Kyushu Institute of Technology
Department of Applied Science for Integrated System Engineering

BIRDS-3 Project
Vibration Test Plans for EM

Laboratory of Spacecraft Environment Interaction Engineering

Date	Version Number	Writer	Annotations
2018/08/13	V1.1	Yuji Sasaki	Draft
2018/08/23	V1.2	Makiko Kishimoto	Structuring
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Contents

List of Acronyms and Abbreviations

A	
AMP	Charge Amplifier
AT	Acceptance Test
ATV	Automatic Transfer Vehicle
B	
BAT	Battery
C	
CH	Channel
CAM	Camera
C.P.	Control Point
D	
DAQ	Data Acquisition System
DR	Design Requirements
Dir	Direction
E	
EM	Engineering Model
F	
FFT	Fast Fourier Transform
G	
Go-p	G zero to peak
Grms	G Root mean square
H	
HTV	HII Transfer Vehicle
J	
JEM	Japan Experimental Module
P	
PC	Personal Computer
R	
RAS	Requirement Allocation Sheet
S	
STM	Structure and Thermal model
STR	Structure team
SVBL	Satellite Venture Business Laboratory
SpX	Space X

1. Introduction

This document highlights mechanical tests (vibration) to be carried out on the BIRDS-3 CubeSat. The aim of the test is to demonstrate that the test article can withstand mechanical vibration when excited with acceleration levels induced by launch vehicles which includes HTV, SpX and Orbital Cygnus. Excitations of the test article will be done within a range of 20 Hz to 2,000Hz to comply with JAXA requirements.

The vibration test types include:

- Modal survey
- Random vibration test (QT level)
- Quasi-static acceleration test (Sine-burst QT level)

By successfully completing these tests, we can show that the structure design has enough strength and rigidity with sufficient safety margin to withstand the environmental stress induced by ground handling and launch vehicle induced loads.

2. Referenced Documentation

Table 1. Reference documents

No.	Document number	Document description	Revision level or Release date
1	JX-ESPC-101133-B	JEM Payload Accommodation Handbook; Small Satellite Deployment Interface Control Document	Vol 8. December, 2017
2	Torque Chart	Maryland Metrics Torque Chart	Retrieved May, 2016 https://mdmetric.com/tech/torqcht1a.pdf

3. Test Purpose

3.1. Overall test description

The purpose of this test is to evaluate the impact of vibration by launch vehicle on BIRDS-3 CubeSat Structure.

Functional tests of the different subsystems will be carried out before and after each vibration test. Modal survey will be done to determine the natural frequencies of structure. After Modal survey, Random vibration will be done to excite the structure within the qualification levels of the launch vehicles indicated in JEM Payload Accommodation Handbook referred to in Table 1. above.

After each Random vibration, Sine Burst vibration and Modal survey will be conducted to evaluate any changes in the vibration response of the structure. The vibration response data will be used as a benchmark in verifying the integrity of the design workmanship as well as determining if the design and configuration satisfies minimum launch provider requirements for strength and stiffness.

3.2. Success Criteria

The success of the vibration test will be determined based on the following criteria;

- Natural frequency: The fundamental frequency of the structure when accelerated along each axis must be greater than 100 Hz in other to be adjudged successful.
- Shift in Natural Frequency: A significant shift in natural frequency indicates *workmanship failure* (loose components on/in the structure). Any broken parts in the primary structure shall be judged as a *failure in design*.
- Torque Mark Shift: When observed visually, there should be no shift in torque marks on the screws on the test article after each test. Any shift in torque mark shows a *workmanship failure* in setting the required torque before testing
- Fracture Critical Parts:
    i. All external fasteners and fasteners holding the main structure shall not be lose after vibration

ii. Glass components (including solar cells and camera lens) shall not be broken after vibration

- Deployable Components
  The deployable UHF monopole antenna shall not deploy during vibration.
- Radio Interference
  Satellite shall not broadcast radio (CW) during vibration.
- Satellite Function
  Satellite functional test shall be conducted before and after vibration tests. Satellite function after vibration tests should be the same as before tests.

