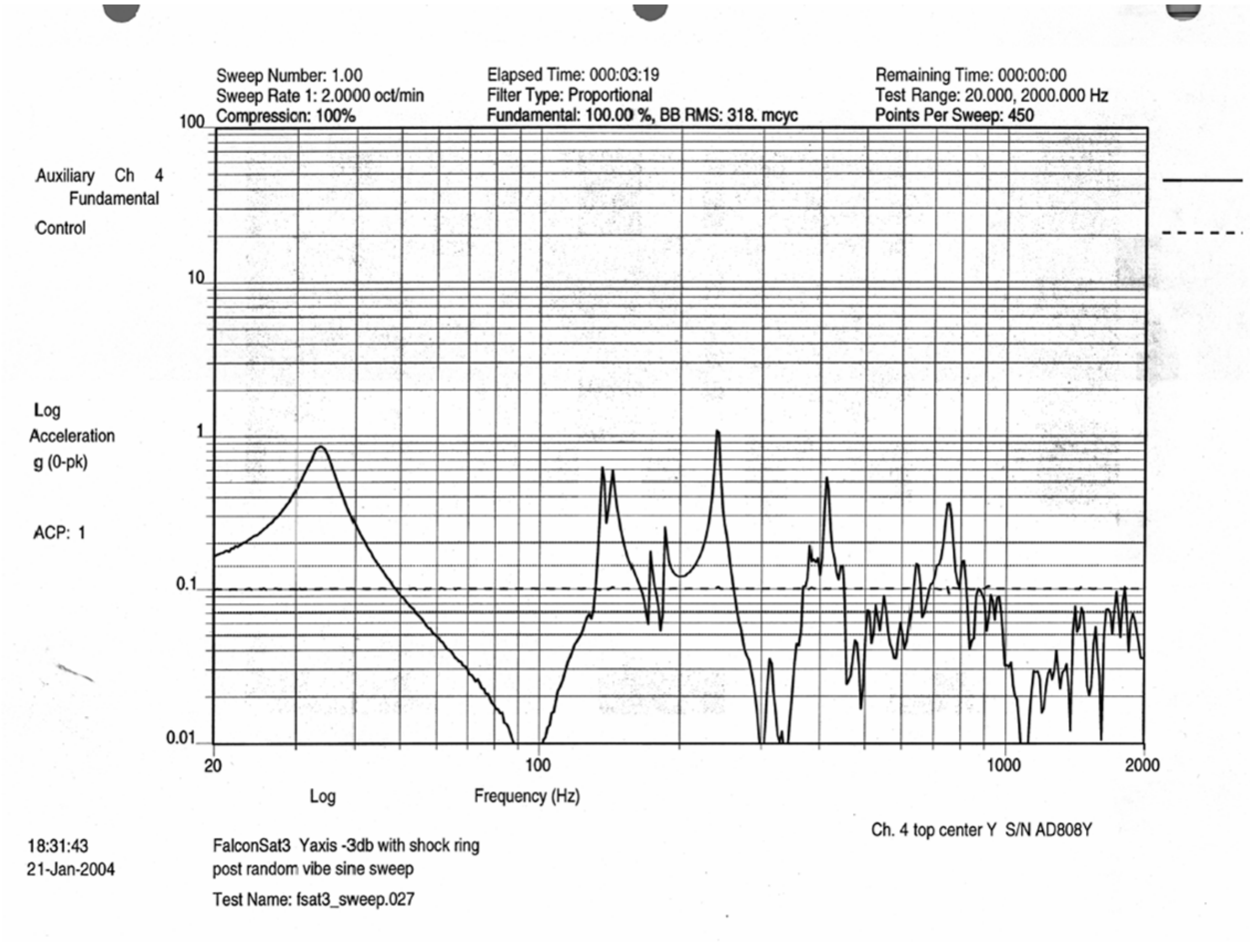


Figure 20: Post Characterization-Level Random Vibe Sine Sweep

7.6 Acceptance Random Vibration Test

7.6.1 Objective

The characterization-level random vibration test was completed to collect data on medium-level dynamic response of spacecraft with shockring to characterize performance and aid in final flight design. The random vibration tests were also conducted in order to verify the capability of the satellite structure and components to withstand the fatigue introduced during launch vibrations. For this reason, the loads introduced during this test should mirror the loads that will be applied to the Flight model in medium-level dynamic loads.

7.6.2 Success Criteria

The success criteria for this test was simply to collect the data referred to above.

7.6.3 Test Level

The random vibration level for FalconSat-3 was estimated in the absence of conclusive environment information about the ESPA from the launch contractor. These levels are shown in Table 17 FS-3 flight random vibration level and Figure 21. The estimate was based on experience from previous satellites of similar size and their launches.

Frequency (Hz)	Acceleration PSD (g^2/Hz)
20	0.01 (for information only)
20-50	+6 dB/octave
50-600	0.06
600-2000	-4.5 dB/octave
2000	0.01 (for information only)
Duration	**1 minute per axis**
Overall g rms	**8.16**

Table 17 FS-3 flight random vibration level

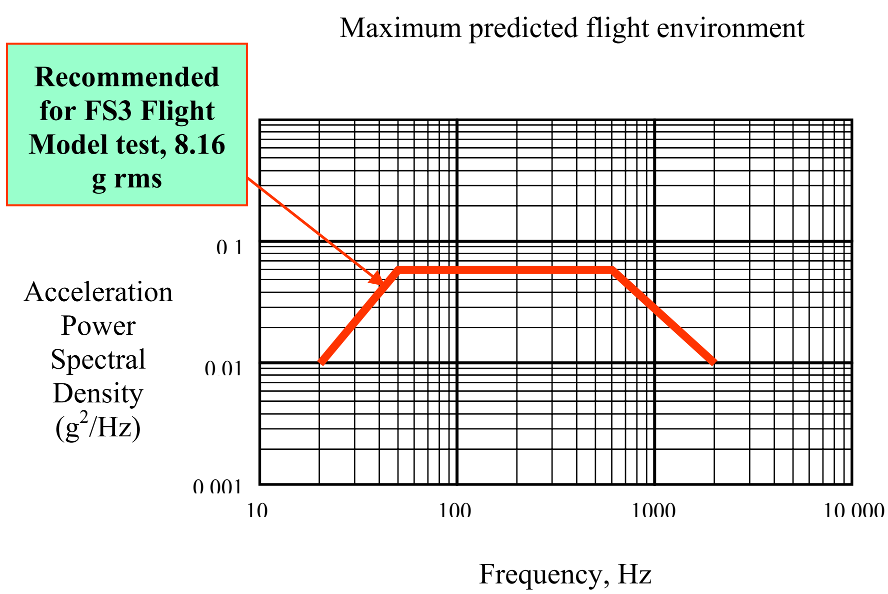


Figure 21: FalconSAT-3 flight-level power spectral density.

Once again, following this test, a sine sweep to the levels indicated in table 15 was conducted.

7.6.4 Results

Following this random vibration test, a swine sweep was conducted to the levels indicated in Table 14 Sine sweep vibration specification. In order to verify structural integrity after the SEM-2 was subjected to the above environment, we checked the torques of the fasteners following the post-testing sine sweep. After a reasonable sample of the bolts were checked for the proper torque it was determined that less than 20% of the torque had been lost on any one bolt. The plot below illustrates the sine sweep results for the top panel following this test. As you can see, the fundamental frequency following this test remained almost unchanged. Plots remain unchanged, for the most part, from one accelerometer to the next.

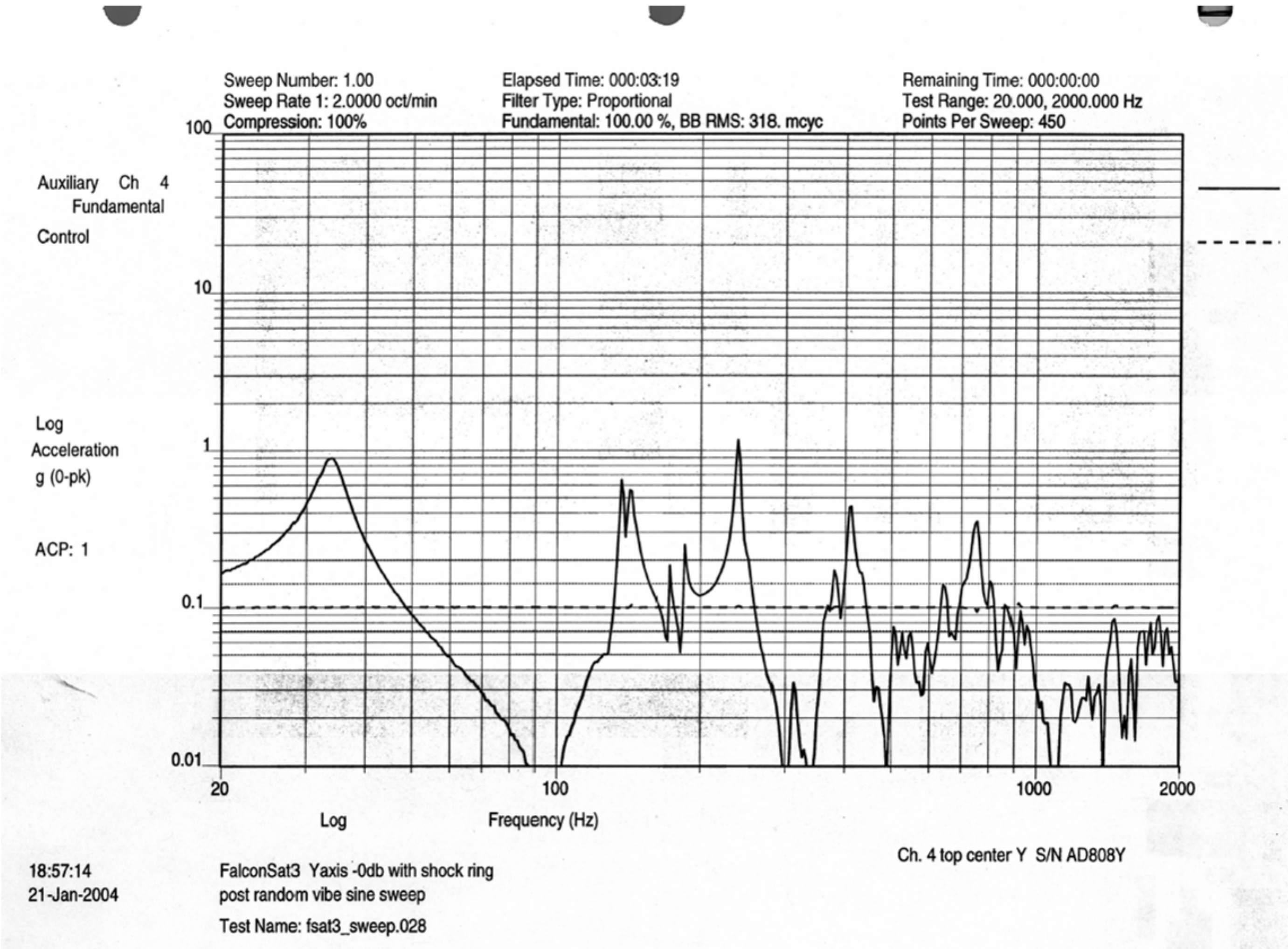


Figure 22: Post Acceptance-Level Random Vibe Sine Sweep

7.7 Sine burst Test

7.7.1 Objective

The sine burst test was completed in order to verify that the spacecraft meets the ESPA static load requirement of 10.6 g limit load is axial and lateral axes simultaneously.

7.7.2 Success Criteria

The success criteria for this test was to ensure that the spacecraft maintains structural integrity following RSS of 10.6 g's in two axes (15 g's) sine burst.

7.7.3 Test Level

The sine burst test was performed with the following frequency and maximum acceleration specification seen below. Due to limitations of the testing equipment, we were able to verify up to 12.82 g's. The test was performed in a number of steps starting from -12 dB, to -9 dB, -6 dB, -3 dB then -0 dB (the final test level) to allow the vibration equipment to analyze the system response and adjust the input levels appropriately.

Frequency (Hz)	Acceleration (g)
f=1/2 of first vibration mode of the ring = 17	12.826

Table 18 Sine burst vibration specification

7.7.4 Results

Following this sine burst test, a swine sweep was conducted to the levels indicated in Table 14 Sine sweep vibration specification. In order to verify structural integrity after the SEM-2 was subjected to the above environment, we checked the torques of the fasteners following the post-testing sine sweep. After a reasonable sample of the bolts were checked for the proper torque it was determined that less than 20% of the torque had been lost on any one bolt. The plot below illustrates the sine sweep results for the top panel following this test. As you can see, the fundamental frequency following this test remained almost unchanged, indicating structural integrity. Plots remain unchanged, for the most part, from one accelerometer to the next. There was a problem with the with the SEM needing low frequency response in order to avoid significant dynamic gain in the response.

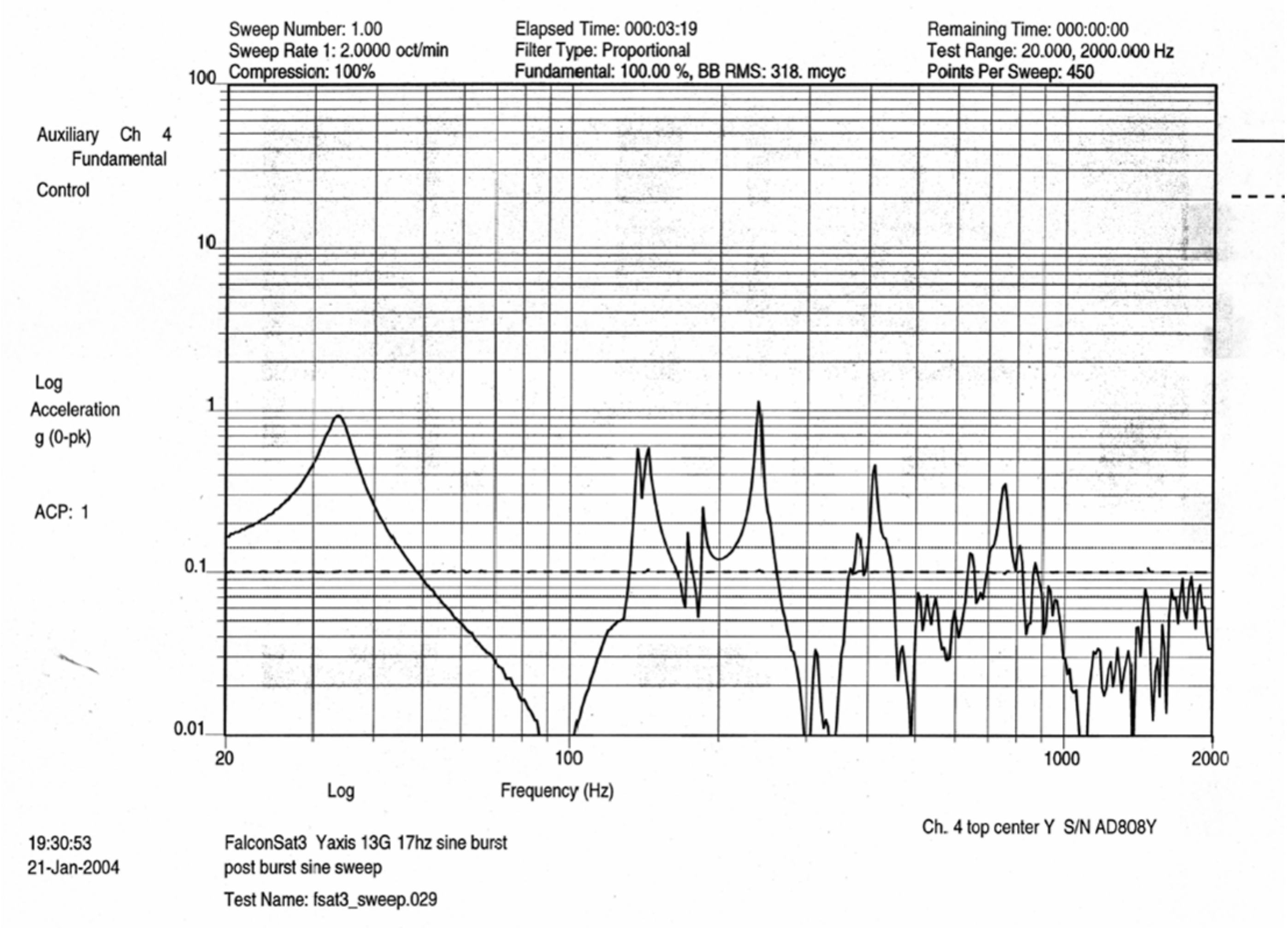


Figure 23: Post Sine Burst Sine Sweep

The following table illustrates responses of several key components to this test:

Component	Response (g's)
Top Panel Y	19.5
Top of Stack Y	17
MPACS	22
Antenna	24
Y Panel	130
Interface Plate	14.5

Table 19: Sine Burst Test Results

7.8 Qualification-Level Random Vibration Test

7.8.1 Objective

The qualification-level random vibration test was conducted to verify the capability of the satellite structure and components to withstand the fatigue introduced during the launch vibrations per ESPA interface requirement. The test was also completed to collect data on spacecraft components and on high-level dynamic response of spacecraft with the shockring to characterize performance and aid in final flight design.

7.8.2 Success Criteria

To verify the structure's ability to withstand the fatigue, a representative sample of fasteners must not lose more than 20% of their original torque. Data must be collected as referred to above.

