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

(June 17th -18th 2011, ISAC, Bengaluru)

Analysis of Structure

UVIT-CDR-01-001

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Design and Analysis of Structure

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1. INTRODUCTION: The UVIT configuration, its subsystems interfaces and its specifications were presented in PDR. The quasi static and dynamic analysis results were also presented in the review. The critical issues like design related (higher reaction forces), secondary process, titanium satellite adapter fabrication were addressed in PDR. Subsequent to PDR design changes were incorporated based PDR/Analysis committee recommendations. The design margins (quasi static) and other dynamic characteristics of the structure are evaluated in the final analysis.

The design changes of post PDR, quasi static design margins and frequency response of the critical subsystem interfaces are presented in the report.

2. DESIGN MODIFICATIONS-POST PDR: The following are the design changes incorporated post PDR, to improve the dynamics of structure.

2.1 Second support for the primary baffles: The primary baffle by its configuration is about 1m long, tubular section of 102 mm diameter and 1 mm thick aluminum tube with knife edges at predetermined locations. It was supported at one end (at its base) on detector bracket as shown in fig 1, by 6 Nos. of M4 screws. The primary baffle had poor dynamic characteristics due to its long cantilever action which had great impact of total stiffness of the main structure. The stiffness of primary baffle was enhanced by providing a support at its free end. The support was provided by 4 radial members placed orthogonal to each other one end at primary baffle and other anchored to bottom segment of telescope tube (TT3) as shown in fig 2. This arrangement enhanced the stiffness of the subsystem.

2.2 Additional support to the NUV bracket by Telescope ring: The NUV bracket had 4 supports which were close by as shown in fig3, adding one more support from TR ring reduced the lever arm and improved the dynamics of the subsystem.

2.3 Modifications in focal plane rod and its interfaces: The support structure of the back focal plane volume which supports the critical subassemblies are strengthened by increasing the tube thickness(1mm to 2 mm), diameter (25 to 35 mm) and the number of interface bolts (4 to 8 Nos.), as shown in the fig4. This enhanced design margins on the structural members and improved overall stiffness.

2.4 Modifications in NUV and FUV detector brackets: Minor changes in NUV and FUV detector brackets were made to accommodate the revised interface of filter wheel motor. The connection between filter wheel to filter wheel motor was by a key way slot and a bolt, the arrangement had driven the subsystem stiffens to a lower value; hence IISU revised the coupling between the filter wheel and its drive motor. The necessary changes to accommodate this extra length of shaft was incorporated in the FUV and VIS brackets.

2.5 Cable anchoring provisions: The distance between the first anchoring point of the cable from the connector end at CPU need to be minimum in order to reduce over hanging of these heavy cables. The overhanging will introduce low frequency oscillations and exerts higher stress on the connector, tend to loss of preloads. To take care of these cable anchoring provisions are designed for all three channels. A tube of OD 35 mm, 1 thick was used, one end of it is secured on the detector bracket and the other end supports the heavy cables (as shown in fig 3).

2.6 Stiffening of the TT2 mid flange: The two telescopes are attached to the satellite adapter by an intermediate flange machined integral with mid telescope tube (TT2). This flange thickness is modified such that, 5 mm thick at the end and 20 mm thick at root, connected by a large fillet radius of about 20 mm as shown in fig 5. This enhanced the coupling stiffness at the root.

2.7 Change in tab position of satellite adapter. The titanium satellite adapter had 18 nos equi-spaced tabs thorough which UVIT was connected to satellite cylinder. The accommodation study of all payloads on astrosat reveled, necessity of angular shift of one of the tab by 6 degrees from its nominal (20 deg equi-spaced) as shown in fig 6. This was necessary to make the SXT interface bolts accessible for torquing. This change was incorporated in FE model and change in dynamics due to this small asymmetry was found less.