4. Test Facility

4.1 Location

Center for Nanosatellite Testing (CeNT)
Laboratory of Spacecraft Environment Interaction Engineering
Kyushu Institute of technology
1-1 Sensui, Tobata, Kitakyushu, 804-8550 Fukuoka, Japan

4.2 Test Facility Characteristics

The vibration testing system specifications are shown in Table 2 and an illustration of CeNT's vibration test machine is shown in Figure 1.

Table 2 Vibration testing system specification

No.	Items	Specification		
1	Type	F-35000BD/LA36AP(made by EMIC)		
2	Exciting Force	Sine		35.0 kN
		Random		28.0 kN
		Shock		87.5 kN
3	No-load maximum acceleration	Vertical	Sine	1060.0 m/s^2
			Shock	1470.0 m/s^2 (0-p)
		Horizontal	Sine	460.5 m/s^2
			Shock	1151.3 m/s^2 (0-p)
4	Maximum loading mass	Vertical		400 kg
		Horizontal		500 kg
5	Horizontal vibration table size	50cm×50 cm		
6	Power	49.0 kVA		

Figure 1 Vibration Test Machine

4.3 Test Equipment

The list of equipment to be used during BIRDS-3 EM vibration test is described in Table 3.

Table 3 Test equipment

No.	Equipment name	Model number	Manufacturer	Quantity
1	Vibration test machine	EMIC F-35000BD/LA36AP	EMIC	1
2	Vibration control machine	DS-98000MJ	EMIC	1
3	Data acquisition PC			1
4	Accelerometers			
5	16 bit DAQ(-10 - +10V)	NI cDAQ 9178 NI 9125	National Instruments(TI)	Max 24 channels
6	Charge Amplifier	Control (EMC 504-CB/TKS-4/214)	EMIC	4 ch
7	Accelerometer checker			1

4.4 Test tools

The list of tools necessary to carry on BIRDS-3 EM vibration test is given in Table 4.

Table 4 Test tools

No.	Designation	Kyutech Number	Memo	Quantity
1	Torque driver 1	TW-1	2~6Nm	1
2	Torque driver 2	TD-1	20~120 cNm	1
3	Torque driver 3	-	M2, 31.5cNm	1
4	Torque driver 4	-	M1.6, 15.6cNm	1
5	Torque wrench 1	20	9.2Nm	1
6	Torque wrench 2	3	30Nm	1
7	Torque wrench 3	2	120Nm	1
8	Allen key set	22	-	1
9	Hammer	18	Accelerometer check	1
10	Alcohol	-	Cleaning	1
11	Kim wipes	-	Cleaning	1
12	Super glue	-	Accelerometer fixation	1
13	Electrical tape	-	Routing	1
14	Gloves	-	KitMaap manipulation	1 pair/person
15	Water level	-	-	1
16	permanent marker		Torque mark	1
17	Sand paper		Accelerometer cleaning	1
18	Polyimide tape			1
19	Video camera		SONY HDR-CX550V	1

5. Test Description

5.1. Test flow

BIRDS-3 EM vibration test is described in Figure 2.