7.8.3 Test Level

Random vibration qualification levels are shown in Table 20 FS-3 Qualification random vibration level and Figure 24: FalconSAT-3 flight-level power spectral density.. These levels represent +6dB above the flight level. Normally, the qualification is done for a full 2 minutes. However, based on recommendation from CSA, the duration of this test was held to 1 minute.

Frequency (Hz)	**Acceleration PSD (g^2/Hz)**
20	0.0384
20-50	+6 dB/octave
50-600	0.24
600-2000	-4.5 dB/octave
2000	0.04
Duration	**1 minute per axis**
Overall g rms	**16.3**

Table 20 FS-3 Qualification random vibration level

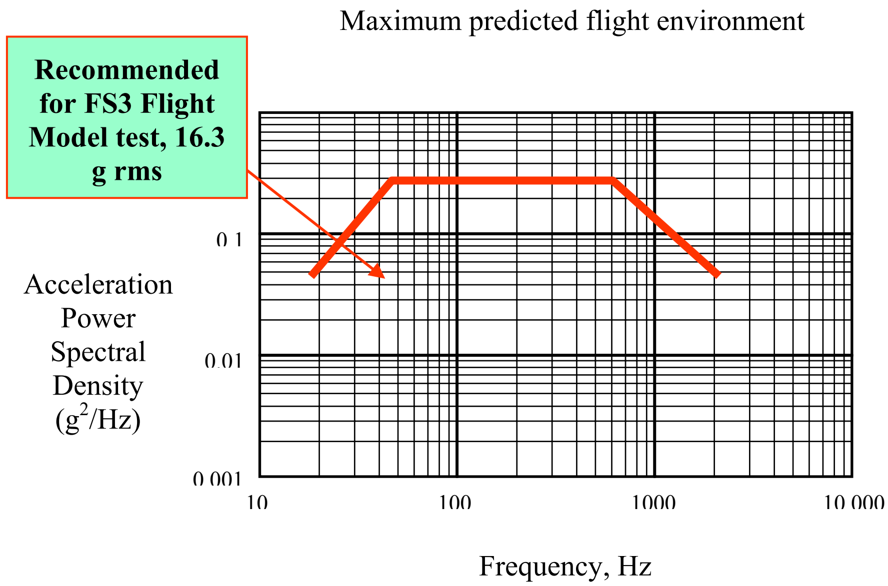


Figure 24: FalconSAT-3 flight-level power spectral density.

7.8.4 Results

Following this random vibration test, a swine sweep was conducted to the levels indicated in Table 14 Sine sweep vibration specification. After a reasonable sample of the bolts were checked for the proper torque it was determined that less than 20% of the torque had been lost on any one bolt. The plot below illustrates the sine sweep results for the top panel following this test. As you can see, the fundamental frequency following this test remained almost unchanged, indicating structural integrity. Plots remain unchanged, for the most part, from one accelerometer to the next.

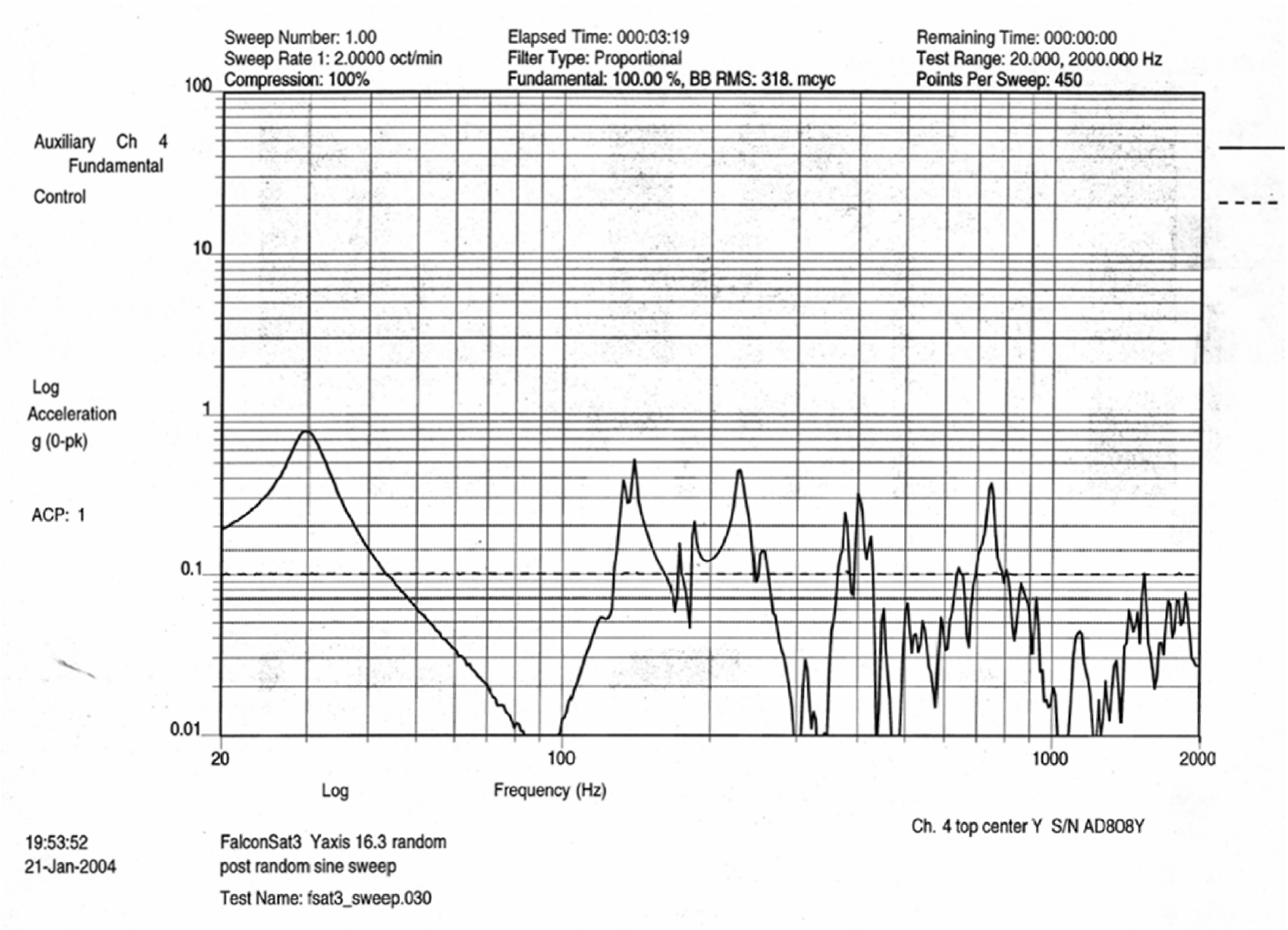


Figure 25: Post Qualification-Level Random Vibe Sine Sweep

Several observations were made with the results of the random vibration test. One observation was that on the Y panel, where the solar panel is mounted, there was an amplification in the Y direction from the input of 16 g's to approximately 26 g's at the 450 Hz frequency. This is illustrated in the figure below.

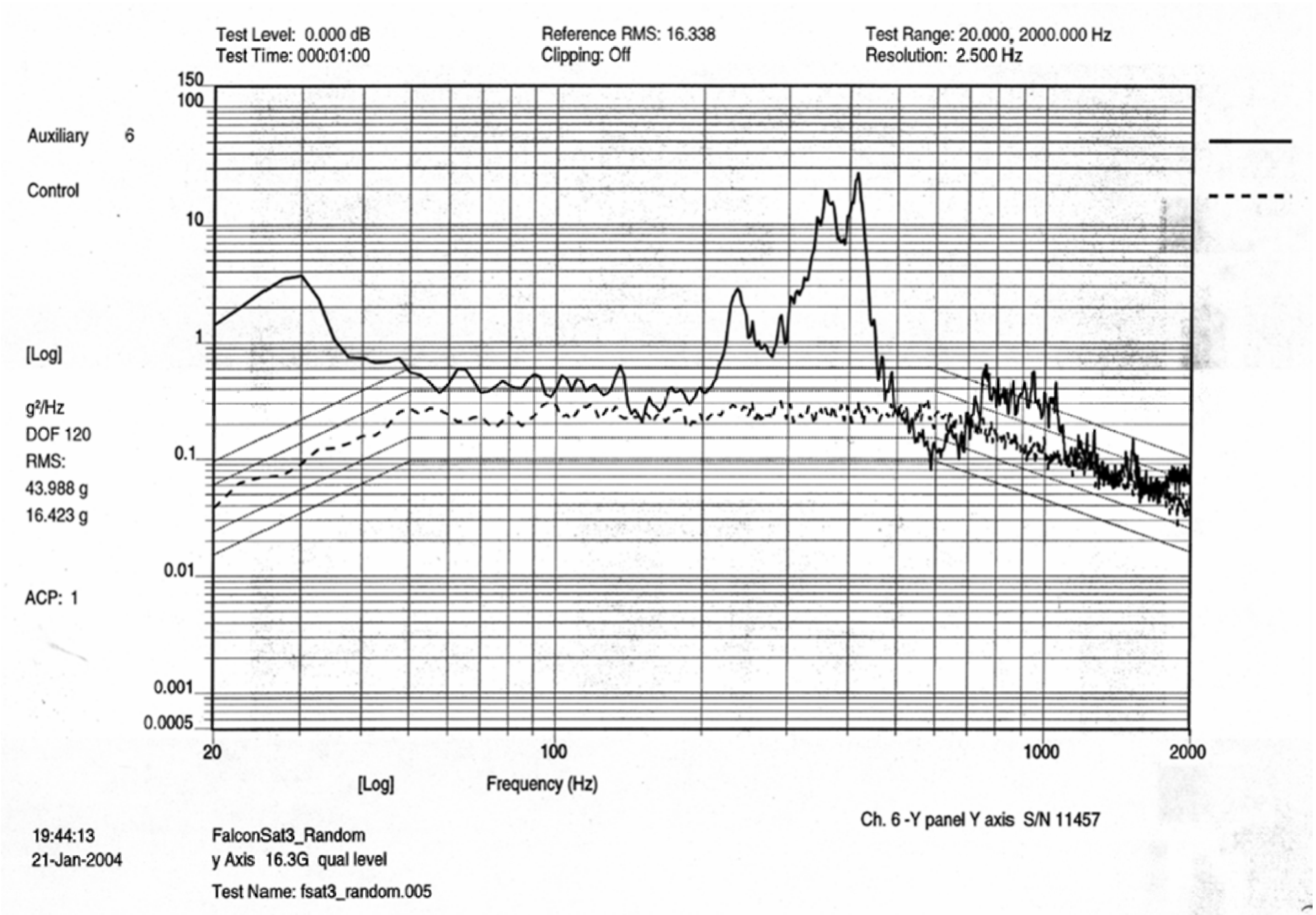


Figure 26: Y Panel Y Axis with Shockring

8 Structural Tests Results—Config B (w/o ShockRing) +/-Y

8.1 Test Configuration

8.1.1 Test Article

The test article consisted of the SEM-2 without the Shockring, only the lightband attached as shown in Figure 22 along with a spacer ring to represent the shockring.

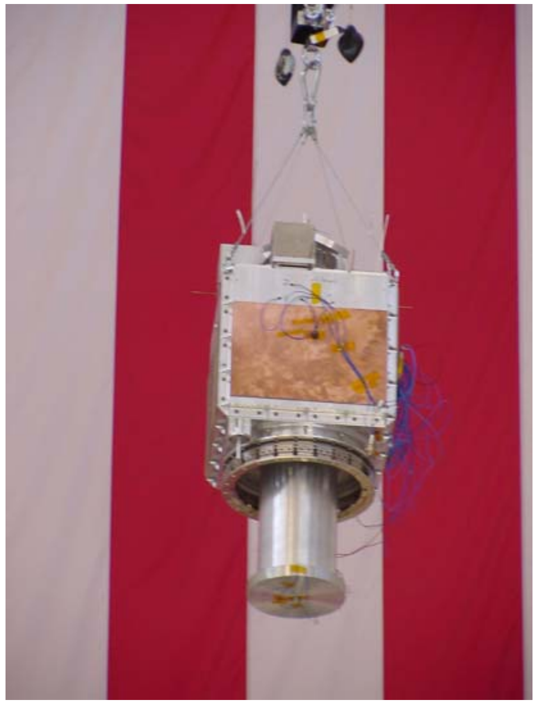


Figure 27: Configuration for +/- Y-axis test article without shockring.

8.1.2 Test Set-up

The SEM-2 was bolted to the FalconSAT-3 test fixture. The test fixture was bolted to the table in the same configuration as described in Section 5. In place of the shockring a simulator was used in order to provide for the length of components of the satellite clearing the table, specifically the boom. The test configuration is shown in Figure 23.

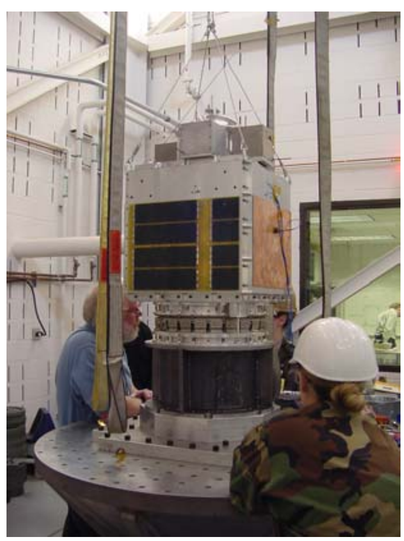


Figure 28: Configuration for +/- Y-axis test without Shockring attached to the test table.

8.1.3 Accelerometer Locations

Accelerometers for this portion of the test were placed as shown in Table 13.

Table 21: +/- Y-axis test accelerometer locations.

Output Number	Serial Number	Sensitivity	Channel Label
1	2346	10.2	Adapter Plate Front Left (SE)
2	2341	10.1	Adapter Plate Front Right (NE)
3	AD808 X	9.3202	Top Center X
4	AD808 Y	10.46	Top Center Y
5	AD808 Z	9.406	Top Center Z
6	11457	104.1	-Y Panel Y
7	21522	10.39	Bottom Corner Z
8	AAM32 X	10.30	Stack Top X
9	AAM32 Y	9.651	Stack Top Y
10	AAM32 Z	9.346	Stack Top Z
11	30818	9.70	Boom Tip X
12	30816	9.83	Boom Tip Y
13	30819	9.60	MPACS Y
14	21523	9.95	Antenna Bracket Y
15	13228	9.42	FLAPS Outside X
16	30817	10.07	Interface Ring Y

8.2 Test data

The tests produced output graphs from the various accelerometers. From these graphs the response of the structure was determined. In the cases when the only output available was hardcopy plots, the main values were captured off the recording equipment before they were cleared off the system and noted on the copies by hand when they could not be printed directly. The plots can be seen in the different sections. Multitudes of data were collected and can be reference in test plots binder that can be found in the astro lab conference room.

8.3 Initial Sine sweep

8.3.1 Objective

The objective of the initial sine sweep test was to determine the natural frequency of the FalconSAT-3 flight configuration in the Y (and by symmetry) the X-axis.

8.3.2 Success Criteria

No specific success criteria were defined for this test. We anticipated the frequency would be a great deal higher than that of those test run with the shockring due to the shockrings damping properties.. It is also expected that no structural damage will occur while this test is being run.

8.3.3 Input Levels

The sine sweep was performed with the following frequency and acceleration specification. (Due to a problem with the test hardware, the upper bound of the sine sweep frequency was lowered slightly for this and subsequent tests).

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-1800	0.1 g	2

Table 22 Sine sweep vibration specification

8.3.4 Results

The sine burst test was run twice. During the first test, it was noticed that the accelerometer on the MPACS was inoperable. The accelerometer was replaced and the test was re-run. Both sets of data were collected, and the first will be used as a reference only if necessary. The location of the first rocking mod occurred at approximately 90 Hz. This is a huge discovery for the FalconSAT 3 SEM-2 as well as the shockring manufacturers. This is approximately 60 Hz higher than that of the test run with the shockring where the first mode was found to be 30 Hz. Fundamentally there was no structural damage to the satellite which allowed us to continue testing without any delays. You can see an example of the output from the satellite in the plot below.

