Critical Design Review (CDR)
Of
ULTRA VIOLET IMAGING TELESCOPE (UVIT)

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Vibration Tests

UVIT-CDR-01-002

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Critical Design Review

Ultra-Violet Imaging Telescope (UVIT)

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1. Scope of the document:

This document details the vibration tests conducted on the Engineering model of the UVIT payload on Astrosat. The results of the tests, failures of sub-systems during the tests and the rectification carried out in the design for the flight model are detailed.

2. Introduction:

The UVIT consists of two telescopes namely FUV and NUV/VIS telescopes. Each telescope is nearly 3.1 metre long with a diameter of nearly 0.88 metre. The two telescopes are mounted on a common titanium adapter which interfaces with the satellite. The UVIT system weighs about 200 Kg. The system has to be qualified before assembling with the satellite. Hence an Engineering model has been developed for qualification before the development of the flight model. This consists of one real telescope and one equivalent mass model simulating the inertia and mass of the FUV telescope.

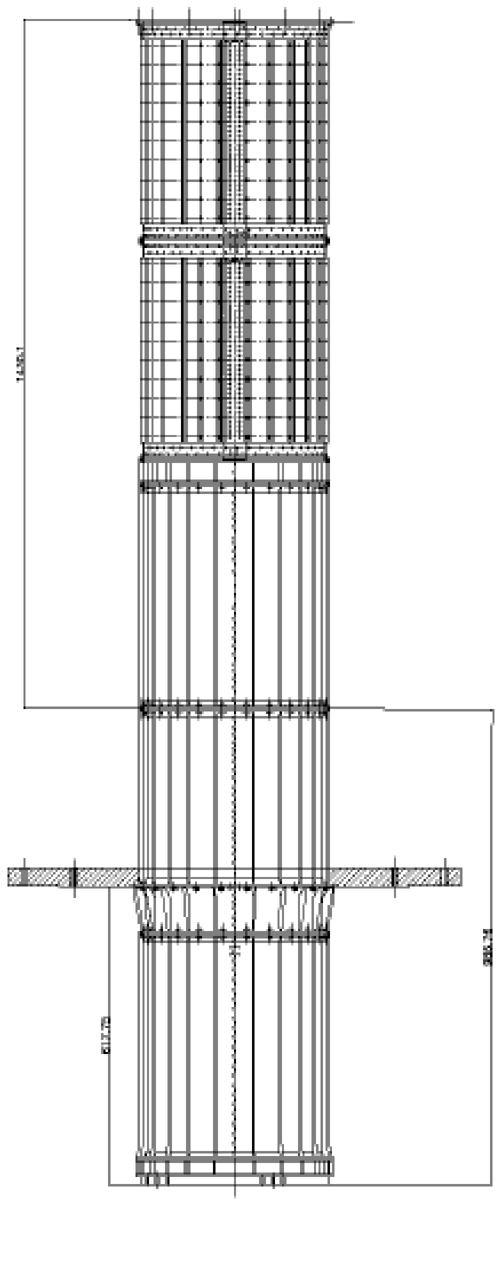

Figure 1: Mass model with the interface plate for vibration test

The mass model (Figure 1) is made of stainless steel which is different from the invar material used in the actual telescope hardware. Hence this telescope was qualified separately as reported in an earlier report (Nataraju et al, July 2010). With this qualification, mass model was confidently integrated with the other telescope for the development of UVIT engineering model. This UVIT system underwent elaborate vibration tests as planned.