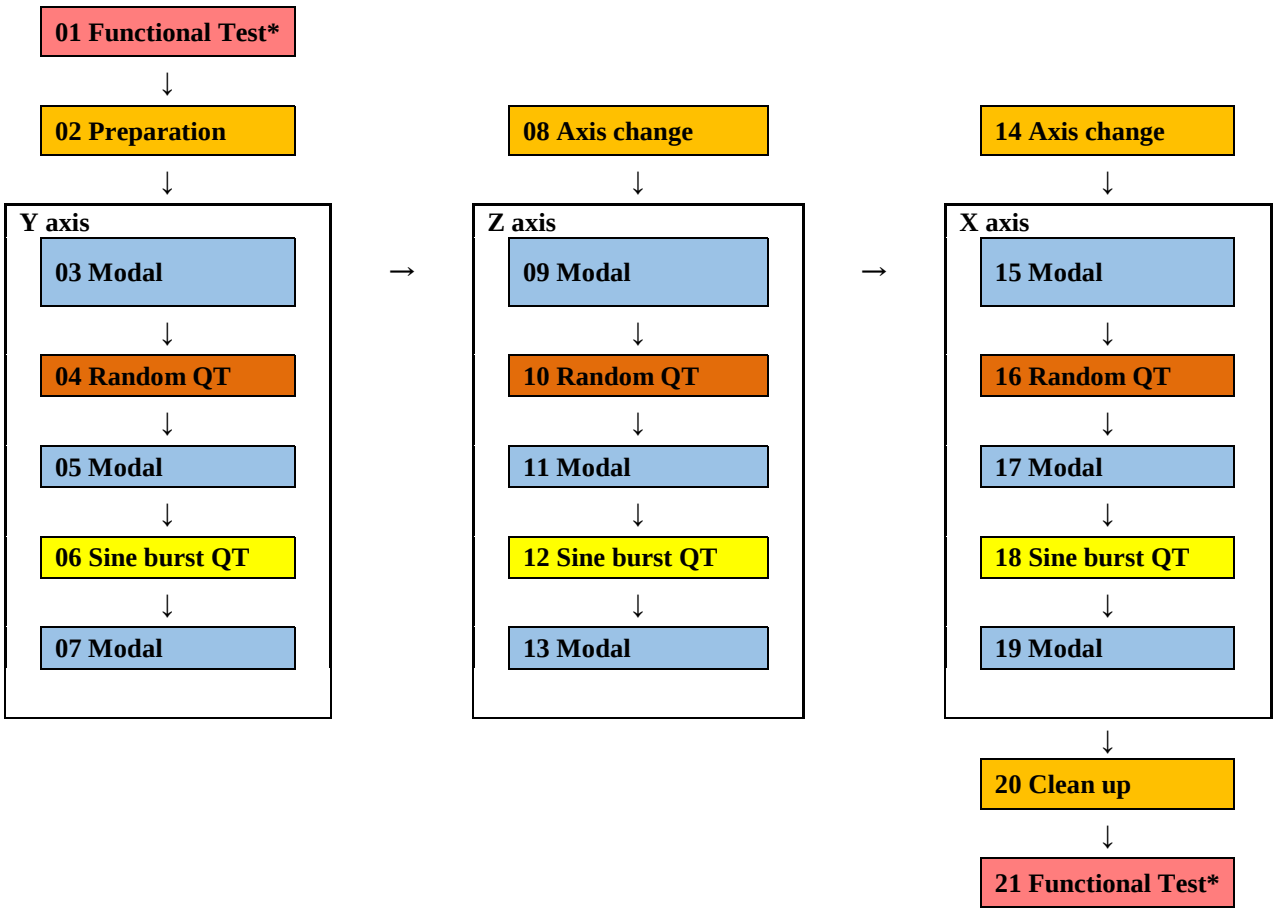


Figure 2 BIRDS-3 EM vibration test flow

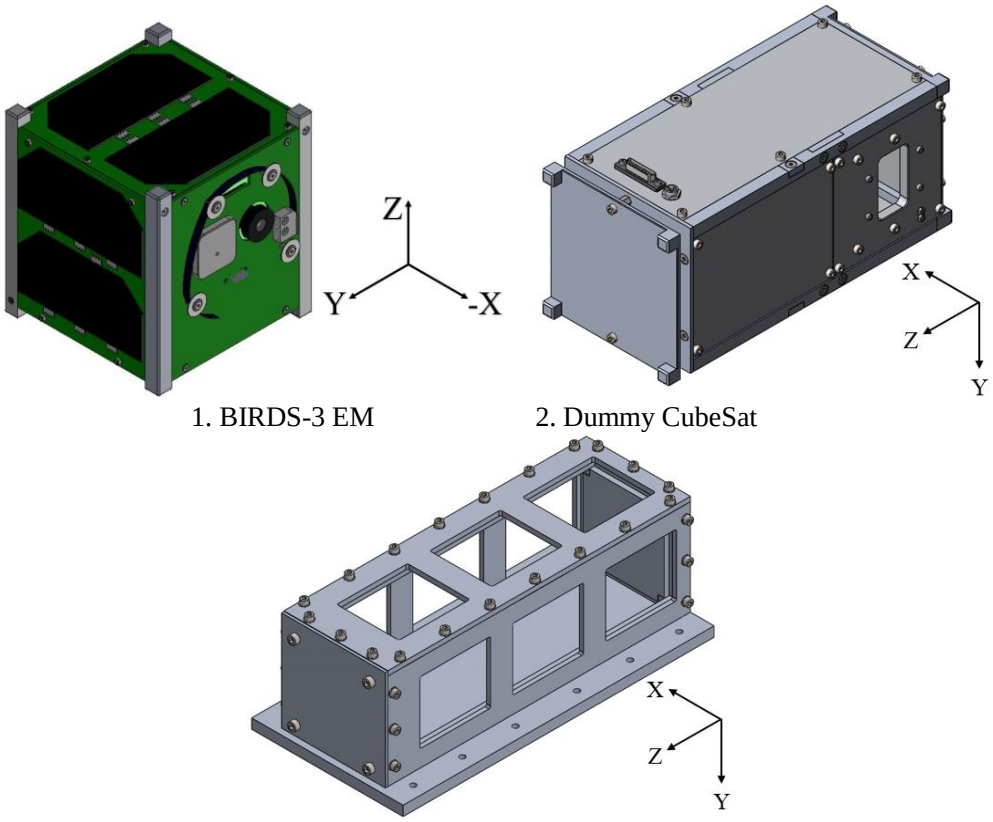
* These functional tests are performed independently of the vibration test.

5.2. Test article(s)

The test articles to undergo QT level vibration test are BIRDS-3 EM CubeSat, 2U dummy CubeSat, and 3U pod. Each test article specifications are described in Table 5 and Figure 3.

Table 5. Test articles

	Article name	Number	Manufacturer	Mass (kg)	Dimension (mm)
1	BIRDS-3 EM	1	Sankyo seiki	1.1	100 (L) × 100 (W) × 113.5 (H)
2	Dummy CubeSat	1	Sankyo seiki	1.44	100 (L) × 100 (W) × 227 (H)
3	3U Pod	1		4.62	



1. BIRDS-3 EM 2. Dummy CubeSat

3. 3U Pod

Figure 3. Test Articles

5.3. Test set-up

BIRDS-3 EM set-up into the POD is shown in Figure 4 and the accelerometers location is described in Figures 5, 6. For the monitoring of the 3U POD and BIRDS-3, three triple-axis accelerometer are mounted at 1) X axis of POD 2) Y Axis of POD and 3) Y Axis of Satellite to monitor their response along X, Y, and Z-axis. Moreover, four single-axis accelerometer are mounted to jig at four different locations. Two of them are used for jig control, while the other two are used for jig monitoring.

Each accelerometer is connected to a charge amplifier (AMP) and the data are taken through DAQ to a PC using a USB cable. Data from the analog signal channels are taken simultaneously and converted to digital signal using 16 bit DAQ (10,000 samples) and Fast Fourier Transform (FFT) is applied using Labview program. The accelerometer description is presented in Table 6 and the description of the test set-up for the different vibration types is shown in Table 7.