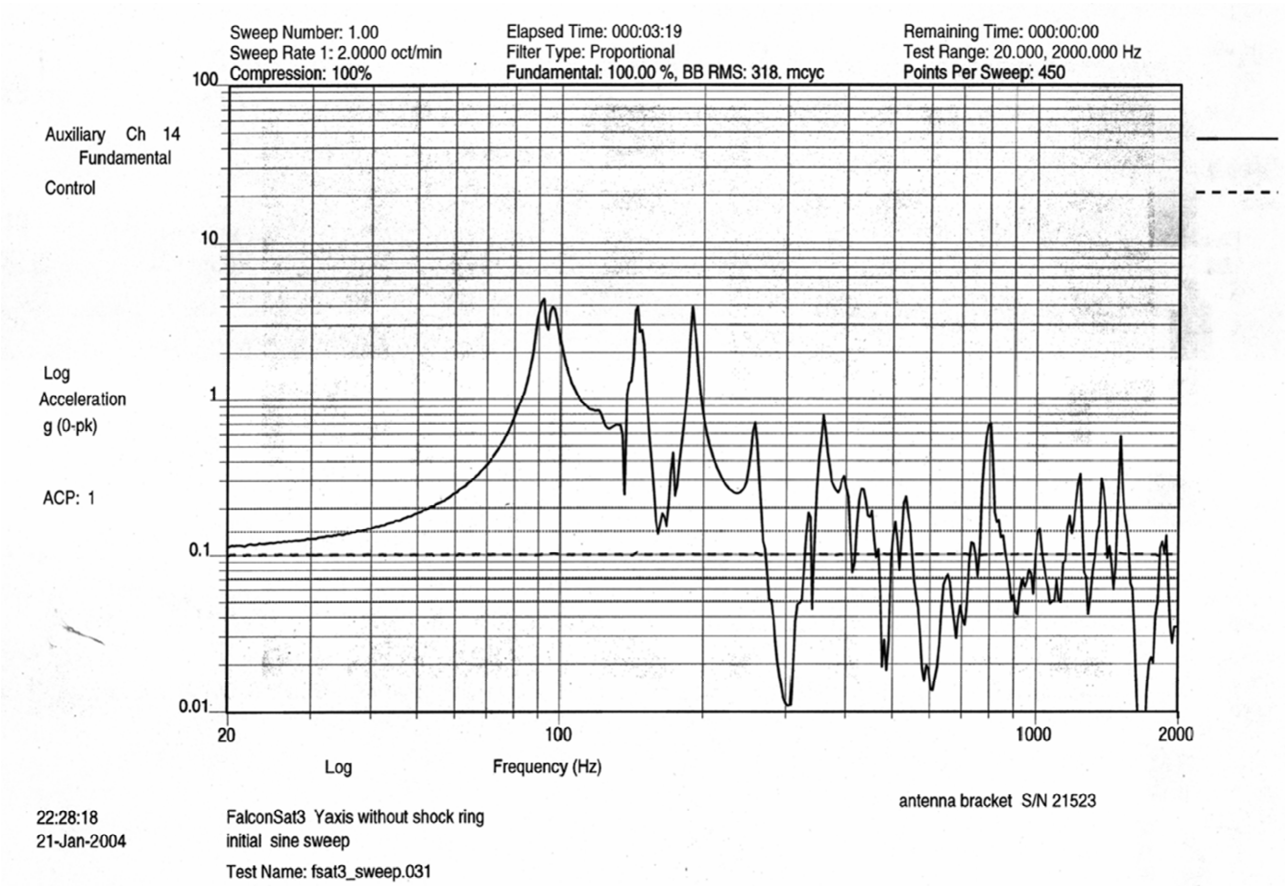


Figure 29: Plot of Attenna Bracket reaction during sine sweep

8.4 Characterization-Level Random Vibration Test

8.4.1 Objective

The objective of this test was to simulate the flight acoustic load to verify test article fatigue margin and gather basic performance data of the structure without the shockring. As this configuration is different from the flight configuration (no shockring) there was no need to repeat qualification-level tests due to the fact that this scenario will never occur during launch.

8.4.2 Success Criteria

The success criteria for this test were very vague but fundamentally some were established. In order for all of these tests to be successful structural integrity needed to be maintained. In order for this to occur no part of the satellite could visible break. And upon further inspection after the test no cracking could be observed. As well the accelerometer outputs could not be observed to have drastic difference once the sine sweeps, pre and post, test have gone through a visual comparison.

8.4.3 Test Level

The following levels were established for this test. These represent -3dB from the flight levels described in Section **Error! Reference source not found.**.

Table 23: Shockring characterization random vibration levels.

Frequency (Hz)	Acceleration PSD (g^2/Hz)
20	0.005
20-50	+6 dB/octave
50-600	0.03
600-2000	-4.5 dB/octave
2000	0.005
Duration	**1 minute per axis**
Overall g rms	**5.78**

Following this series of sine bursts, a swine sweep was conducted at the following level.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-2000	0.1 g	2

8.4.4 Results

During the random vibe tests may things were observed that should spark our interest, but at the same time we do not need to pay them to much worry due to the fact that this will not normally occur due to the fact that the shocking will reduce the effects felt by the satellite by a great deal.

Some of the most notable results came from the structure of the satellite. The first being the antenna bracket on top of the structure. The bracket saw a great deal of vibration as seen in the plot below.

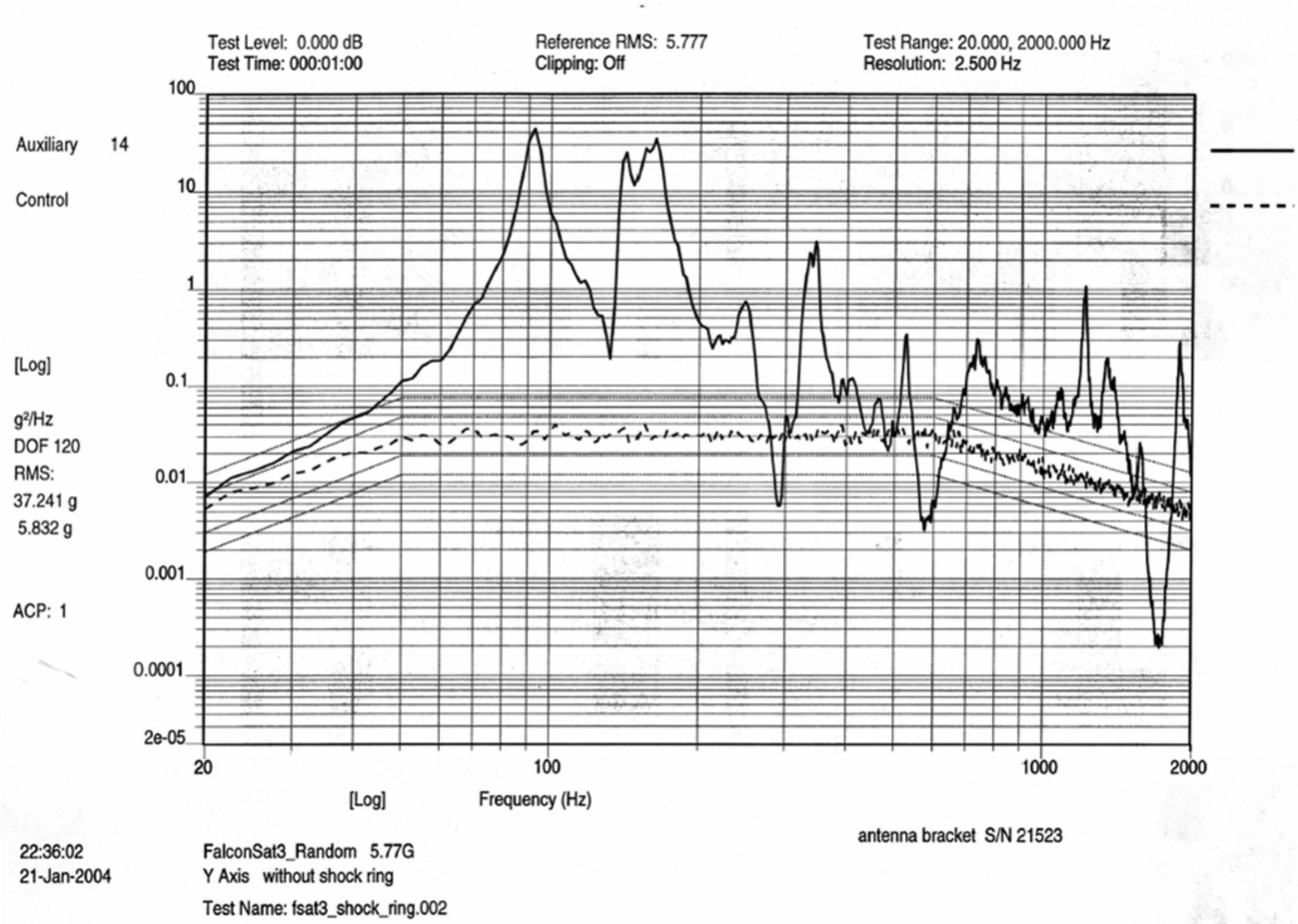


Figure 30: Plot of Antenna bracket response during random vibe

In the plot you can see that the bracket reached amplification on the order of 300 g's rms around the first mode that was found to be at 90 Hz. This could prove difficult with many delicate sensors that are to be attached to the bracket. The other section of the satellite that showed notable results was the boom tip. Its results can be seen below.

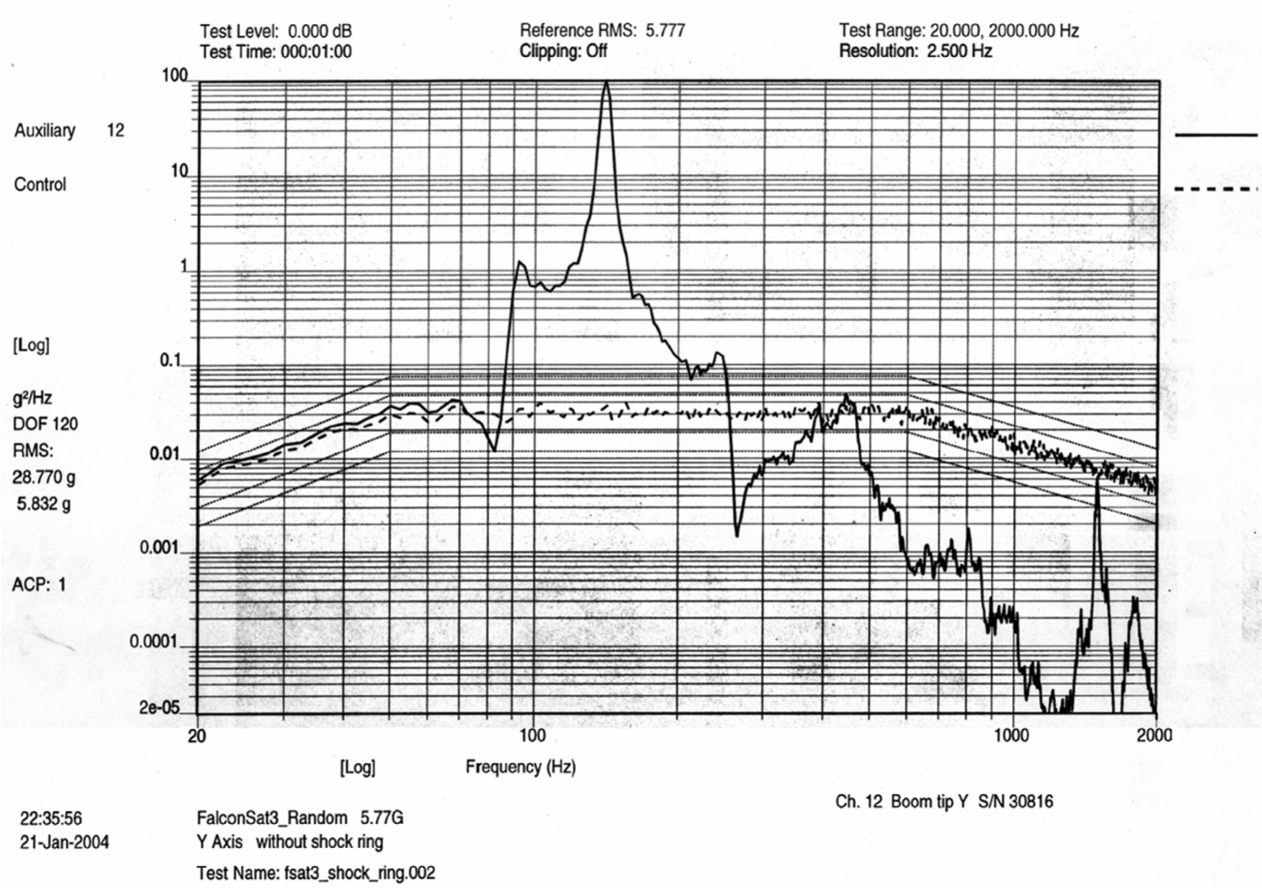


Figure 31: Results from the Random Vibe test on the Boom Tip in the +/-Y direction

The boom tip saw amplification up to 100 g's rms at its second mode. This mode occurred at approximately 150 Hz as shown by the plot shown above. This could prove difficult to handle because of the MPACS that will be left at the end of the boom.

In th general there were some common results from the random vibe throughout the satellite. At higher frequency great deals of amplification was found. This can been seen in the following plot of the Y panel towards the higher frequencies on the plots.

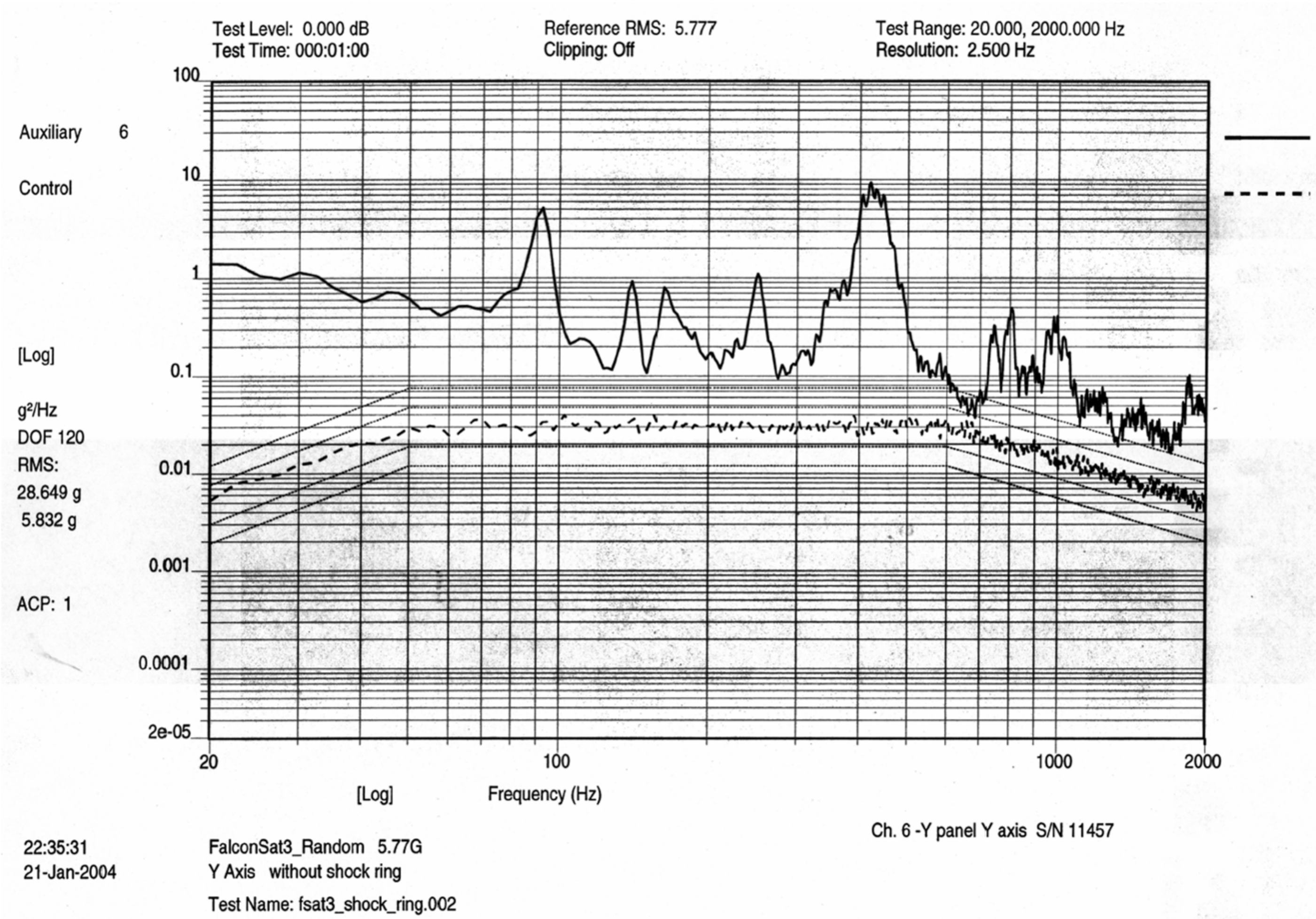


Figure 32: Plot of the random vibe response on the -Y panel

As the higher frequency is reached on all of the parts the same thing occurs. The sattlelite become saturated and cannot vibrate at the same level that the table is putting out and the measurements become wild and blurred as seen above.

8.5 Sine burst Test

8.5.1 Objective

The objective of the sine burst test was to simulate a quasi-static load on the test article to verify strength.

8.5.2 Success Criteria

Success of the sine burst test was determined based on any changes to natural frequency as a result of the test. A change of less than 10% was deemed to be successful.

8.5.3 Test Levels

The sine burst test was performed with the following frequency and maximum acceleration specification. The center frequency was selected based on ~1/4 the natural frequency of the shockring as seen from the previous tests. The g-level was based on the stated qualification level for the program.

Frequency (Hz)	Acceleration (g)
f=1/4 of first vibration mode of the spacecraft = 25 Hz	21.3

Table 24 Sine burst vibration specification

The test was performed in a number of steps starting from -12 dB, to -9 dB, -6 dB, -3 dB then -0 dB (the final test level) to allow the vibration equipment to analyze the system response and adjust the input levels appropriately.

Following this series of sine bursts, a swine sweep was conducted at the following level.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-2000	0.1 g	2

8.5.4 Results

The overall conclusion is that the final sine sweep was found to be the same as initial sine sweep. This means that no structural damage was apparent by the way the satellite was characterized at this point.

9 Structural Tests Results—Config B (w/o ShockRing) +/-Z

9.1 Test Configuration

9.1.1 Test Article

The test article consisted of the SEM-2 without the Shockring, only the lightband attached as shown in Figure 33 along with a spacer ring to represent the shockring.

Figure 34: Configuration for +/- Z-axis test article without shockring.