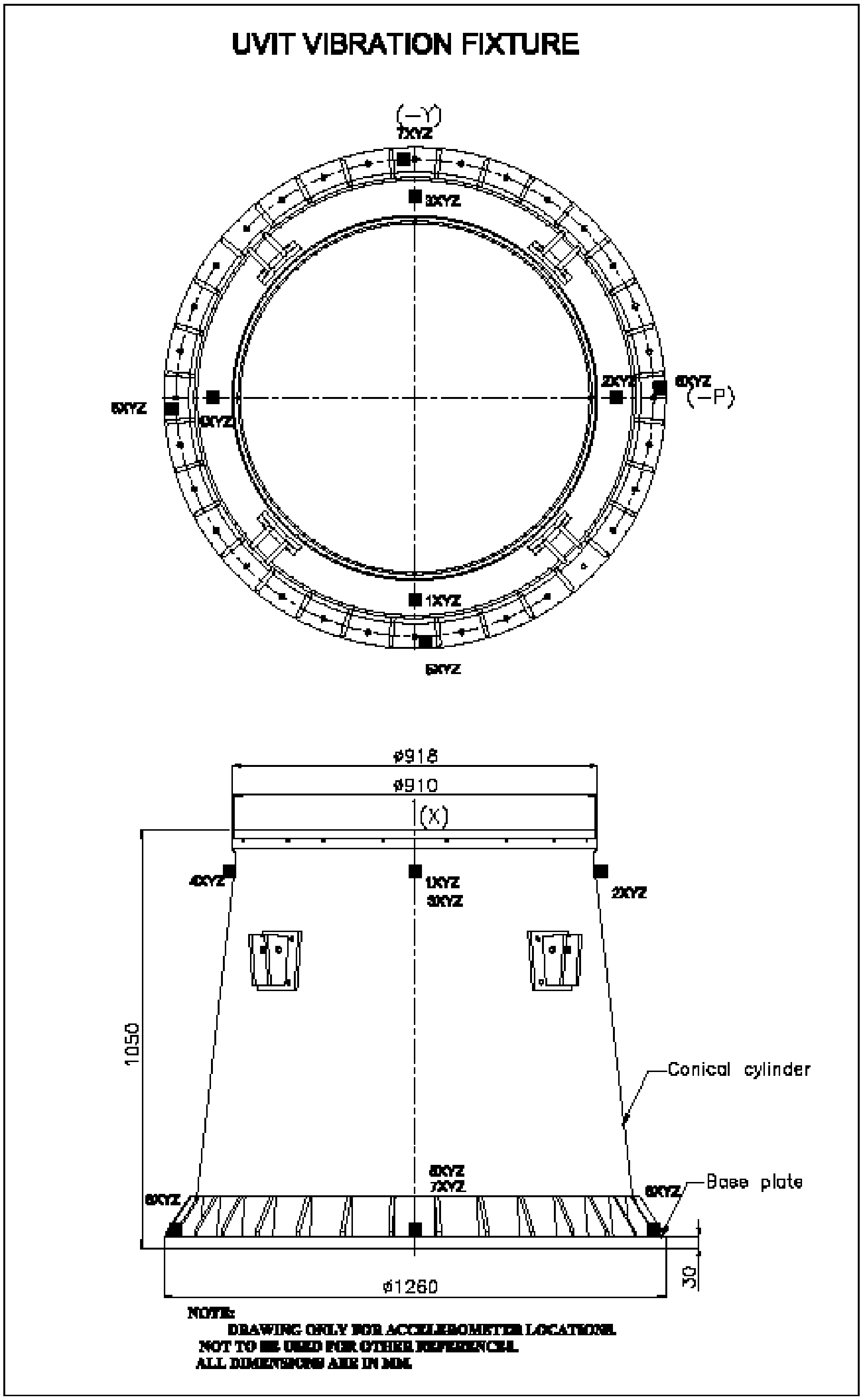

Figure 2: Vibration test fixture

The vibration test fixture (Figure 2) which simulates the satellite interface was qualified separately. It was made sure that the vibration fixture will have a frequency well above 100 Hz. Further it was ensured that the control system of the shaker is able to control during the qualification tests of the Engineering model by adopting the multipoint maximal control during the test of vibration fixture. With this test, the fixture capability to stand the expected vibration load during the qualification of UVIT system was proved. It may be noted that the separate qualification of vibration fixture was required as the fixture was made of mild steel and had several welded joints. After the tests the vibration fixture welded joints were inspected for cracks and the fixture had the same frequency before and after qualification tests.

The qualification of the vibration fixture and the mass model is a forerunner to the Engineering model vibration testing and has given good confidence. The qualification of the Engineering model got started with this.