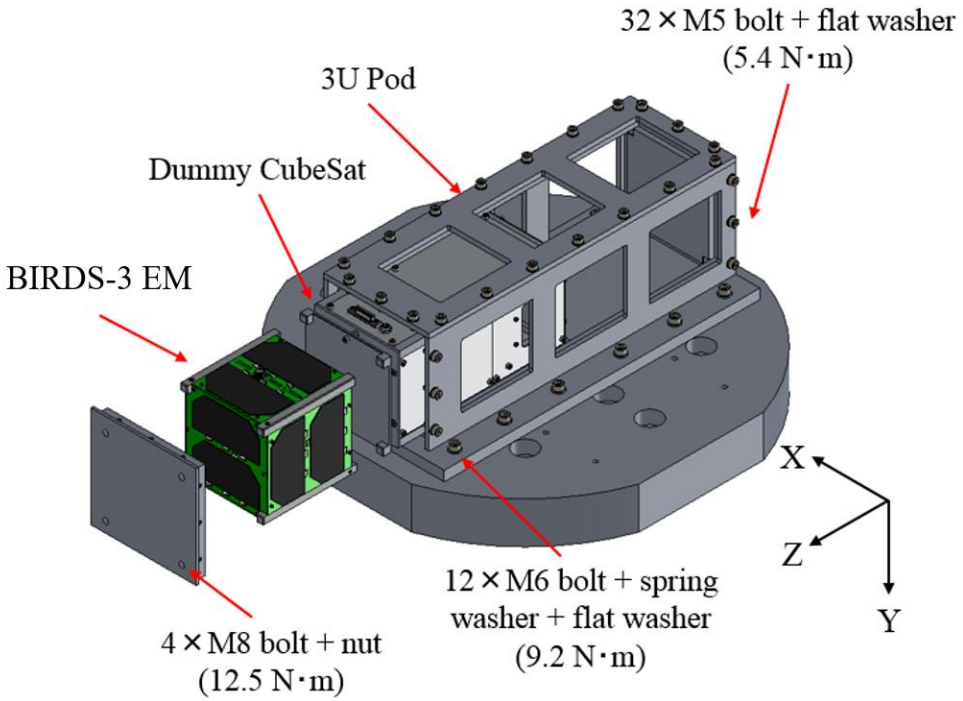


Figure 4. BIRDS-3 **set-up into 3U POD**

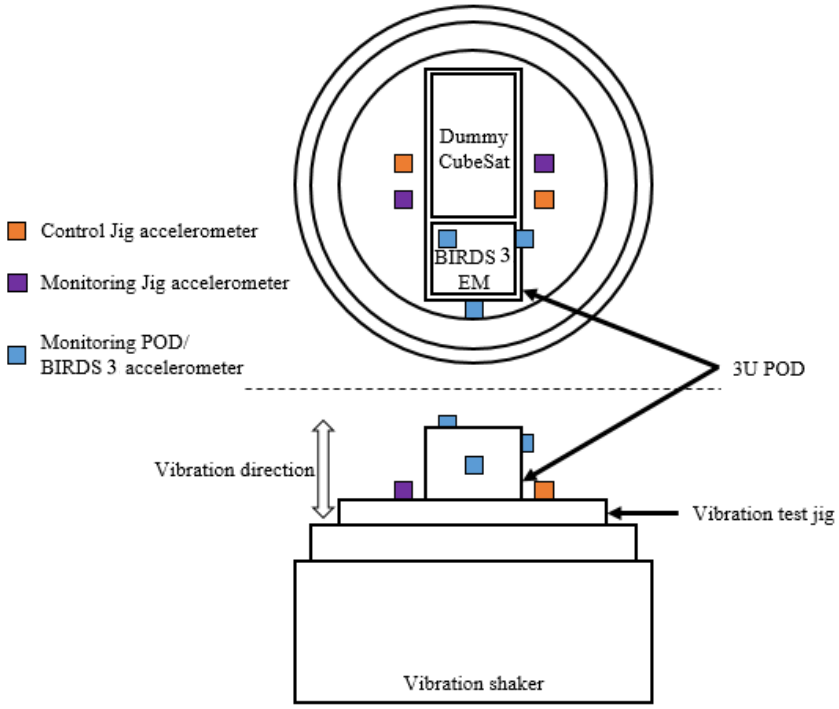


Figure 5. Accelerometers configuration for acceleration in X-, Z-direction

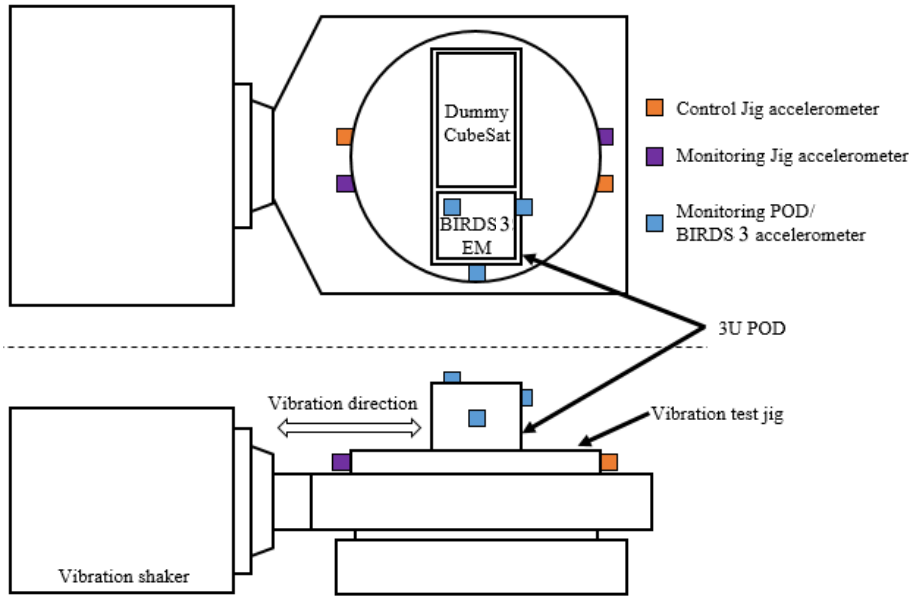


Figure 6. Accelerometers configuration for acceleration in X and Z-direction

Table 6. Accelerometer Channel Number Designation and Charge Amplifier settings

Channel No	**Axis**	**Mounting position**	**Accelerometer number**	pC/G	G/V range Of Modal survey, Sine, Sine burst	G/V range Of Random
1	Y	Z AXIS (3U Pod)				
2	X					
3	Z					
4	X	Y AXIS (BIRDS-3 EM -Y)				
5	Y					
6	Z					
7	X	X AXIS (BIRDS-3 EM -X)				
8	Y					
9	Z					
10	-	Jig				
11	-	Jig				
Controller	-	Jig				
Controller	-	Jig				

Table 7. Setting on the PC for control, PC for measurement, Vibration machine control and AMP

Vibration test type		**Modal survey**	**Sine burst**	**Random**
Vibration Profile		Random	Sine	Random
Vibration parameters On Labview	Test type	Modal	Sine Burst	Random
	Frequency band [Hz]: Min [Hz]	20	5	20
	Frequency band [Hz]: Max [Hz]	2000	100	2000
	Setting of measuring: Number of channels	12	12	12
	Setting of measuring: Measuring time [sec]	50	20	110

	Setting of measuring: Sampling rate [sample/sec]	10,000	5,000	10,000
	Setting of analysis: Number of FFT point	8192	2048	8192
	Setting of analysis: G/V	10	10	31.6
	Monitor (OSC) Display time (Sec)	0.2	0.2	0.2
	Monitor (OSC) Max value of voltage (V)	0.5	7	7
Vibration Machine control	Switch: Sine - Random	Random	Sine/Shock	Random
	External level	Half	Max	Max

5.4. Supporting analyses

Preliminary structural analysis was done using Solidworks. The natural frequency from analysis is shown in Table 8.