9.1.2 Test Set-up

The SEM-2 was bolted to the FalconSAT-3 test fixture. The test fixture was bolted to the table in the same configuration as described in Section 5. The test configuration is shown in Figure 35.

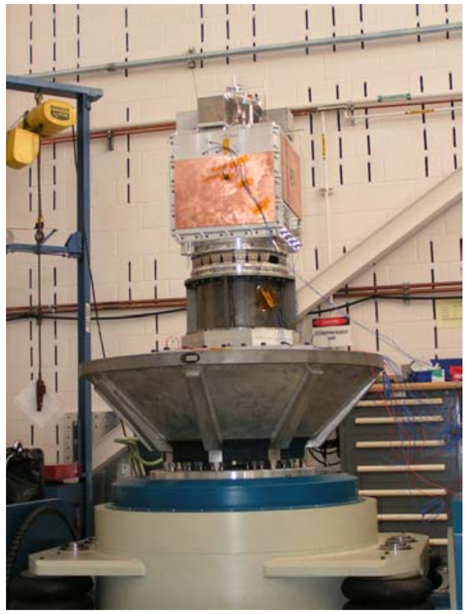


Figure 36: Configuration for +/- Z-axis test without Shockring attached to the test table.

9.1.3 Accelerometer Locations

Accelerometers for this portion of the test were placed as shown in Table 13.

Table 25: +/- Z-axis test accelerometer locations.

Output Number	Serial Number	Sensitivity	Channel Label

1	2346	10.2	Adapter Plate Front Left (NW)
2	2341	10.1	Adapter Plate Front Right (SE)
3	AD808 X	9.3202	Top Center X
4	AD808 Y	10.46	Top Center Y
5	AD808 Z	9.406	Top Center Z
6	11457	104.1	-Y Panel Y
7	21522	10.39	Bottom Corner Z
8	AAM32 X	10.30	Stack Top X
9	AAM32 Y	9.651	Stack Top Y
10	AAM32 Z	9.346	Stack Top Z
11	30818	9.70	Boom Tip X
12	30816	9.83	Boom Tip Y
13	30819	9.60	MPACS Z
14	21523	9.95	Antenna Bracket Y
15	13228	9.42	FLAPS Outside X
16	30817	10.07	Interface Ring Z

9.2 Test data

The tests produced output graphs from the various accelerometers. From these graphs the response of the structure was determined. In the cases when the only output available was hardcopy plots, the main values were captured off the recording equipment before they were cleared off the system and noted on the copies by hand when they could not be printed directly.

9.3 Initial Sine sweep

9.3.1 Objective

The objective of the initial sine sweep test was to determine the natural frequency of the FalconSAT-3 flight configuration in the Y (and by symmetry) the X-axis.

9.3.2 Success Criteria

No specific success criteria were defined for this test. We anticipated the frequency would drop to approximately 30 Hz.

9.3.3 Input Levels

The sine sweep was performed with the following frequency and acceleration specification.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-2000	0.1 g	2

Table 26 Sine sweep vibration specification

9.3.4 Results

The sine sweep came out much as predicted. The fundamental mode was found to be 170 Hz. This is no where near the predicted number due to the fact that the predicted number was based off of the Y axis testing. The results from the Z axis testing can be seen below.

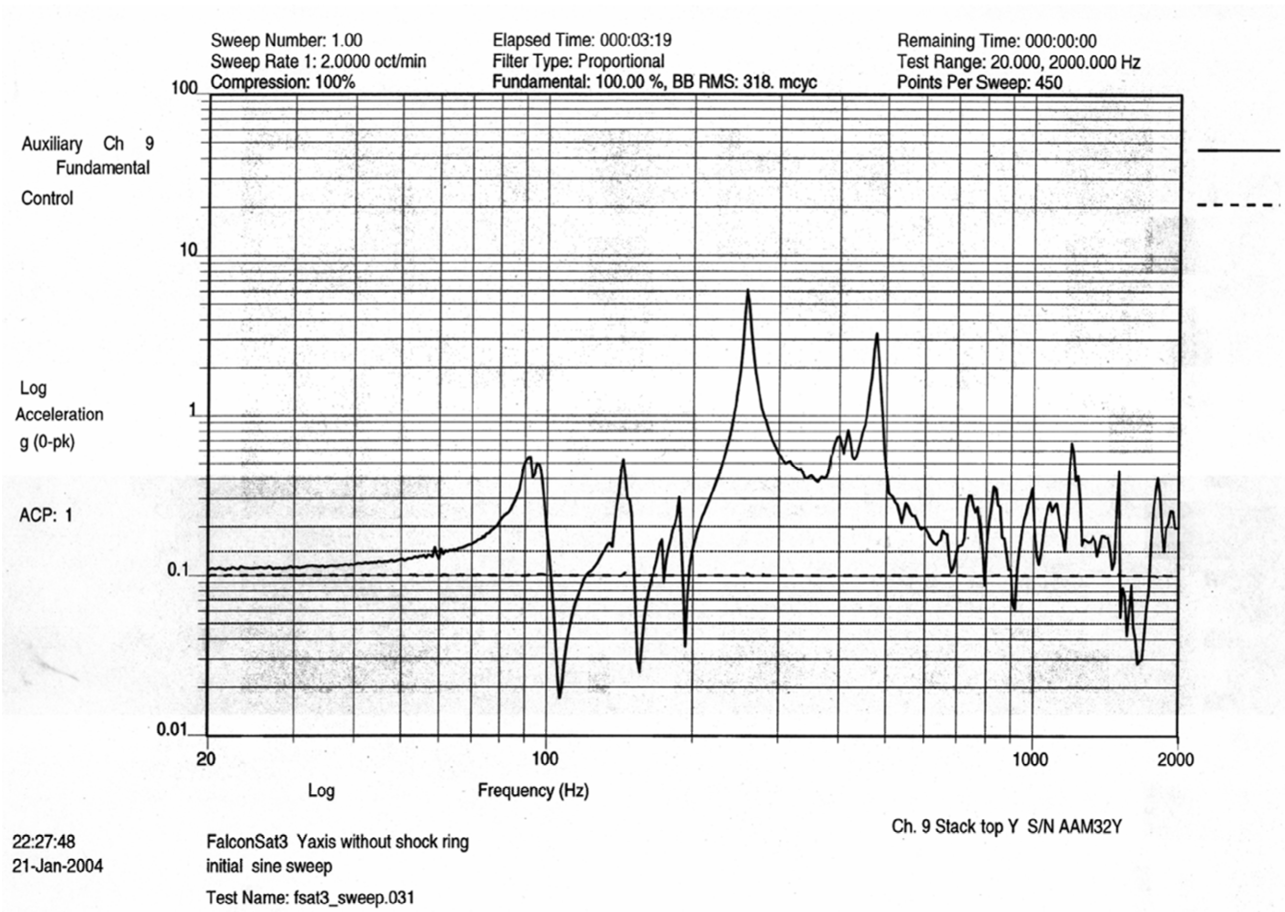


Figure 37: Stack top initial sine sweep

9.4 Characterization-Level Random Vibration Test

9.4.1 Objective

The objective of this test was simulate the flight acoustic load to verify test article fatigue margin and gather basic performance data of the structure without the shockring. As this configuration is different from the flight configuration (no shockring) there was no need to repeat qualification-level tests.

9.4.2 Success Criteria

The primary success criterion was to maintain structural integrity throughout the duration of the test.

9.4.3 Test Level

The following levels were established for this test. These represent -3dB from the flight levels described in Section **Error! Reference source not found.**.

Table 27: Shockring characterization random vibration levels.

Frequency (Hz)	Acceleration PSD (g^2/Hz)
20	0.005
20-50	+6 dB/octave
50-600	0.03
600-2000	-4.5 dB/octave
2000	0.005
Duration	**1 minute per axis**
Overall g rms	**5.78**

Following this series of sine bursts, a swine sweep was conducted at the following level.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-1800	0.1 g	2

9.4.4 Results

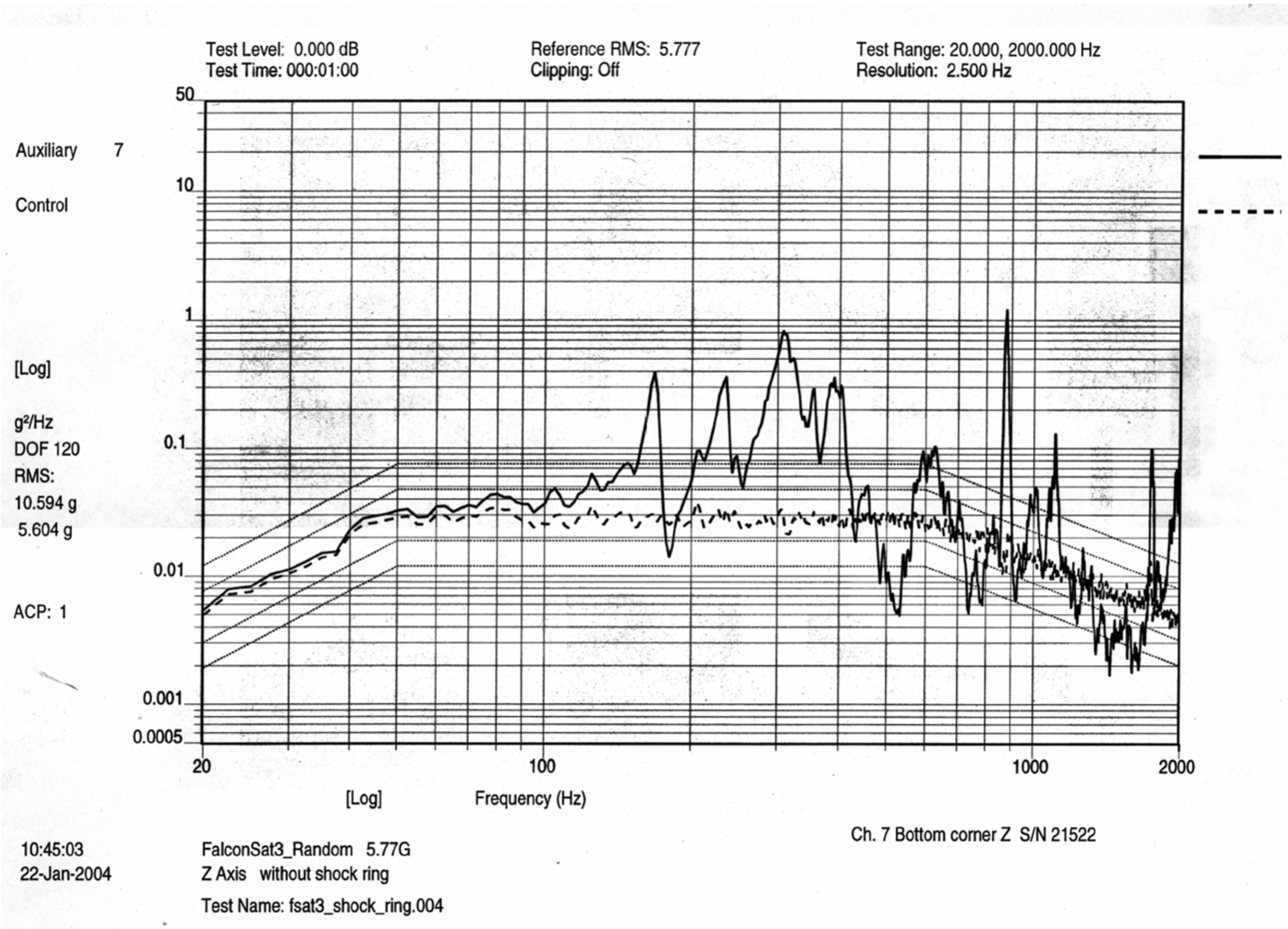


Figure 38: Random vibe test of the Bottom Corner Z axis

As seen in the plot above there were no extremes to the Z axis. In general this test brought about very few shocking results that should be taken note of. The following plots illustrates some of the other responses to the random vibe at flight levels.

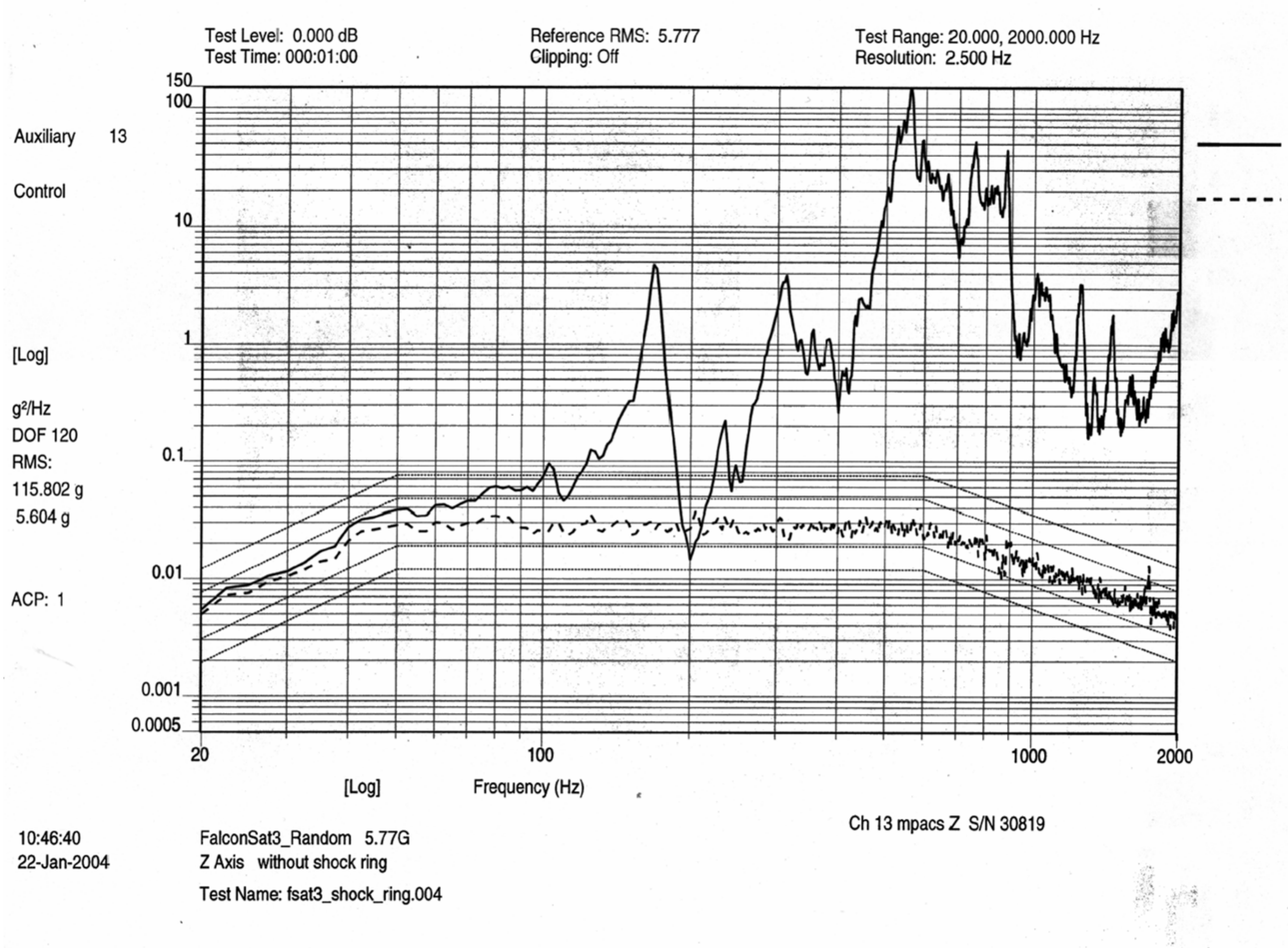


Figure 39: MPACS Reponse to the Flight Level Random Vibe

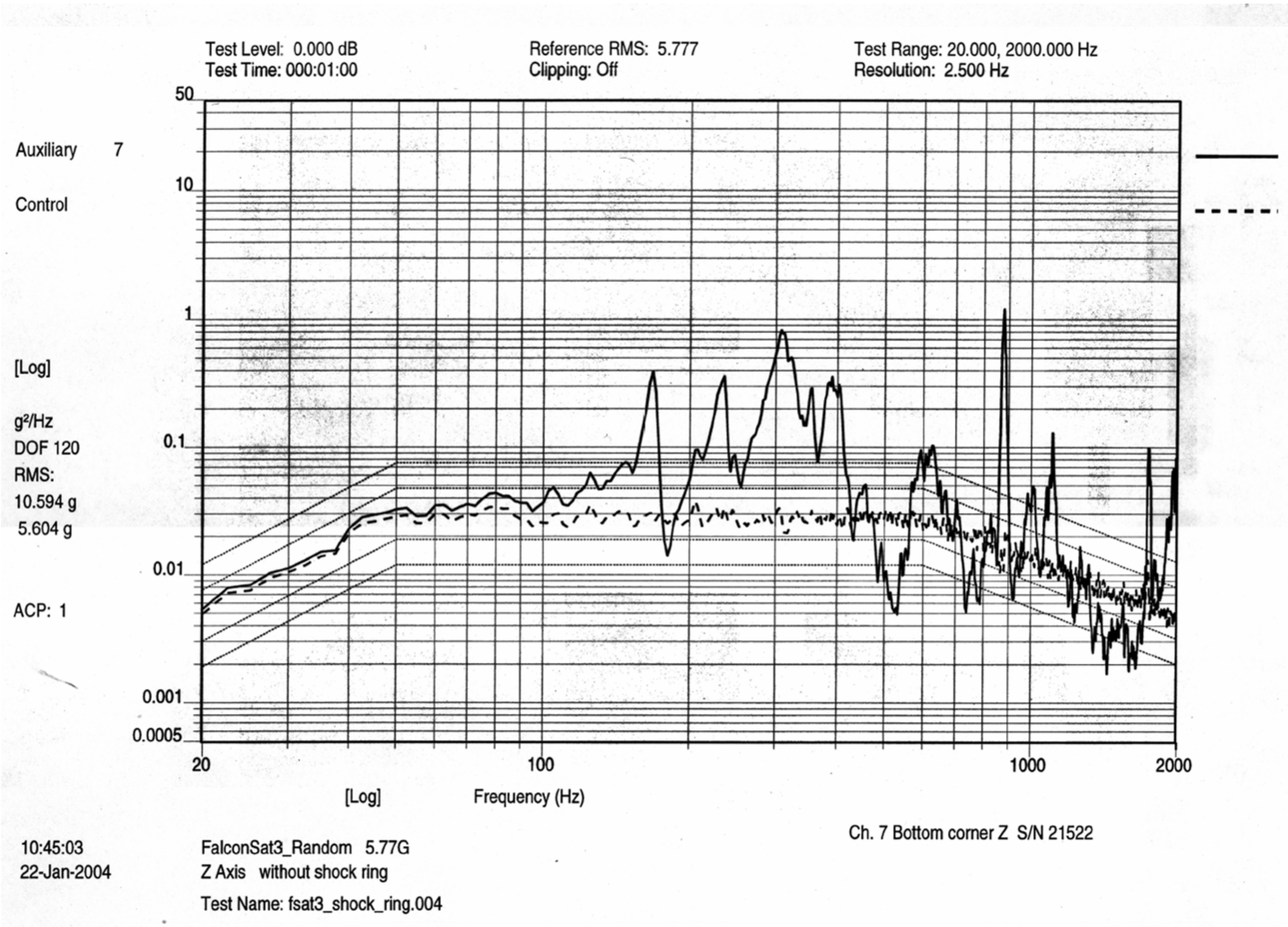


Figure 40: Bottom Corner Response to Flight Level Random Vibe

9.5 Sine burst Test

9.5.1 Objective

The objective of the sine burst test was to simulate a quasi-static load on the test article to verify strength.