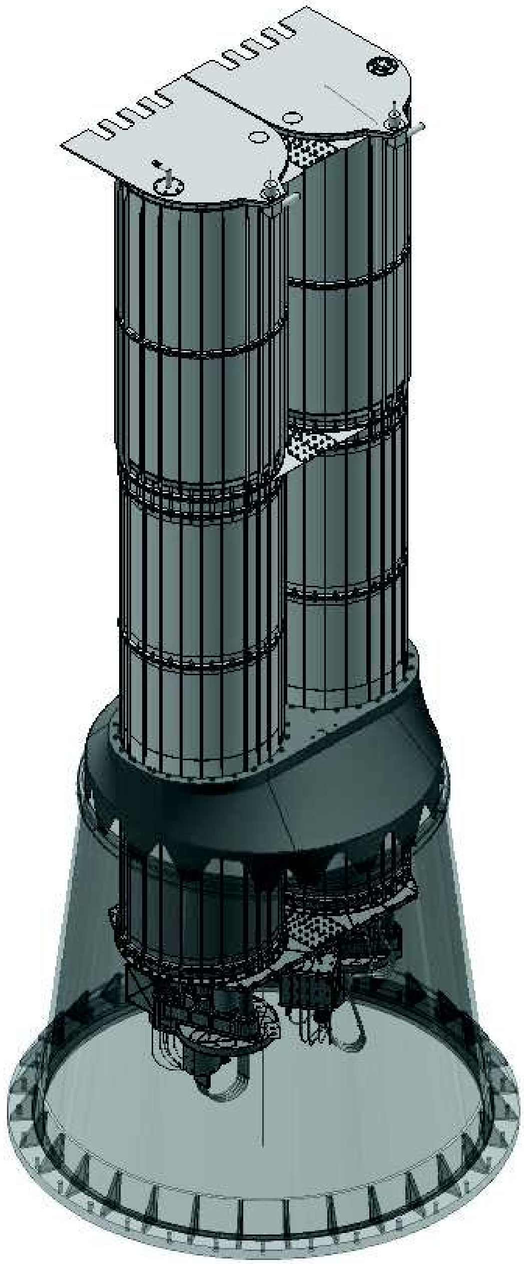

FIGURE 3 UVIT system with vibration fixture

(Thermal cover not shown in order to highlight details of focalvolume)

Control Accelerometers 16-19 (X, Y, Z) mounted on vibration fixture close to adapter interface

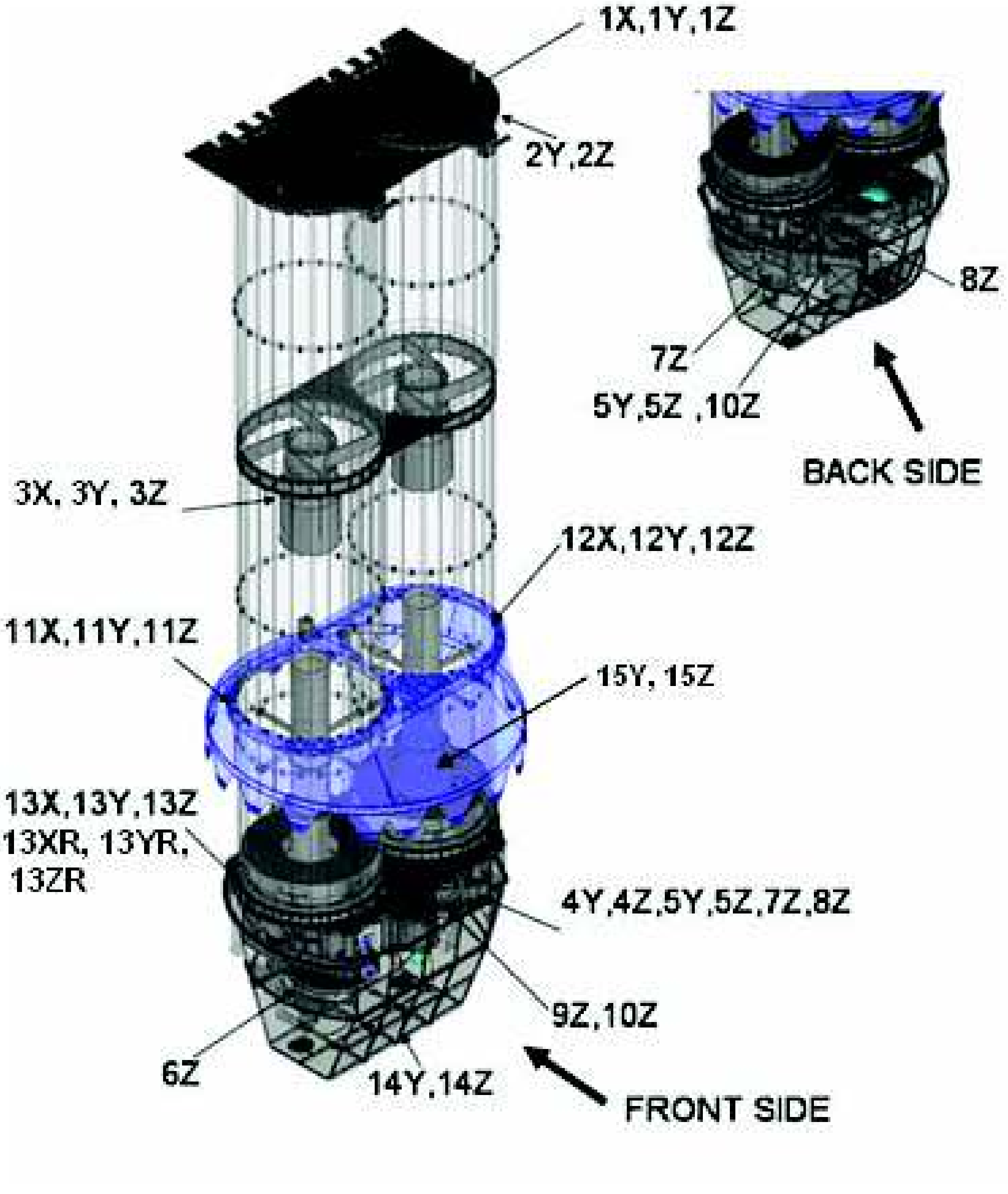

Figure 4: Accelerometer locations and their identifications

3. Specifications for the vibration tests:

The levels for testing of the system has been specified by the ETLC (Environmental Test Level Committee). The specifications are listed in the table. The system has been tested as per these specifications and wherever under testing has happened due to notching the system has been tested for quasi-static loads to prove that the system has met the design requirements.