Table 8. Natural Frequency of Satellite from Structural Analysis

Axis	Natural Frequency (Hz)
X	
Y	
Z	

5.5. Test input data

- Modal survey
  Modal survey test parameters are descried in Table 9.

Table 9. Modal survey test table

MODAL SURVEY			
Direction	**Frequency [Hz]**	**Acceleration [Grms]**	**Time [min]**
Z, X, Y	5~2000	0.5	1

- Random vibration (QT level)
  The Random Acceleration Profile for the Test is as shown in Figure 8 and Table 10. The profile is derived using Maximum PSD values of Space-X (SpX) and HTV (Figure 7. and Table 10).

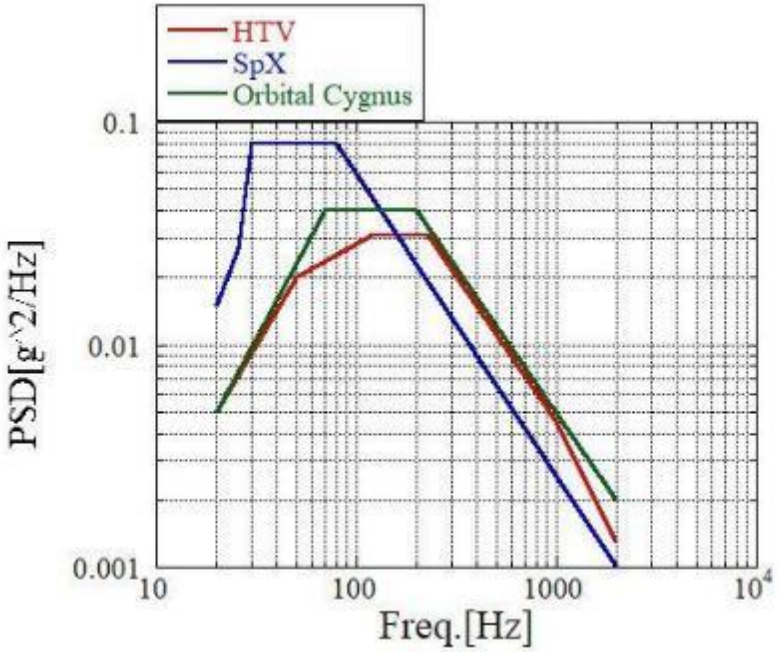


Figure 7. QT Random Vibration Profile for HTV, SpX

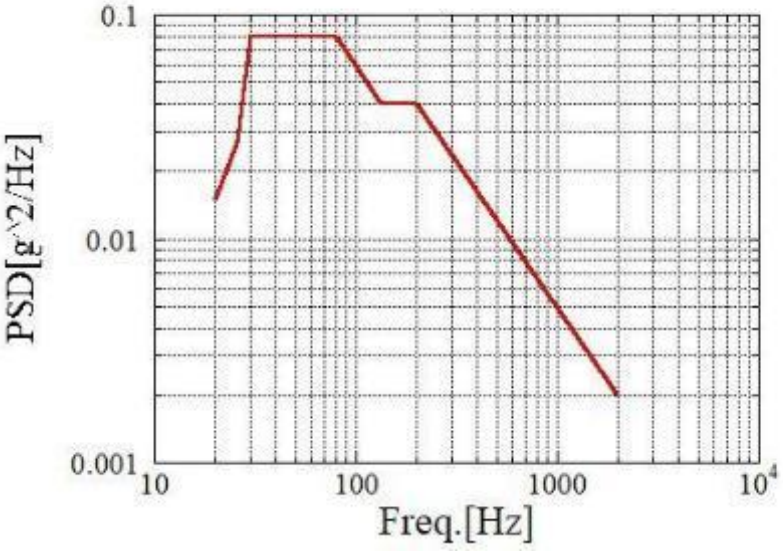


Figure 8. QT Test (Envelope) Random Vibration Profile

Table 10. Random Vibration (QT level) of Each Launch Vehicle and Max PSD (HTV+SpX)