9.5.2 Success Criteria

Success of the sine burst test was determined based on any changes to natural frequency as a result of the test. A change of less than 10% was deemed to be successful.

9.5.3 Test Levels

The sine burst test was performed with the following frequency and maximum acceleration specification. The center frequency was selected based on ~1/4 the natural frequency of the stack as seen from the previous tests, or less. The g-level was based on the stated qualification level for the program.

Frequency (Hz)	Acceleration (g)
25 Hz	21.3

Table 28 Sine burst vibration specification

The test was performed in a number of steps starting from -12 dB, to -9 dB, -6 dB, -3 dB then -0 dB (the final test level) to allow the vibration equipment to analyze the system response and adjust the input levels appropriately.

Unfortunately, the table topped out at the peak of the burst. So a swine sweep was conducted at the following level.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-1800	0.1 g	2

Following this sine sweep, another sine burst was conducted using the following modified profile.

Frequency (Hz)	Acceleration (g)
35 Hz	21.3

Table 29 Sine burst vibration specification

The test was performed in a number of steps starting from -12 dB, to -9 dB, -6 dB, -3 dB then -0 dB (the final test level) to allow the vibration equipment to analyze the system response and adjust the input levels appropriately.

9.5.4 Results

The Sine burst success criteria were met by the fact that there was no structural failure after the satellite was run through a sine sweep after the test. There was no change in the fundamental frequency. It was a number approaching zero on the change in the fundamental frequency.

Fundamental Frequencies	Hz
Top Panel Bending	170
Rocking	110
Stack Top	235
Boom Axial (Suspected)	310

Boom Axial (suspected: boom up, everything else down)	410

Figure 41: Z axis modes without shockring

10 Test Fixture Characterization +/- Z

10.1 Test Set-up

First, the entire shaker table was cleaned with alcohol and rags. The test fixture, which was cleaned with Simple Green before leaving USAFA, consists of two parts. The fixture was removed from FalconSat3, and all hardware (bolts, washers, etc.) was separated for inventory and inspection. Four people carried the fixture to the vibration table, where ½ in. shaker table bolts (2 ½ in. length) were used to bolt the fixture to the table. The team used as many bolts as possible to secure the fixture. The bolts were torqued to 44 ft-lbs using a 3/8" hex head socket. The torque was double-checked by a second person, and two loose bolts were discovered. The error was corrected.

Next, the bolts securing the two parts of the test fixture together were checked for proper torque (100 in-lbs). The first torque wrench used for this procedure was improperly calibrated, and one of the bolts was broken. As a result, all the bolts had to be removed and the two parts of the test fixture had to be separated. The broken bolt was extracted and the two parts were reassembled. When inserting the bolts for reassembly, each one had to be tightened by hand first, and then tightened with the torque wrench one at a time, alternating sides of the test fixture in a star pattern.

10.2 Test Objectives

Test objectives for this portion of the test campaign are summarized in Table 8.

Table 30: Test Fixture Test Objectives and Success Criteria.

Test	Objective	Success Criteria
Sine Sweep	Characterize natural frequency of the test fixture	First mode natural frequency of the test fixture >~2x highest mode natural frequency of the spacecraft (>400 Hz)
Sine Sweep, sine burst and random vibe	Verify data and test control from test facility	Data input from all available channels
Sine Sweep, sine burst and random vibe	Verify ability of test facility to conduct all planned tests	Facility successfully executes planned test profiles

10.3 Sine Sweep

10.3.1 Test Levels

A sine sweep of the test fixture was performed with the frequency and acceleration specification shown in Table 31: Sine Sweep Levels for Test Fixture Testing..

Table 31: Sine Sweep Levels for Test Fixture Testing.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-1800	0.1 g	2

10.3.2 Test Results

During the first sine sweep the test computer froze and aborted at ~1800 Hz. The test controllers spent the rest of the first day and half of the second day resolving the problem. In the mean time, CG/MOI tests were conducted.

Once the vibration table was returned to service, the sine sweep was repeated. Results from the top of the fixture indicated the first mode natural frequency of the test fixture was ~800 Hz as shown in

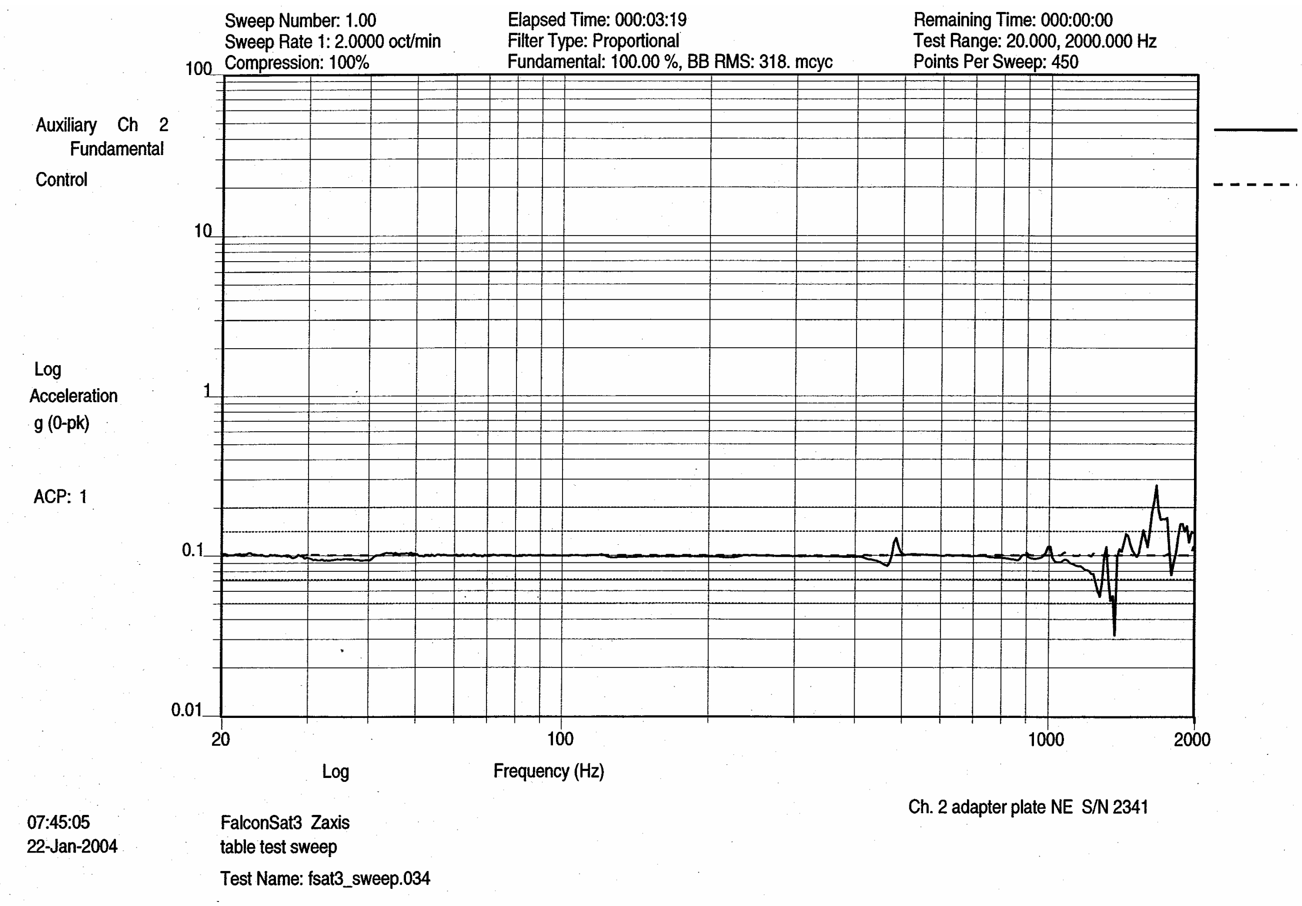


Figure 42: FalconSat3_Zaxis Initial Sine Sweep Table Test (Auxiliary 3).

10.4 Random Vibration

10.4.1 Test Levels

10.4.1.1 Test Fixture Qualification Levels

The random vibration test was conducted at the highest planned level under the assumption that if it was successful, then all lower levels would be assumed successful without testing. The levels are shown in Table 32: Test Fixture Random Vibration Levels..

Table 32: Test Fixture Random Vibration Levels.

Frequency (Hz)	Acceleration PSD (g^2/Hz)
20	0.04
20-50	+6 dB/octave
50-600	0.24
600-2000	-4.5 dB/octave
2000	0.04
Duration	**1 minute per axis**
Overall g rms	**16.3**

Following the random vibration test, a sine sweep of the test fixture was performed with the frequency and acceleration specification shown in Table 33: Sine Sweep levels for test fixture testing..

Table 33: Sine Sweep levels for test fixture testing.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-1800	0.1 g	2

10.4.2 Test Results

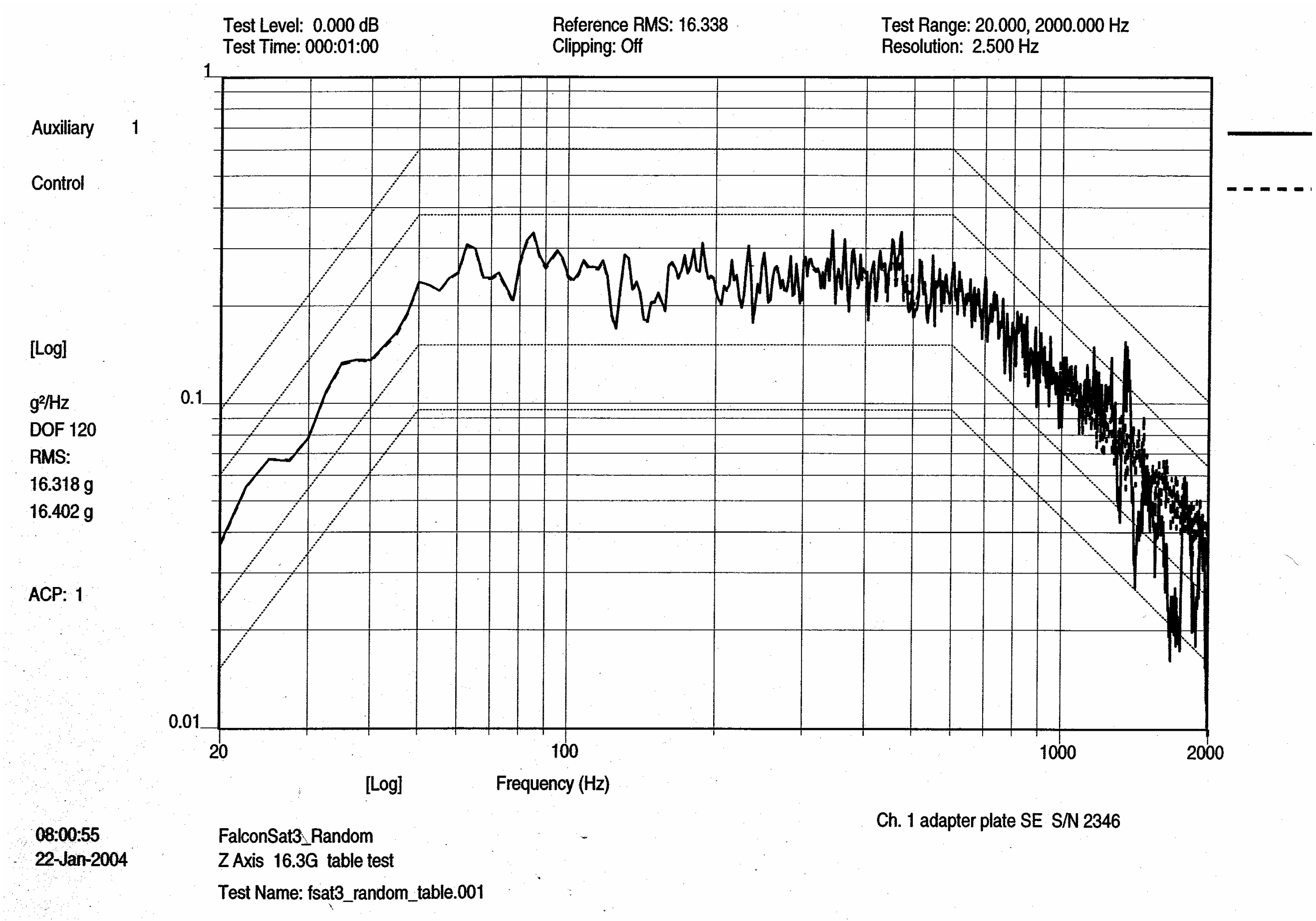


Figure 43: FalconSat3_Random Z Axis fixture test 16.3G (Auxiliary 2).

(Shows the response of the accelerometer at the top of the test fixture during the high-level random vibration test.)

10.5 Sine Burst

The sine burst test was run on the test fixture in order to fully characterize the test fixture before the satellite was added. There was no sine sweep to follow the sine burst test due to the fact that no failure was observed in the test fixture nor is it at all likely that the extremely durable test fixture had any failure or change in its structure.

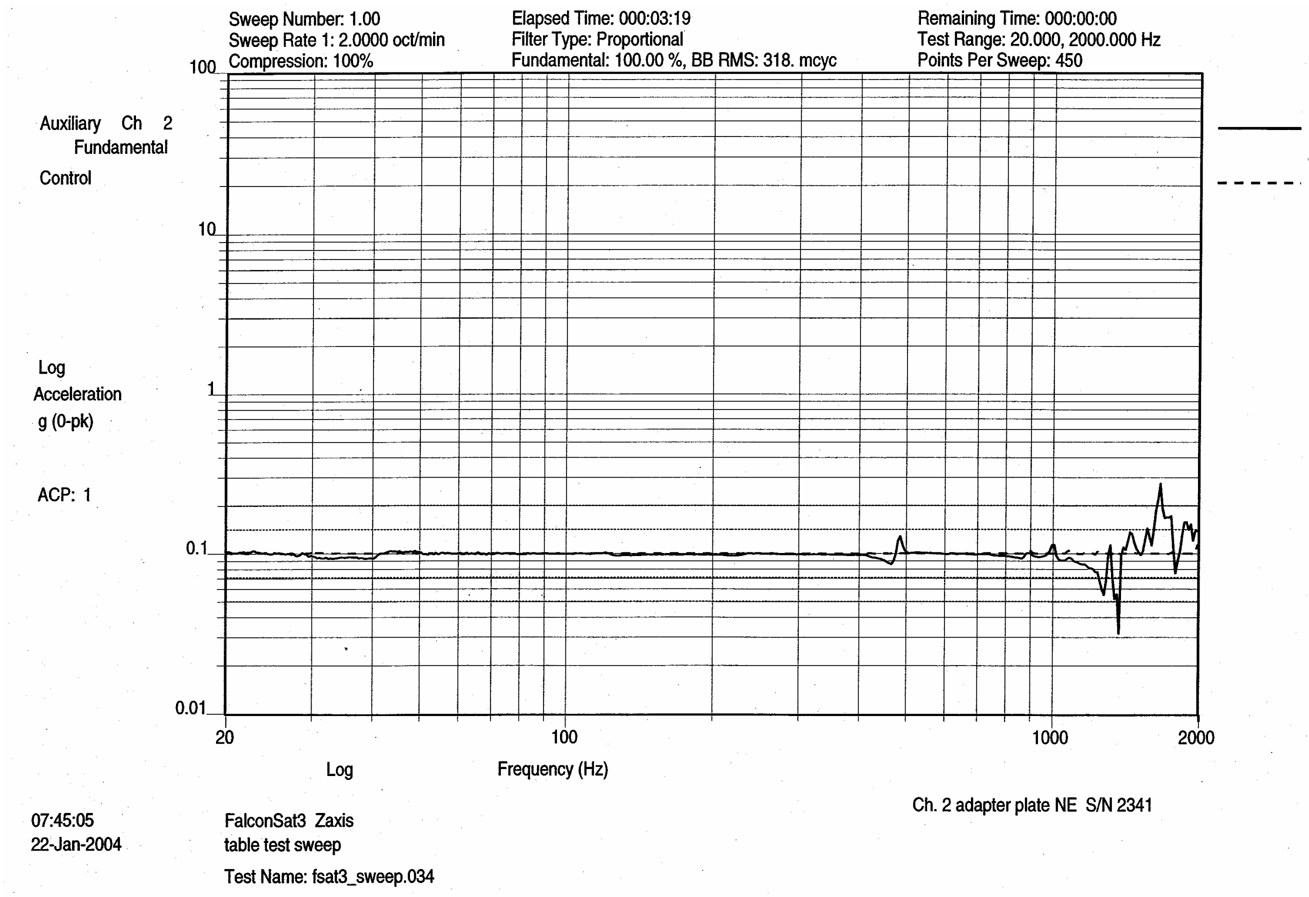


Figure 44: Test Fixture Sine Burst.