A) Sinusoidal Vibration Level

Longitudinal Axis (X axis)

Frequency (Hz)	Qualification Level	Acceptance level
5-16	9.7mm	6.5mm
16 – 50	10 g	6.7 g
50 – 80	6 g	4 g
80 – 100	3.5 g	2 g
Sweep Rate	2 Oct/ min	4 Oct/ min

Lateral Axis (Y & Z axis)

	Qualification Level	Acceptance level
5-11	10.3 mm	6.9mm
11 – 60	5 g	3.3 g
60 – 100	3 g	2g
Sweep Rate	2 Oct/ min	4 Oct/ min

B) Random Vibration level

Normal to mounting Plane (X axis)

Frequency (Hz)	Qualification Level* (PSD g^2 / Hz)	Acceptance level* (PSD g^2 / Hz)
20 -100	+ 3dB/Octave	+ 3dB/Octave
100 – 700	0 .05	0.02
700 – 2000	-3dB/Octave	-3dB/Octave
Overall g RMS	8.3 g	5.5 g

- PSD - Power Spectral Density

Parallel to mounting Plane (Y and Z axis)

Frequency (Hz)	Qualification Level* (PSDg^2/Hz)	Acceptance level* (PSD g^2 / Hz)
20 -100	+ 3dB/Octave	+ 3dB/Octave
100 – 700	0 .05	0.02
700 – 2000	-3dB/Octave	-3dB/Octave
Overall g RMS	8.3 g	5.5 g

- PSD - Power Spectral Density

The tests have been carried out first about Y axis as the frequency about this axis was low and large responses were expected. Next the tests were carried about Z axis and the last set of tests were carried about X axis. The sequence of the tests was also planned. These tests have been carried out in steps.

Acceptance Sine test

Qualification level Sine test

Quasi-static load test (wherever required)

Acceptance level random vibration test and

Qualification level random vibration test

Between tests a low level sine/random vibration test is carried out and compared for monitoring the health of the system. All the sequence of tests has been listed in the vibration test plan. Before carrying out acceptance level random vibration test about any axis an intermediate level test has been carried out in all the axes. This has helped to decide the inputs to the system so that the subsystem of the UVIT which have already undergone the qualification level testing will not experience abnormally high levels. This has been incorporated for subsystems like mirrors, detectors and FWDM (filter wheel drive mechanism). Whenever the levels were exceeding for these subsystems the notching has been adopted. Notching level has been decided based on the subsystems testing levels.

In a few tests, the notching has come into effect and the system was safeguarded. Wherever the system has not seen a level beyond the quasistatic loads the system was tested for quasi-static load and the design was qualified.

The system was tested in three axes and the total number of runs is 52.

4. Failures during the tests:

The system had four failures during the tests, as detailed below:

i) 3 Nos of M5 bolts, holding the secondary mirror assembly, came loose during the Qualification level random vibrations on Y-axis – the first of the 3-axes to be tested for, After the discussions on this failure, the bolts were retightened, and in addition to the normal nuts a lock nut was introduced in each of these 3 bolts. *No other bolt showed loss of torque through the full test, as seen by inspection after the tests. For the flight model, it was decided that these 3 bolts shall be replaced by M6 bolts – to get >X 1.5 larger torque, and an additional locknut shall be used on these 3 bolts.*

ii) Hinges of the door broke during the qualification level sine test on Z-axis – the second of the 3-axes to be tested for. After discussions on this issue, some changes as noted below were incorporated in the design of the assembly.

The material of the support hinge bracket was changed from aluminium AA 6061 T6 to titanium Ti6Al4V. The design of the bracket was also changed.

iii) During the check conducted after the tests, a crack was observed in a part of the thermal cover. The details are given below.