HTV		**SpX DRAGON**			**QT Envelope**	
Freq. (Hz)	PSD (g^2/Hz)	Freq. (Hz)	PSD (g^2/Hz)		Freq. (Hz)	PSD (g^2/Hz)
20	0.010	20	0.03		20	0.03
50	0.04	25.6	0.054		25.6	0.054
		30	0.16		30	0.16
		80	0.16		80	0.16
120	0.062				133	0.08
160	0.062				200	0.08
230	0.062				2000	0.004
1000	0.009					
2000	0.0026	2000	0.002			
Overall (grms)		Overall (grms)			Overall (grms)	
Duration(s)	120	Duration (s)	14.4		Duration (s)	120
Orbital Cygnus						
Freq. (Hz)	PSD (g^2/Hz)					
20	0.020					
70	0.08					
200	0.08					
2000	0.004					
Overall (grms)						
Duration(s)	120					

- Sine burst (QT level)

The Sine burst Acceleration Profile for the Test is as shown in Table 11.

Table 11. Sine burst test table

SINE BURST TEST(ALL AXES)		
Freq [Hz]	QT	
	Acceleration [G]	Time [sec]
20	22.63G	1*

*1 sec includes 10 waves or more.

5.6. Test output data

- Raw vibration data from Labview
- Vibration Testing pictures
- Vibration Test Report
- Vibration Testing Video
- Functional Test Report
- Antenna Deployment Video

5.7. Test Schedule

The test schedule is detailed in Table 12.

Table 12. Test schedule

Date	Time	Task
2018/08/16	9:00	Functional Test
	10:30	Preparation of Vibration test
	13:00	X axis Vibration
	15:00	Z axis Vibration
	17:00	Change the vibration test machine axis
2018/08/17	9:00	Y axis Vibration
	11:00	Clean up
	11:30	Functional Test

6. Detailed Procedural Checklist

This section provides step-by-step instructions for setting up and conducting test activities.

Test checklist

No.	Dir	Test	Check Torque marks	Picture and video	Check parameters	Check Pickup condition	Remarks (Relevant information or comments)
01	Functional Test						
02	Preparation						
03	Y	Modal	N/A	N/A			
04	Y	Random QT					
05	Y	Modal	N/A	N/A			
06	Y	Sine burst QT					
07	Y	Modal	N/A	N/A			
08	Axis Change			N/A	N/A		
09	Z	Modal	N/A	N/A			
10	Z	Random QT					
11	Z	Modal	N/A	N/A			
12	Z	Sine burst QT					
13	Z	Modal	N/A	N/A			
14	Axis Change			N/A	N/A		
15	X	Modal	N/A	N/A			
16	X	Random QT					
17	X	Modal	N/A	N/A			
18	X	Sine burst QT					
19	X	Modal	N/A	N/A			
20	Clean up			N/A	N/A		
21	Functional Test						

7. Safety management

During the test period, work safety shall be taken into consideration and the following items shall be strictly observed and worked.

(1) During the examination period, the person responsible for conducting the examination supervises the work and acts on the safety of the work.

(2) The place to use in this exam is always organized.

(3) When handling this satellite, carry out work with Kualatek gloves attached.

8. Test Personnel

The following personnel are expected to Participate in the test

No	Work	Person in charge	Remarks
1	Test plan		
2	Operate the test machine controller PC		
3	Operate the measurement PC		
4	Observe the test articles		
5	Record the test (camera, document)		
6	Assistance		
7	Report		

9. Emergency Procedure

The emergency procedure is shown in Table 10-1 (compliant with Kyushu Institute of Technology emergency contact network)

Table 10-1 Emergency contact network