(Shows the response to the sine burst loads applied)

10.6 Summary of Results

Results of all tests conducted on the test fixture are shown in Table 34.

Table 34: Summary of Test Fixture Results

Test	Objective	Success Criteria	Result
Sine Sweep	Characterize natural frequency of the test fixture	First mode natural frequency of the test fixture >~2x highest mode natural frequency of the spacecraft (>400 Hz)	Pass
Sine Sweep, sine burst and random vibe	Verify data and test control from test facility	Data input from all available channels	Pass

Sine Sweep, sine burst and random vibe	Verify ability of test facility to conduct all planned tests	Facility successfully executes planned test profiles	Pass

11 Structural Tests Results—Config A (w/ShockRing) +/-Z

11.1 Test Configuration

11.1.1 Test Set-up

The test article consisted of the SEM-2 with both the shockring and lightband attached as shown in Figure X. The SEM-2 was bolted to the FalconSAT-3 test fixture. The test fixture was bolted to the table in the same configuration as described in Section 5. The test configuration is shown in Figure X.

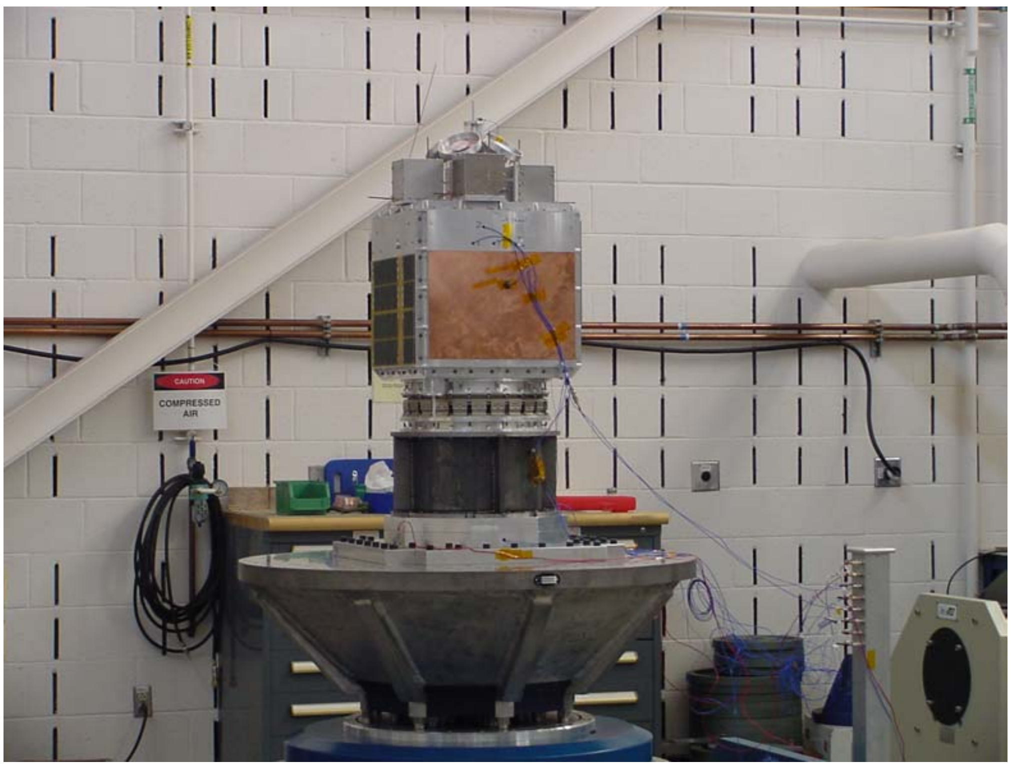


Figure 45: Configuration for +/- Z-axis test with Shockring and lightband

(shown attached to test table.)

11.1.2 Accelerometer Locations

Accelerometers for this portion of the test were placed as shown in Table 13.

Output Number	Serial Number	Sensitivity	Channel Label

1	2346	10.2	Adapter Plate Front Left (SE)
2	2341	10.1	Adapter Plate Front Right (NE)
3	AD808 X	9.3202	Top Center X
4	AD808 Y	10.46	Top Center Y
5	AD808 Z	9.406	Top Center Z
6	11457	104.1	-Y Panel Y
7	21522	10.39	Bottom Corner Z
8	AAM32 X	10.30	Stack Top X
9	AAM32 Y	9.651	Stack Top Y
10	AAM32 Z	9.346	Stack Top Z
11	30818	9.70	Boom Tip X
12	30816	9.83	Boom Tip Y
13	30819	9.60	MPACS Y
14	21523	9.95	Antena Bracket
15	13228	9.42	FLAPS Outside
16	30817	10.07	Interface Ring

Table 35: +/- Z-axis test accelerometer locations.

11.2 Summary of Test Objectives, Success Criteria & Results

Test	Objectives	Success Criteria	Result
Initial Sine Sweep	1. Characterize natural frequencies of the SEM-2 flight configuration in the Z axis. 2. Capture performance data on the shockring to validate its benefits and help to refine its final flight design. 3. Capture transfer function data on dynamic response of different parts of the spacecraft.	1. Successful measurements 2. Data collected 3. Data collected	1. Primary mode is at about 90 Hz, 2nd mode is at about 190 Hz. 2. Pass 3. Pass
Sine Burst	1. Verify spacecraft meets the ESPA static load requirement of 10.6 g limit load in axial and lateral axes simultaneously. 2. Collect data on dynamic response of spacecraft	1. Spacecraft maintains structural integrity following RSS of 10.6 g's in two axes (15 g's) sine burst. 2. Data collected	1. Verified up to 12.82 g's due to limitations of test equipment. 2. Pass

	components.		
Subsequent Sine Sweep (after each test)	1. Verify structural integrity following major test.	1a. Peak acceleration at fundamental frequency does not shift by more than +/- 20% during tests, as determined by the low-level sine sweeps before and after the high-level tests. 1b. Fundamental frequency does not shift by more than +/- 5% during tests, as determined by the low-level sine sweeps before and after the high-level tests	1. Pass
Shockring Characterization Random Vibration	1. Collect data on low-level dynamic response of spacecraft with shockring to characterize performance and aid in final flight design.	1. Data collected	1. Pass
Qualification Random Vibration	1. Verify the capability of the satellite structure and components to withstand the fatigue introduced during the launch vibrations per ESPA interface requirement. 2. Collect data on dynamic response of spacecraft components. 3. Collect data on high-level dynamic response of spacecraft with shockring to characterize performance and aid in final flight design.	1a. Representative sample of fasteners do not lose more than 20% of original torque 1b. Post Random Vibration Sine sweep meets above criteria. 2. Data collected 3. Data collected	1a. Pass 1b. Pass 2. Pass 3. Pass

11.3 Test data

The tests produced output graphs from the various accelerometers outlined in Table 35: +/- Z-axis test accelerometer locations.. From these graphs the response of the structure was determined. In the cases when the only output available was hardcopy plots, the main values were captured off the recording equipment before they were cleared off the system and noted on the copies by hand when they could not be printed directly.

11.4 Initial Sine sweep

11.4.1 Objective

The objective of the initial sine sweep test was to determine the natural frequency of the FalconSAT-3 flight configuration in the Z axis.

11.4.2 Success Criteria

The success criterion for this test was simply to find the natural frequency. We anticipated the frequency would drop.

11.4.3 Input Levels

The sine sweep was performed with the following frequency and acceleration specification.

Frequency range (Hz)	Acceleration (g)	Sweep rate (octaves/minute)
20-1800	0.1 g	2

Table 36 Sine sweep vibration specification

11.4.4 Results

From this initial sine sweep, we determined the following fundamental and secondary frequencies.

Mode	Frequency (Hz)
First	90
Second	190

Table 37: Initial Sine Sweep Results

These frequencies are illustrated in the following figure which depicts the initial sine sweep response of the top panel with the shockring.

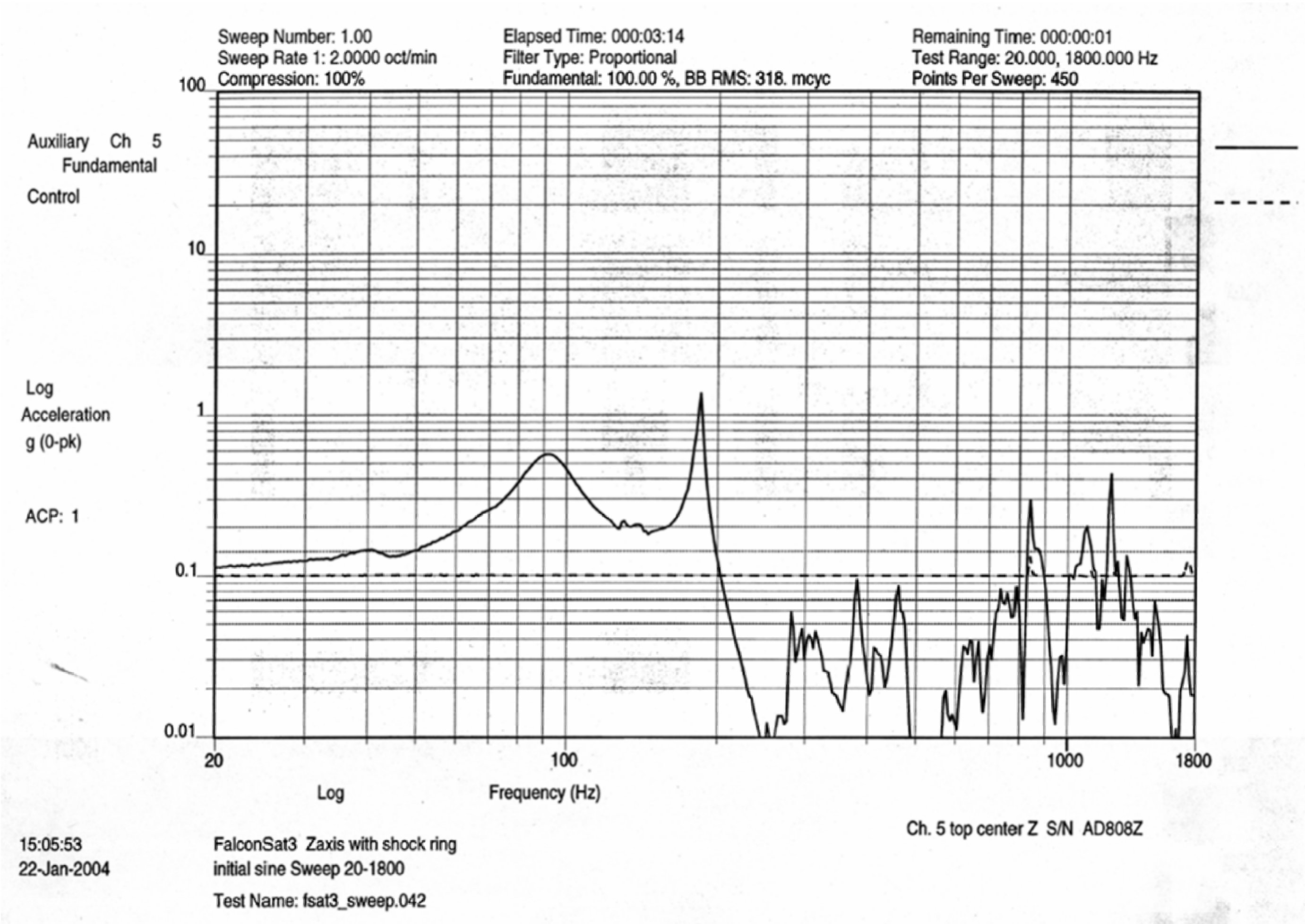


Figure 46: Initial Sine Sweep +/- Z

11.5 Characterization-Level Random Vibration Tests

11.5.1 Objective

The characterization-level random vibration test was completed to collect data on low-level dynamic response of spacecraft with shockring to characterize performance and aid in design. The random vibration tests were also conducted in order to verify the capability of the satellite structure and components to withstand the fatigue introduced during launch vibrations. For this reason, the loads introduced during this test should mirror the loads that will be applied to the Flight model in low level dynamic loads.

11.5.2 Success Criteria

The success criteria for this test was simply to collect the data referred to above.

11.5.3 Test Level

The following levels were established for this test. These represent -3dB from the flight levels.

Frequency (Hz)	Acceleration PSD (g^2/Hz)
20	0.005 (for information only)
20-50	+6 dB/octave
50-600	0.03
600-2000	-4.5 dB/octave
2000	0.005 (for information only)
Duration	**1 minute per axis**
Overall g rms	**5.78**

Table 38: Shockring characterization random vibration levels.

11.5.4 Results

Following this random vibration test, a swine sweep was conducted to the levels indicated in Table 36 Sine sweep vibration specification. After a reasonable sample of the bolts were checked for the proper torque it was determined that less than 20% of the torque had been lost on any one bolt. The plot below illustrates the sine sweep results for the top panel following this test. As you can see, the fundamental frequency following this test remained almost unchanged. Plots remain unchanged, for the most part, from one accelerometer to the next. Another notable response is the high cross axis response at the 840 Hz on the center of the top panel up 10.3 g rms.

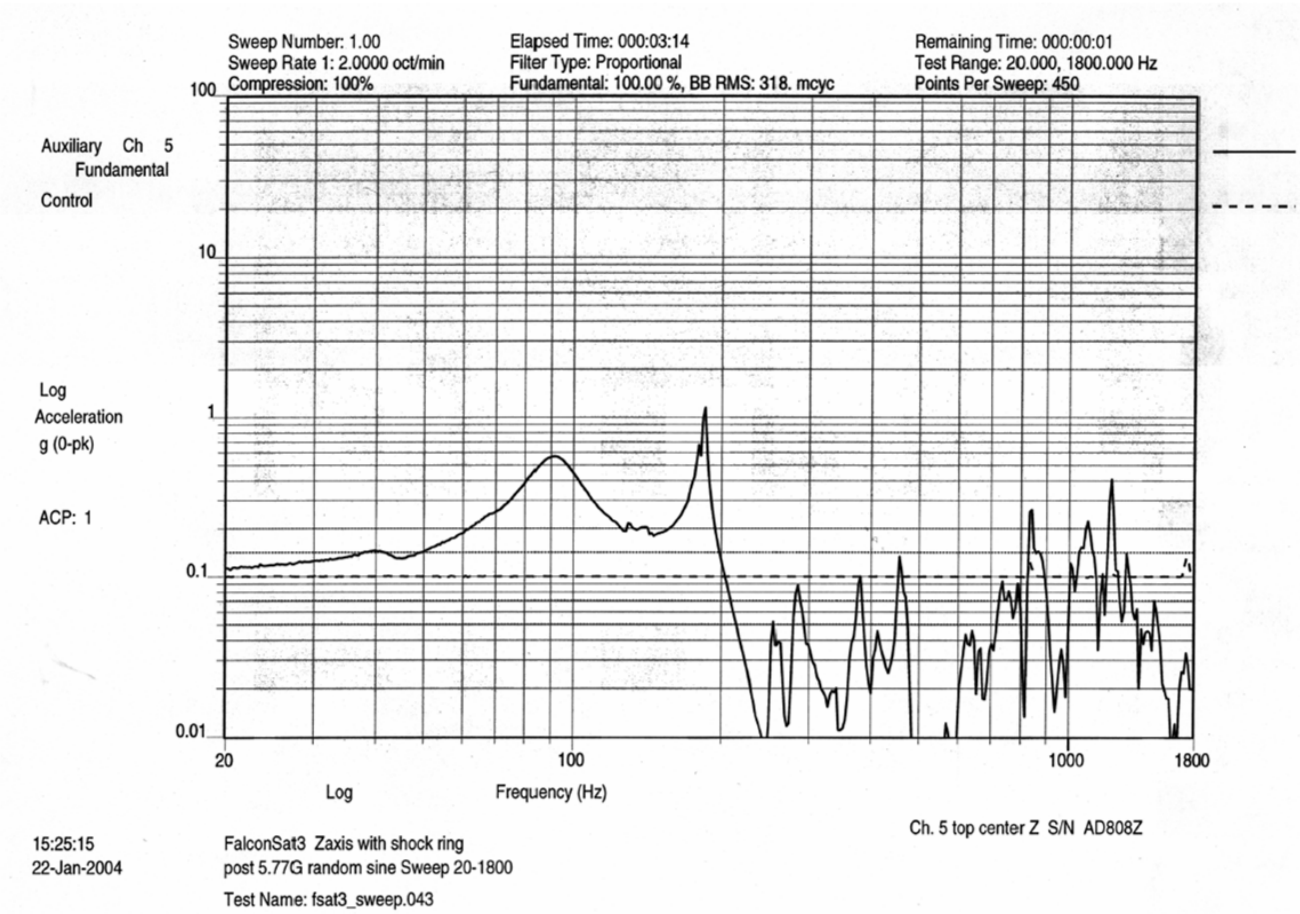


Figure 47: Post Characterization-Level Random Vibe Sine Sweep

11.6 Sine burst Test

11.6.1 Objective

11.6.2 Success Criteria

Success of the sine burst test was determined based on any changes to natural frequency as a result of the test. A change of less than 10% was deemed to be successful.