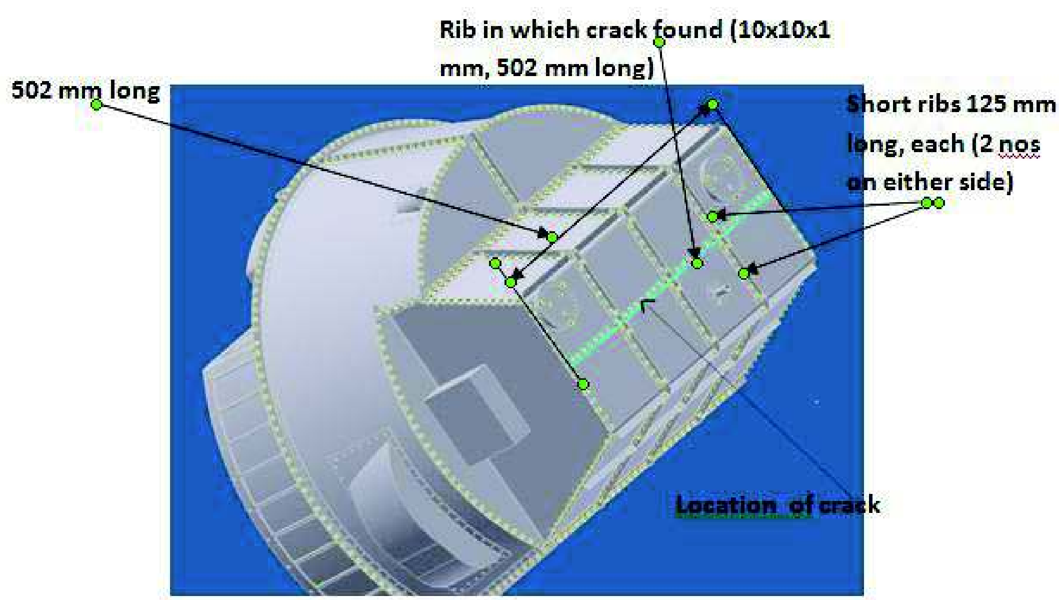

Fig 2: Thermal cover showing location of crack on the rib

Fig 5: Thermal cover showing location of crack on the rib

Eliminate all the details after Fig. 5, and say that the committee examined the failure and made recommendation for modifications which are done for the FM. SNT

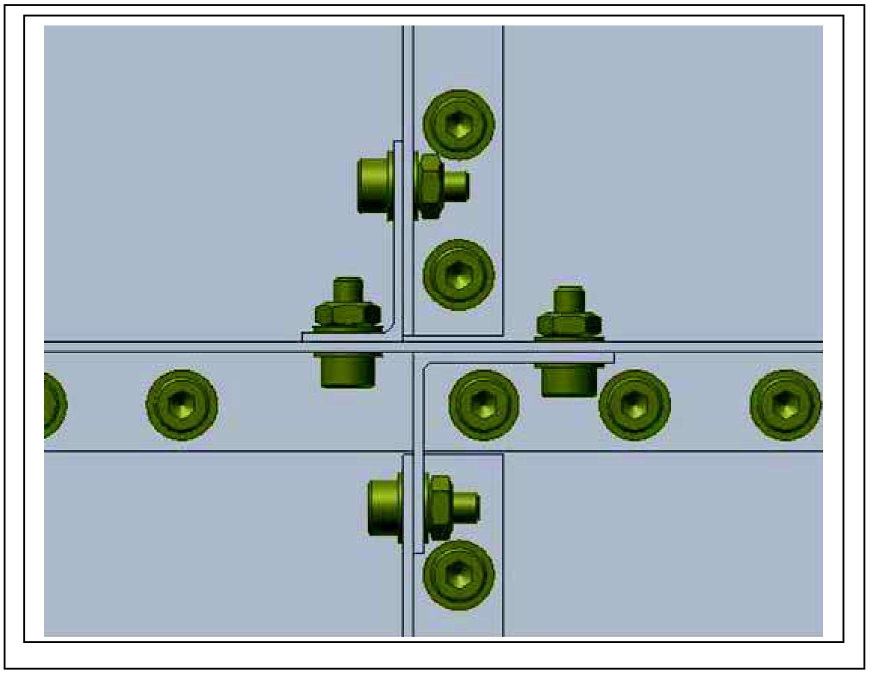

Fig 6: Rib connection details
(As existing in the present design)

The review committee recommended the following change in configuration, which has been implemented in both flight model and Engineering model.