11.6.3 Test Levels

The sine burst test was performed with the following frequency and maximum acceleration specification. The center frequency was selected based on ~1/4 the natural frequency of the shockring as seen from the previous tests. The g-level was based on the maximum recommended by CSA.

Frequency (Hz)	Acceleration (g)
25	14.995

Table 39 Sine burst vibration specification

The test was performed in a number of steps starting from -12 dB, to -9 dB, -6 dB, -3 dB then -0 dB (the final test level) to allow the vibration equipment to analyze the system response and adjust the input levels appropriately.

11.6.4 Results

Following this series of sine bursts, a swine sweep was conducted to the levels indicated in Table 36 Sine sweep vibration specification. After a reasonable sample of the bolts were checked for the proper torque it was determined that less than 20% of the torque had been lost on any one bolt. The plot below illustrates the sine sweep results for the top panel following this test. As you can see, the fundamental frequency following this test remained almost unchanged. Plots remain unchanged, for the most part, from one accelerometer to the next.

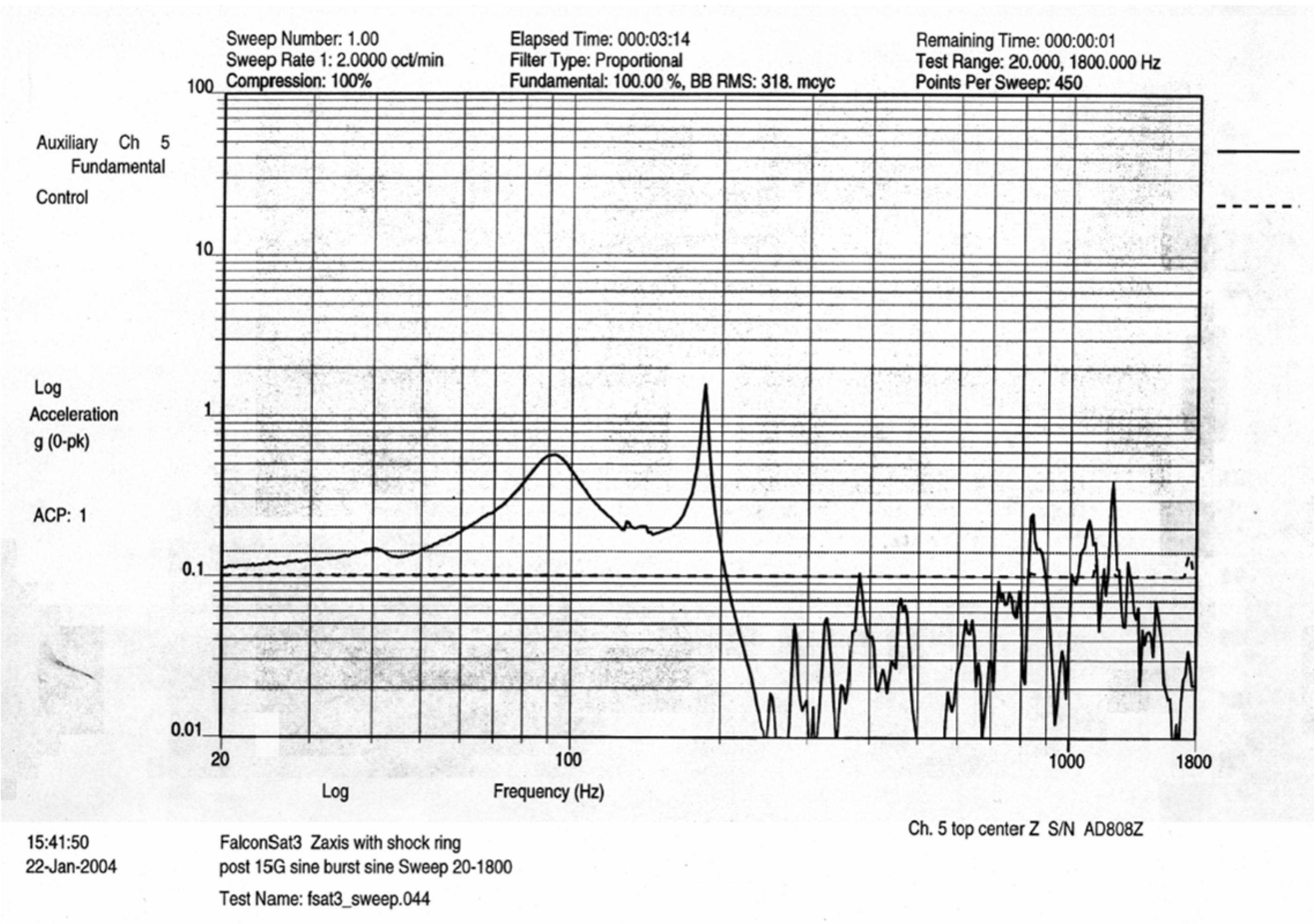


Figure 48: Post Sine Burst Sine Sweep

The following table illustrates responses of several key components to this test:

Component	Response (g's)
Top Panel Y	19
Top of Stack Y	20
MPACS	24
Antenna	4
Interface Ring	17
Boom Tip	24

Table 40: Sine Burst Test Results

11.7 Qualification-Level Random Vibration Test

11.7.1 Objective

The qualification-level random vibration test was conducted to verify the capability of the satellite structure and components to withstand the fatigue introduced during the launch vibrations per ESPA interface requirement. The test was also completed to collect data on spacecraft components and on high-level dynamic response of spacecraft with the shockring to characterize performance and aid in final flight design.

11.7.2 Success Criteria

To verify the structure's ability to withstand the fatigue, a representative sample of fasteners must not lose more than 20% of their original torque. Data must be collected as referred to above. Success Criteria

11.7.3 Test Level

Random vibration qualification levels are shown in Table 41 FS-3 Qualification Random Vibration Leveland Figure 49: FalconSAT-3 Qualification-Level power spectral density.. These represent +6dB above the flight level. Based on recommendation from CSA, the duration was increased to a full 2 minutes.

Frequency (Hz)	Acceleration PSD (g^2/Hz)
20	0.0384
20-50	+6 dB/octave
50-600	0.24
600-2000	-4.5 dB/octave
2000	0.04

Duration	**2 minute per axis**
Overall g rms	**16.3**

Table 41 FS-3 Qualification Random Vibration Level

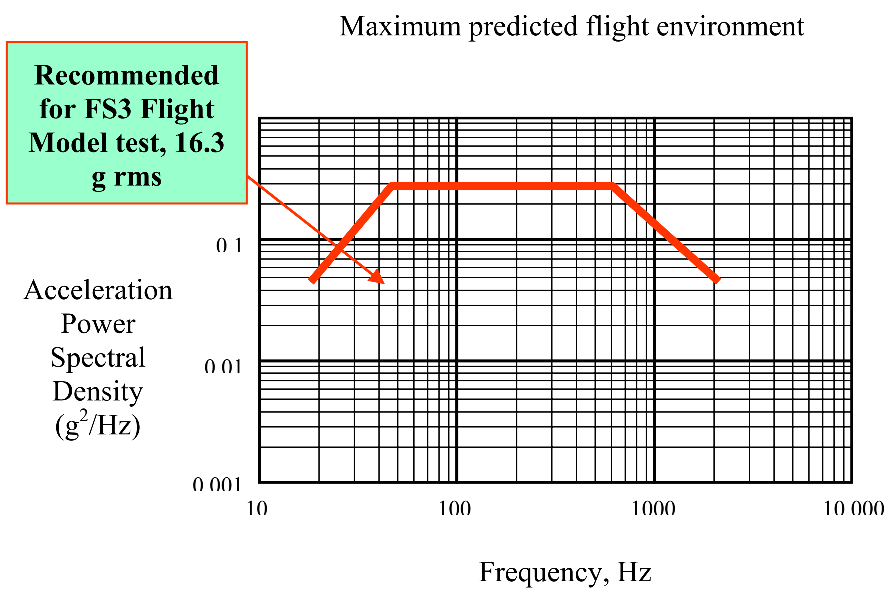


Figure 49: FalconSAT-3 Qualification-Level power spectral density.

11.7.4 Results

Following this random vibration test, a swine sweep was conducted to the levels indicated in Table 36 Sine sweep vibration specification. After a reasonable sample of the bolts were checked for the proper torque it was determined that less than 20% of the torque had been lost on any one bolt. The plot below illustrates the sine sweep results for the top panel following this test. As you can see, the fundamental frequency following this test remained almost unchanged. Plots remain unchanged, for the most part, from one accelerometer to the next. There was some trouble in the qualification level tests. The boom showed some unacceptable responses through the test. It showed nearly 100 gs at 3 sigma. This is mostly due to the rocking mode of the boom. This showed no permanent damage to the structure but according to Tom Serafin in his report titled " FalconSAT Structural Engineering model #2 Test Report" he says that this is a bad outcome and it presents and "unquantifiable risk". He also goes onto say that such shifting will cause the bolts to loose strength and thus the overall structure will begin to loose strength while in the long run resulting in a fatigue failure.

There were other parts of the structure that showed interesting responses throughout the tests. The stack showed a module response as a whole that was polluted by a failure inside of the entire system. For this reason Mr. Seraphin recommends that we ignore the peak at the 240 Hz mark. The MPACS response was also skewed by the same occurrence. The peaks at 400 Hz PSD need to be ignored due to system failure. The MPACs themselves as a unit will not vibrate on such a high level.

The levels reached in the below figure were resultant of the accelerometer being mounted to a thin piece of metal on the inside of the MPACs instead of a piece of metal on the outside of the accelerometer which would be more representative of the experiments actual response.

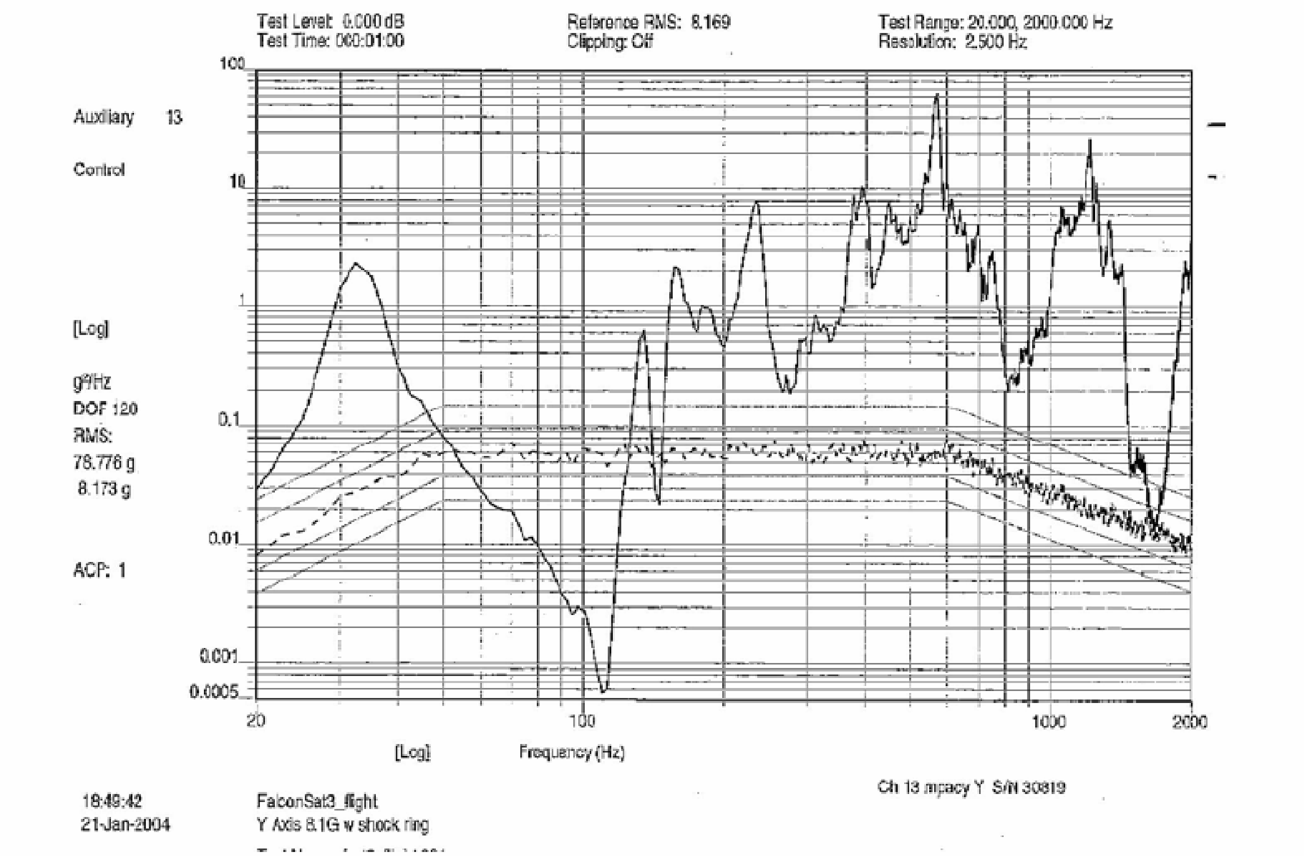


Figure 50: MPACS Response (note 400 Hz response that comes from accelerometer placement)

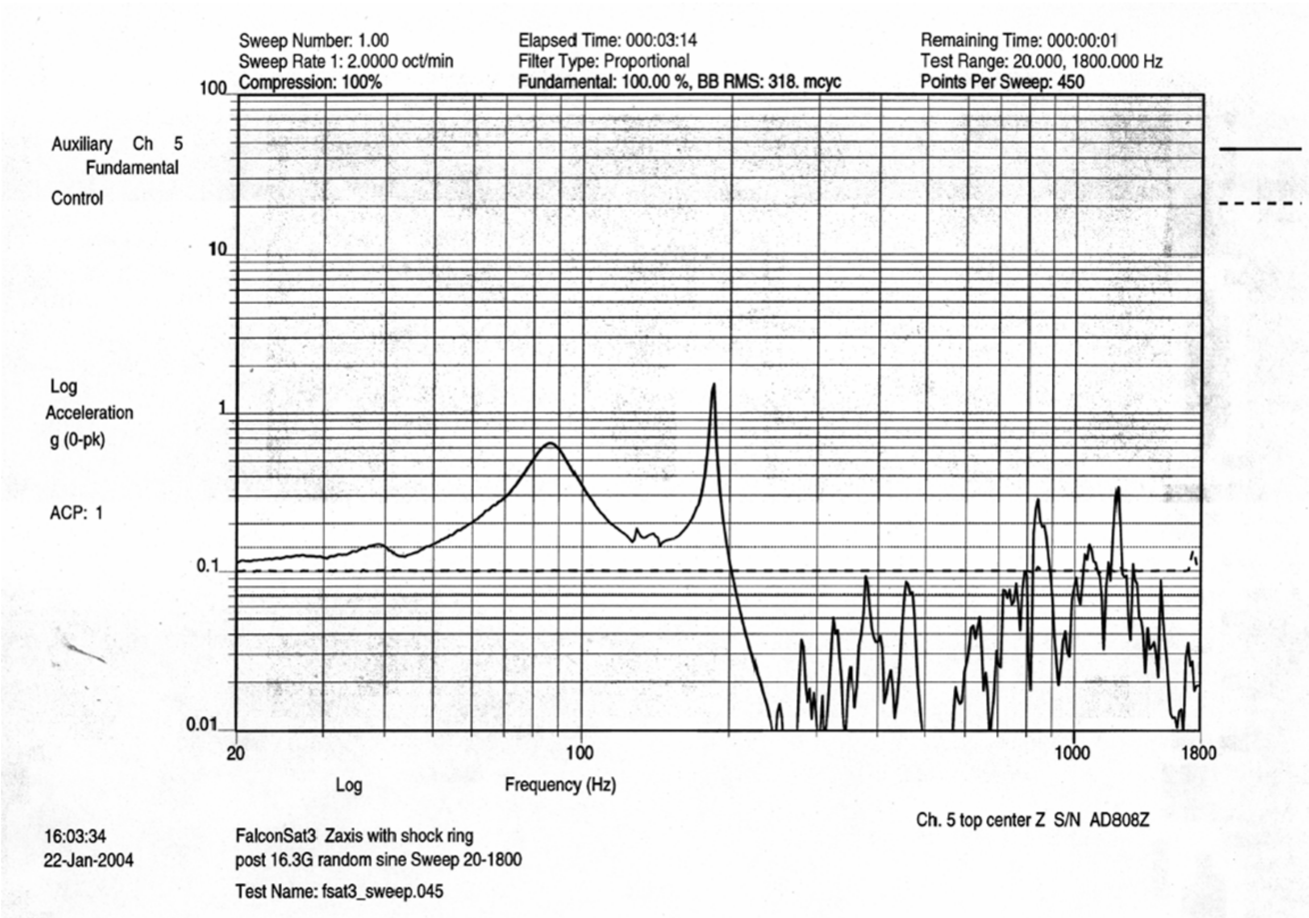


Figure 51: Post Qualification-Level RandomVibe Sine Sweep

12 Shockring Characterization Summary of Results and Analysis

12.1 Objective

The objective of this section is to compare the responses of some critical components to the various random vibration and sine burst tests both with the shockring and without the shockring. This comparison will illustrate the benefits of the shockring and help to refine the final flight design.