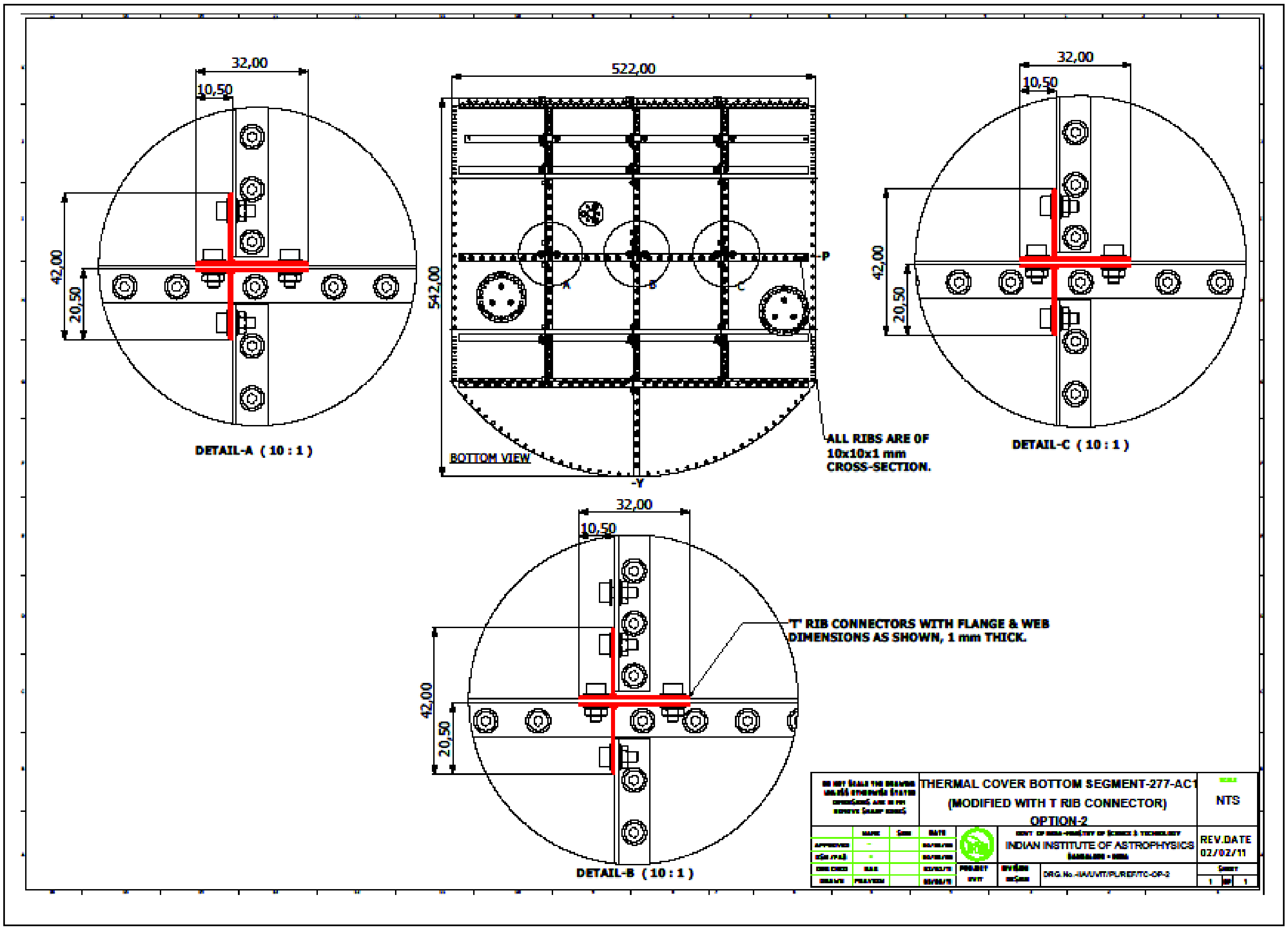

Fig 7: Proposed solution (Option 2) connection with "T" section, single bolt on each

iv) A cable beta was found broken during an inspection after all the tests. The beta was fixed onto the structure with adhesive alone. The review committee recommended the usage of fasteners along with the adhesive to prevent failure.

5. Response of the accelerometers that reached notching level.

Responses of the accelerometers that reached notching level are listed in the following tables.

Responses of Accelerometers

Table No.:1

Test: Vibration test on UVIT about Y-axis – ***Acceptance Level Sine Vibration test***

Run Number: 3

Accelerometer Location	Accelerometer number	Axis	Acceleration Levels			Remarks /others Freq.Hz(Transmissi-bility level)
			Frequency 1 ≈44Hz.	Frequency 2 ≈80 Hz.	Frequency3 ≈/acc.(high)	
HVU on NUV DB	5	y	9.7 g	13.2 g		At 60 Hz. 9.8 g

System went through Acceptance level sine vibration test. Notching was set on 4y,5y,13y 13.8g level.5y came to notch. System withstood.

Responses of Accelerometers

Table No.:2

Test: Vibration test on UVIT about Y-axis – ***Qualification Level Sine Vibration test***

Run Number: 5

Accelerometer Location	Accelerometer number	Axis	Transmissibility Levels			Remarks /others Freq.Hz(Transmissi-bility level)
			Frequency 1 ≈44 Hz.	Frequency 2 ≈80 Hz.	Frequency3 ≈/β (high)	
HVU on NUV DB	5	y	14.4 g	20.2 g		Reached Notch

Test went through. Notching came into effect. Input dipped to 0.6g. Notching channels are 13y,4y and 5y. 5y which was set at notching level of 20g came into effect and the input dropped to 0.6g.

Responses of Accelerometers

Table No.:3

Test: Vibration test on UVIT about Z-axis –***Acceptance Level Sine Vibration test (Post refurbishment)***

Run Number: 29

Accelerometer location	Accelerometer number	Axis	'g' Levels			Remarks
			Frequency 1	Frequency 2	Frequency3	
HVU on NUV DB	5	z	44/3.5g		89/17.3g	Notching level 16.7g

The test went through. The 5z channel came into notching. The input dipped marginally. There was no undertest. The door was also one of the notching channels. Lot of chattering was seen at the door. The door can stand upto 100g. So the limit was set at 70g and the maximum g level was 52g in 1z. Also the resultant g level was also lower than 70g.

Responses of Accelerometers

Table No.:4

Test: Vibration test on UVIT about Z-axis – ***Qualification Level Sine Vibration test (After door inspection)***

Run Number: 32

Accelerometer location	Accelerometer number	Axis	'g'Levels			Remarks/ 'g'Levels
			Frequency 1	Frequency 2	Frequency3	
Door	1	Hz	58/51.3g	65/38.7g		
		Cx		67/32.5g		High chatter seen
		Cz	57/42.8g	65/31.6g		
		x	43/7.3g	59/12.2g	70/11.2g	High chatter seen
		y	43/8.9g	66/8.3g	85/13.5g	High chatter seen
		z	58/48g	65/36g		
I/F door with MB	2	y	43/6.6g			Chatter seen
		z	43/15g	57/32g	65/18.8g	
SMA on spacer	3	x	low			Chatter seen
		y	43/3.1g			Chatter seen
		z	54/14.4g	65/5g	96/3g	Notching effected
		z	43/5.4g	92/25g		Notching effected
Control accl.meter	16-19	x,y,z				No over test. Input dipped to

The test went through smoothly. Notching came into effect as the level got exceeded. The responses at the bottom region where mass concentration is high experienced high g levels over 24g. Cg response was found to be high. Hence it was decided not to do any Quasistatic load test. Interestingly the door was also set at 52g notching level. But it experienced less than 52g & surprisingly did not come for notching. Hence it was decided by the committee that the door should not be in notching channel and the door has to be qualified separately.

Responses of Accelerometers

Table No.:5

Test: Vibration test on UVIT about X-axis – ***Qualification Level Sine Vibration test***

Run Number: 44

Accelerometer location	Accelerometer number	Axis	'g'Levels			Remarks /others
			Frequency 1 ≈	Frequency 2 ≈/β (high)	Frequency3 ≈/β (high)	
Door	1	Cx	46.8/26.7g			Chatter and Noisy
		x	43/40.3g			High chatter and noisy(100g)
		y	43/30.2 g			High chatter and noisy
Mass model door I/F	20	y	45/5.2 g			
		z	72/1.2 g			
I/F door with MB	2	x	49/10g			
		y	45/4.2			Noisy
		z	99.7/1.9 g			Noisy
SMA on spacer	3	x	42/10.7g			
		y	45/1.1 g			Noisy
		z	45.4/0.4 g			Noisy
HVU on VIS DB	4	y	45/3 g			Noisy
		z	99.7/1 g			Noisy
HVU on NUV DB	5	y	45/3 g			Noisy
		z	99.7/ 1.3 g			Noisy
FUV detector brkt.	6	z	99.7/0.5 g			Noisy
VIS detector brkt.	7	z	99.7/1.1 g			Noisy
NUV detector brkt.	8	z	72/0.4 g			Noisy
VIS- FWDM	9	z	99.7/0.8 g			Noisy
NUV- FWDM	10	z	50/1 g			
FUV adapter	11	x	99.4/48 g			Chatter and noisy
		y	45/0.5 g			Noisy
		z	45/2.3 g			Noisy
VIS adapter	12	x	50/9.5 g			
		y	45/0.9 g			Noisy
		z	45/0.9 g			Noisy
PMA TR (Main ac)	13	x	49/10 g			
		y	44/2.2 g			Noisy
		z	44/0.3 g			Noisy
PMA TR (Redt. Ac)	13	yr	47.2/23.2 g			Noisy
		zr	45/0.7 g			Noisy
Thermal Cover	14	x				Not working
		z	99.3/17.4 g			Noisy
Primary Mid flange	15	y	45/1.8 g			Noisy
		z	45/ 0.4 g			Noisy
Control accl.meter	16-19	x,y,z				

The qualification test went through. The door response was high. The accelerometer block on the door came off. This introduced noise in most of the channels. As expected many channels measuring x direction response showed flat response with no amplification. The door preload was checked. It was holding in spite of experiencing over 100 g load (with noise). Even the load on the door in the in plane direction was high and chatter was seen. There was no over testing. Control was holding. Channel 1x was included as notching channel set at 100g. The response was coming to notching but, the frequency had crossed at that instant. So in control channel dip is marginally seen.