12.2 Results

12.2.1 Characterization-Level Random Vibration

12.2.1.1 +/- Y Configuration

Component	g rms Input	Response w/SR (g^2/Hz)	Response w/o SR (g^2/Hz)
Top Panel Y	5.777	6.404	10.842

Top of Stack Y	5.777	19.485	27.271
Baseplate Y	5.777	4.233	5.865
Boom Tip	5.777	25.213	28.770

Table 42: +/- Y Configuration Shockring Comparison

12.2.1.2 +/- Z Configuration

Component	**g rms Input**	**Response w/SR (g^2/Hz)**	**Response w/o SR (g^2/Hz)**
Top Panel Z	5.777	7.784	20.916
Top of Stack Z	5.777	10.117	80.160
Baseplate Z	5.777	5.78	5.604

Table 43: +/- Z Configuration Shockring Comparison

12.2.2 Sine Burst

Unfortunately, the levels that the sine burst tests were conducted to with and without the shockring were different. Therefore, a fair comparison such as the ones made above for the random vibration tests, cannot be done for this test. Instead, this section will simply outline the input versus the response for configurations with and without the shockring. Some information should be able to be gathered from these comparisons.

12.2.2.1 +/- Y Configuration

Component	Reference Input w/SR	Response w/SR	Reference Input w/o SR	Response w/o SR
Top Panel Y	12.826	19.610	21.294	24.398
Top of Stack Y	12.826	17.141	21.294	27.727
Baseplate	12.826	3.424	n/a	n/a

Table 44: +/- Y Configuration Shockring Comparison

12.2.2.2 +/- Z Configuration

Component	Reference Input w/SR	Response w/SR	Reference Input w/o SR	Response w/o SR	Reference Input w/o SR	Response w/o SR
Top Panel Z	14.995	18.997	21.294	22.015	21.630	28.344
Top of Stack Z	14.995	20.093	21.294	22.015	21.630	31.14
Baseplate	14.995	23.948	n/a	n/a	21.630	53.914 (MPACS), 66.5631 (Antenna)

Table 45: +/- Z Configuration Shockring Comparison

12.2.3 Shockring Temperature

12.2.3.1 +/- Y Configuration

Initial shockring temperatures were recorded for each test and then and set intervals throughout each test. The temperature data collected can be seen in the table below.

Test number	Initial /Final	Temp. Channel 1 (Loaded longitudinal) (°F)	Temp. Channel 2 (45 ° off of longitudinal) (°F)
1 Sine Sweep	Initial:	73.85	74.38
	Final:	73.84	74.37
2 Acceptance Random	Initial:	74.27	74.34
	Final:	80.03	77.00
3 Sine Sweep	Initial:	75.08	74.27
	Final:	74.35	74.66
4 Sine burst (13 g's)	Initial:	74.89	75.54
	Final:	75.30	75.7
5 Sine Sweep	Initial:	75.23	75.69
	Final:	75.28	75.9
6 Qual. Random	Initial:	75.70	76.13
	Final:	105.2	96.2
7 Sine Sweep	Initial:	78.99	78.47
	Final:	77.77	76.20

Table 46: Shockring Temperatures (°F), +/- Y

12.2.3.2 +/- Z Configuration

Initial shockring temperatures were recorded for each test and then and set intervals throughout each test. The temperature data collected can be seen in the table below.

Test number	Initial /Final	Temp. Channel 1 (Loaded longitudinal) (°F)	Temp. Channel 2 (45 ° off of longitudinal) (°F)
1 Sine Sweep	Initial:	70.6	71.45
	Final:	70.25	71.10
2 Characterization Random	Initial:	70.24	70.88
	Final:	79.23	75.5
3 Sine Sweep	Initial:	71.36	71.48
	Final:	71.22	71.23
4 Sine Burst (to 16.5 g's)	Initial:	71.10	71.19
	Final:	71.5	71.42
5 Sine Sweep	Initial:	71.20	71.27
	Final:	71.18	71.18
6 Qualification Random (Start)	Initial:	70.64	70.95
Level 1 (-12)	Initial:	70.64	70.95
Level 2 (-9)	Initial:	72.40	72.80
Level 3 (-6)	Initial:	75.50	74.50
Level 4 (-3)	Initial:	79.20	77.00
Level 5 (full)	Initial:	122.20	118.00
7 Sine Sweep	Initial:	75.50	76.50
	Final:	73.60	75.40

Table 47: Shockring Temperatures (°F), +/- Z

12.2.4 Conclusions

With the tests where a fair comparison could be made between the "with" and "without" shockring scenarios, it is apparent that the shockring is aiding to dampen the random vibrations experienced by the satellite. In some cases we see that the difference in response between the two scenarios is as great as 87%.

Upon examination of these temperatures, at higher levels of vibration the temperature of the shockring increases. This can be seen in the qualification and flight level random tests, numbers 6 and 4 respectively. The greatest increases in temperature were seen in channel one due to movement in the test axis. The fundamental frequency of the satellite was reduced by 10 Hz due to an increase in temperature of the viscoelastic material in the shockring. The viscoelasatic material accounts for 20-40% of the stiffness in the shockring. The projected fundamental frequency of the satellite was proposes to be 30 Hz but instead ended up being 33 Hz. This was due to the fact that the weight of the satellite was 10 lbs less than expected and much of the weight was lost in the top portion of the satellite causing the fundamental frequency to be higher than predicted.

13 Test facility

All tests were done at in the Aerospace Engineering Facility (AEF) at Kirtland Air Force Base (KAFB), New Mexico. The tests took place from January 19 to January 22, 2004. The test was delayed by the fact that the table broke on the very first day. The Mass property tests were done during this delay time in order to maximize our use of the facilities. During the down time helicopter rides were taken from the neighboring special operations. This was a great way to spend the extra time and made the trip more productive due to the constructive use of done time. The following table wil allow you to see what level the AEF at Kirtland AFB wil allw for future planning of tests at their facility. This was constructed by Mr. Tom Serafin using his knowledge of the test table.

Stroke (maximum full-range displacement) of shaker: 1.00 inch
Max displacement of shaker from zero = half the stroke: 0.50 inch
f = forcing frequency in cycles per second
w = forcing frequency in radians per second = 2*pi*f

a-max = maximum acceleration = max displacement * w^2
a-allow = 80% of a-max (to account for the shaker not being centered at start)
(a-allow is the assumed max acceleration that you can count on the shaker providing)

f (Hz)	w (rad/s)	a-max (in/s^2)	a-allow (in/s^2)	a-max (g)	a-allow (g)
6	37.7	711	568	1.8	1.5
7	44.0	967	774	2.5	2.0
8	50.3	1263	1011	3.3	2.6
9	56.5	1599	1279	4.1	3.3
10	62.8	1974	1579	5.1	4.1
11	69.1	2388	1911	6.2	4.9
12	75.4	2842	2274	7.4	5.9
13	81.7	3336	2669	8.6	6.9
14	88.0	3869	3095	10.0	8.0
15	94.2	4441	3553	11.5	9.2
16	100.5	5053	4043	13.1	10.5
17	106.8	5705	4564	14.8	11.8
18	113.1	6396	5116	16.6	13.3
19	119.4	7126	5701	18.5	14.8
20	125.7	7896	6317	20.4	16.4
21	131.9	8705	6964	22.5	18.0
22	138.2	9554	7643	24.7	19.8
23	144.5	10442	8354	27.0	21.6
24	150.8	11370	9096	29.4	23.6
25	157.1	12337	9870	32.0	25.6
26	163.4	13344	10675	34.6	27.6
27	169.6	14390	11512	37.3	29.8
28	175.9	15476	12380	40.1	32.1
29	182.2	16601	13281	43.0	34.4
30	188.5	17765	14212	46.0	36.8

Figure 52: Maximum Acceleration Capability of the Kitland AEF shaker in Sine Burst Tests

14 Test personnel

The following personnel will be responsible for activities relating to the SEM2 tests.

Lt.Col. Jerry Sellers, USAFA: Director Space Systems Research Center, Head of Mission

Major Dan Miller, USAFA: Fs-3 Chief Engineer, Responsible Test Engineer

Prof. Maarten Meerman, Schriever Chair, USAFA: General test overview and support

Dale Stoller, AEF Kirtland: Test Conductor, responsible for safety, test equipment, instrumentation, providing initial test and measurement data and controlling the shaker and mass property equipment.

Capt. David Richie, USAFA: FS-3 Program Manager, Responsible for Cadet supervision

C1C Prichard Keely, FS-3 Cadet AIT Chief: Responsible for all USAFA supplied test equipment, and for ensuring all measurement data is collected, and all tests are documented in writing, sketches and photographs.

C1C Steve Hollingsworth, FS-3 Cadet program Manager: Cadet responsible for planning the daily operations

C1C Alexis Eberle, FS-3 AIT Working Group: Cadet in charge of writing the test report

C1C Cristin Smith, FS-3 Cadet Light Band Specialist: In charge of torqueing the light band and insuring that it is properly installed

C1C Obadiah NG Ritchey, FS-3 Cadet MSGE Specialist: in charge of delivering the MGSE for the satellite test in all configurations. Also assisted in testing.

C1C Nicki Hill, FS-3 AIT Working Group: Lab assistant

C1C Ryan Simpson, FS-3 Mech System team: In charge of all drawing for the testing campaign. All responsible for all torques on the satellite ad insuring that all bolts are torqued to the proper levels.

C2C Curtis Switzer, FS-3 AIT Working Group: In charge of documenting, in writing all of the vents of the test for the duration of the testing campaign.

C2C Josh Strafaccia, FS-3 Physics Team: In charge of creating a photo documentary of the testing campaign. Also a Lab assistant.

C2C Nick Corshin, FS-3 Mech. Team Assistant: Assisted in the assembly of the MGSE. In charge of accountability for all of the nuts, bolts, and other parts removed from the satellite.

15 Test Log

20 Jan 04		
Start:	Description:	Finish:
0837	Hooked up the smaller Hydra-Set.	0846
0846	Hooked up SEM2 to the Hydra-Set.	0850
0850	Removed SEM2 from the USAFA supplied extender and interface plate (USEAIP) so that we can put on the light band and shock ring.	0857
0857	Removed USEAIP from dolly.	0908
0906	Put light band on (6 people; use dog bones).	1005
	Retourque	1017
0914	Mounted USEAIP to test platform and removed handles. It is a good procedure to have one technician apply desired torque and then another technician goes back and checks all of them.	0933
0945	Hooked up accelerometers to USEAIP.	0955
0955	Tightened screws on USEAIP. We broke a head off and had to take it off and do it again.	1026
1030	Sine sweep (Y axis; test fixture with USEAIP; 700 Hz; .25 G).	1040
1330	MOI, calibrated mounting bracket (jig).	1338
1339	MOI, putSEM2 on the table. Had to apply some force to SEM2 because the Hydra-Set was going down too slow.	
	Bolts didn’t line up so we had to rotate the mounting fixture.	1415
	Started actual test. (MOI-Z axis; CG X,Y plane).	1430
1446	Weighed SEM2.	1453
1453	Calibrated CG machine.	1508
1456	Moved SEM2 from the vertical mounting bracket to horizontal mounting bracket. The jig had to be modified due to the screws not line up correctly.	1630
1630	Mounted SEM2 to horizontal mounting bracket. Turned sideways (Z axis).	1647

	Moved on top of table (on board). Removed loose leg. Removed vertical mounting bracket. Lifted SEM2 and removed plywood board. Rested SEM2 and jig on rod to find balancing point and marked it on the jig. Moved SEM2 and jig over to mass properties table. Lowered with crane.	
1647	Put 5 bolts through jig into the table to hold it steady. 11 24/32 `` from end pin to edge of MOI table.	1740
1740	SEM2 was removed from horizontal mounting bracket. Horizontal mounting bracket was moved to mass properties table for MOI readings.	1746
1746	Moved SEM2 to vertical mounting bracket for night storage.	1805
1805	Got MOI data from horizontal mounting bracket. 4 3/8 `` from edge of pin to center of center pin.	1817

21 Jan 04		
Start:	Description:	Finish:
1248	Fixed the gap between the boom and the adaptor ring. We machined the adaptor ring in order to get it to fit.	1526
1303	Sine burst (Y axis; test fixture with USEAIP).	1305
1526	Attached accelerometers using super glue and Kapton tape.	1543
1543	Put SEM2 in position to test (Y axis with shock ring).	1604
1604	Unbolted SEM2 from test fixture to retrieve serial numbers of the accelerometers. The studs came out.	1620
1620	Studs replaced with NAS 1351N4-14	1630
1630	Reattached SEM2 to the test fixture.	1650
1500	Measured tension in light band cable (425-500 lbs). Recorded at 490 -> 486 lbs.	1745
1745	Sine sweep (Y axis; with shock ring).	1752
1752	Bad accelerometer replaced and sine sweep repeated (Y axis; with shock ring).	1800
1820	Random vibration (Y axis; with shock ring; 5.7 G; characterization level).	1830
1830	Sine sweep (Y axis; with shock ring).	1837
1837	Checked torques.	1847

1847	Random vibration (Y axis; with shock ring; 8.1 G; flight level).	1855
1855	Sine sweep (Y axis; with shock ring).	1858
1858	Checked Torques. Torques dropped from 60 in-lbs to 57.5 in-lbs on average. The lowest was 55 in-lbs.	1918
1918	Sine burst (Y axis; with shock ring; 13.6 G; 17 Hz).	1930
1930	Sine sweep (Y axis; with shock ring). Torque check found them all good.	1942
1942	Random vibration (Y axis; with shock ring; 16.2 G; qual level).	1950
1950	Sine sweep (Y axis; with shock ring).	2000
2010	Selected NAS 1351N4-24 and -20 to attach simulated shock ring (24 and 20 alternating).	2015
2015	Started removing shock ring.	2220
2220	**Shock ring replaced with spacer.**	**2225**
2225	Sine sweep (Y axis; without shock ring).	2229
2229	Random vibration (Y axis; without shock ring; -3 db).	2237
2237	Sine sweep (Y axis; without shock ring).	2252
2252	Sine burst (Y axis; without shock ring; 21.3 G; 25 Hz).	2259
2259	Sine sweep (Y axis; without shock ring).	1105

22 Jan 04		
Start:	Description:	Finish:
0825	Released accelerometer wires from stand. Undid bolts from test fixture. Modified lifting crane by hanging straps from a square frame and running the handles on the interface plate through the straps and then attaching them. Then we rant the old lifting cables in the middle (they did not support weight but kept the SEM2 from tipping).	0909
0913	Swapped accelerometers to top of MPACS to measure Z axis. We changed the one that was on the shock ring and the two control accelerometers.	0930
0935	Sine sweep (Z axis; without shock ring). They did it twice because we didn't get the full range the first time. The vibration table kept messing up.	1029
1037	Random vibration (Z axis; without shock ring; -3 db). The controller sent an abort signal so we had to do it again.	1045
1108	Sine sweep (Z axis; without shock ring).	1111
1113	Checked accelerometers. We had to remove the –Y panel to check accelerometer. It had fallen off.	1153
1153	Sine burst (Z axis; without shock ring; 21.3 G; 25 Hz).	
	Hit table limit. Retried with just a sine sweep.	1209
	Sine burst (Z axis; without shock ring; 21.3 G; 35 Hz).	1219
1226	Sine sweep (Z axis; without shock ring).	1235
1235	Removed SEM2 from test fixture. Unbolted light band from spacer ring (fake shock ring). Then unbolted the spacer ring from the test fixture.	1310
1320	Lifted SEM2 from spacer ring.	1344
1344	Sine sweep (Z axis; test fixture with USEAIP).	1352
1352	Random vibration (Z axis; test fixture with USEAIP). The vibration table messed up again.	1358
1402	Sine sweep (Z axis; test fixture with USEAIP).	1408
1408	**Put shock ring on SEM2. Then we put the SEM2 on test fixture. Torque screws at 120 in-lbs.**	
	Shock ring on SEM2.	1423
	SEM2 on test fixture.	1457
1500	Initial sine sweep (Z axis; with shock ring). We switched ch 2 accelerometer wire with ch 1. We made ch 2 control.	1507

1510	Random vibration (Z axis; with shock ring; -3 db). Characterization level.	1518
1521	Sine sweep (Z axis; with shock ring).	1526
1533	Sine burst (Z axis; with shock ring; 15 G; 25 Hz).	1536
1536	Sine sweep (Z axis; with shock ring).	1545
1545	Random vibration (Z axis; with shock ring; +6 db; 2 min).	1556
1556	Sine sweep (Z axis; with shock ring).	1600