6. Checks on alignment.

The relative angles between the cubes were good between the secondary mirror assembly and the adapter cube. The relative angle between the adapter and the focal plane volume maintained in one plane and the other had a deviation which is difficult to explain without any loosening of some or the other bolt – But none of the bolts showed loss of torque after the tests. For most of the joints of the flanges, marks were made and Epoxy drops were fixed across the joint to check if any slips occur. Post vibration inspection did not show any slips.

7. Observations.

Many meetings were held and the result of the tests was presented to the special committee set up by the Director, ISAC. The committee gave guidelines for further testing specifying the notching limits also. The committee also specified that the door which is a small important component of the system cannot be used for notching resulting in gross under test of the system. Hence it recommended a separate qualification test for the door.

The thermal cover was opened and a few particles from the door labyrinth seal had collected at the bottom. This has been informed to the designer of the door.

The engineering model vibration test has totally undergone fifty two runs during its qualification. The whole qualification process was done in a careful way to avoid over testing of the system. The system underwent 18 runs about Y axis, two preliminary runs in Z axis and two exploratory runs with low g low frequency dwell. With these two exploratory runs it was found that the telescope secondary mirror had loosened and the telescope was opened. The telescope was refurbished and again mounted on the Z axis vibration test. During the course of the vibration test the specialist committee met and reviewed the result. Before mounting the telescope on the vibration shaker for the Z axis test an alignment measurement was carried out for future comparison after the vibration test. The alignment included the measurement of relative angles between the cube on the adapter a with the secondary mirror assembly and with the cube in the focal plane volume. The relative angles were measured in two planes. These were measured using two theodolites with autocollimation feature (theodolites were located at four stations for the secondary mirror and focal plane volume measurements).

After mounting the refurbished telescope on vibration shaker for Z axis test the system went through acceptance level sine vibration test about Z axis (from Run 23 -27). During qualification level sine vibration test (Run 28) the door broke at the hinges and further test had to be done only after refurbishment. The door hinge design was modified. The link which was made of aluminum was changed to titanium with no scooping. The weight increased by nearly 16 grammes each. The door experienced over 100g loads and withstood this load (The door deployment was done after the X axis test. It deployed successfully with all microswitch /gold contact indication.). In the Z axis after refurbishment the system underwent 12 runs (from Run 28 -39). The system went through the entire acceptance and qualification level sine and random vibration tests successfully.The amplification of the system was high and by calculation it was found that the system had experienced nearly 12g equivalent loads during qualification level sine vibration test near centre of gravity point. Also the vibration shaker would have imparted a load equivalent to 12.8g.Hence the quasi-static load test was not carried out about Z axis.

After Z axis test the system was moved for testing about X axis. The control accelerometers on the vibration fixture were moved from Z axis to X axis. A few measurement accelerometers were shifted from Z/Y axis to X axis. Two accelerometers were mounted on mass model assembly also. The system went through all the tests successfully (from Run 40 – 52). In this axis the responses were benign. All runs were smooth. Only door had high responses.

After every major run like acceptance level and qualification level sine and random vibration tests and the quasi-static load test through dwell vibration test at low frequency, the health of the system was assessed by the following checks.

- Comparison of the accelerometer plots between prior to and post of that vibration test to assess the frequency of the system
- Measurement of preload at the hold down of the door
- Checking of bolt preload torque
- Functional check of the system
- Visual inspection of UVIT system

Before shifting of the telescope to CREST, IIA, Hosakote, the post vibration alignment checks were made. It was found that the three of the four readings were matching. One reading had a deviation. This is to be understood and answered in view of the matching of three of the four angles.

At the end of the test the system was moved to CREST and further checks were made. Functioning of the system was found okay.

Mechanical observation is that 3 nos. M5 bolts at one interface in the secondary mirror assembly loosened during Y axis vibration test. Lock nut was also used and the test was continued.

Door hinge broke and required modification. Hence the hinge design was changed by making it solid and the material was changed to titanium. Later the test was continued. Further the committee also specified that the door which is a small (mass) and important component of the system cannot be used for notching resulting in gross under test of the system. Hence it was recommended a separate qualification test for the door.

After all the tests it was found that the cable harness support metallic beta had broken. This is being modified.

In the thermal cover one of the stiffeners made of aluminum angle had a tear in one leg for a small depth. This is being modified.

Another observation is that in the thermal cover a few particles of the door seal had collected.
This has to be addressed seriously in view of any particle falling on the mirrors which can be catastrophic for the experiment.

With these tests the Engineering Model is qualified. Hence the UVIT system is flight worthy.