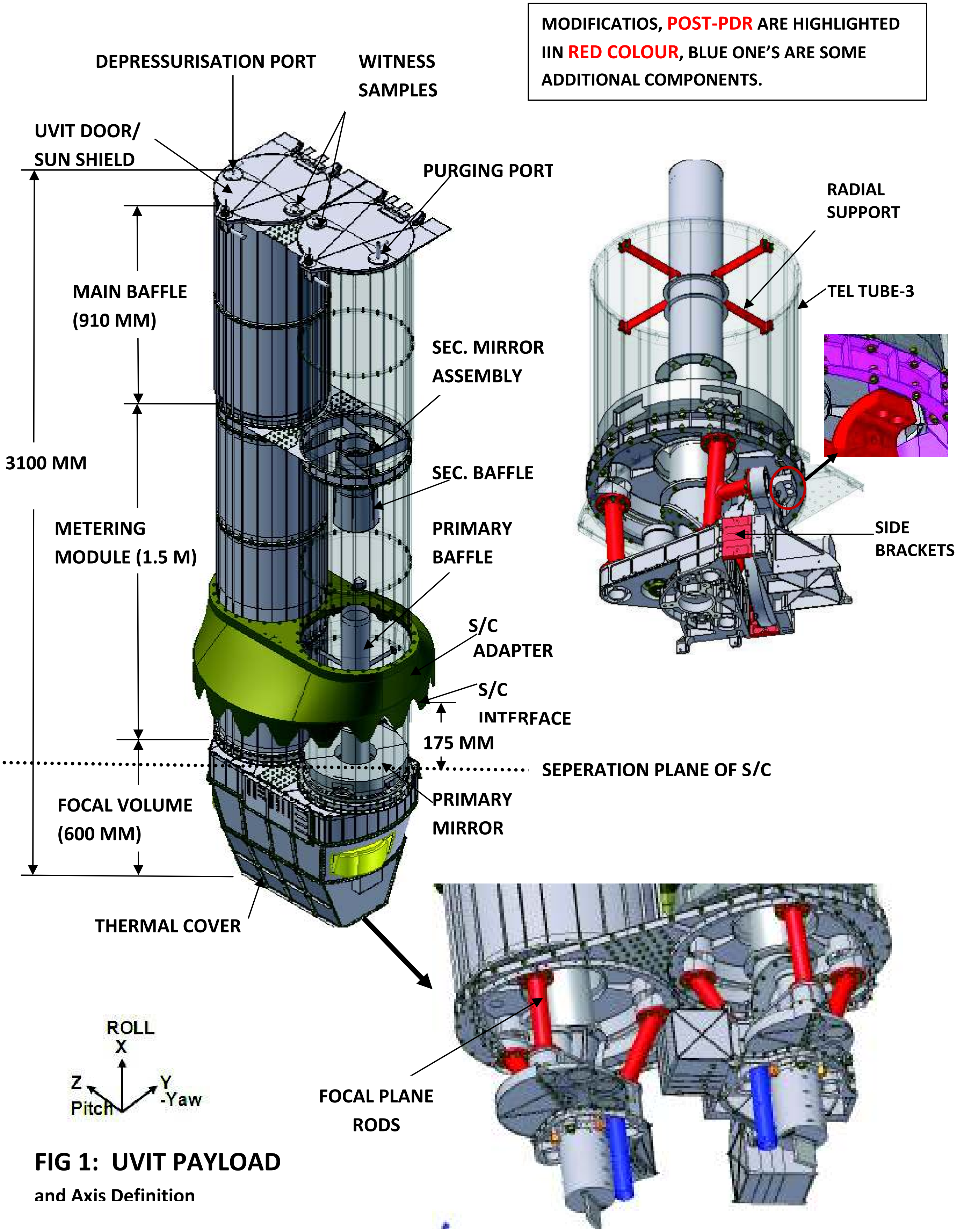


FIG 1: UVIT PAYLOAD

and Axis Definition

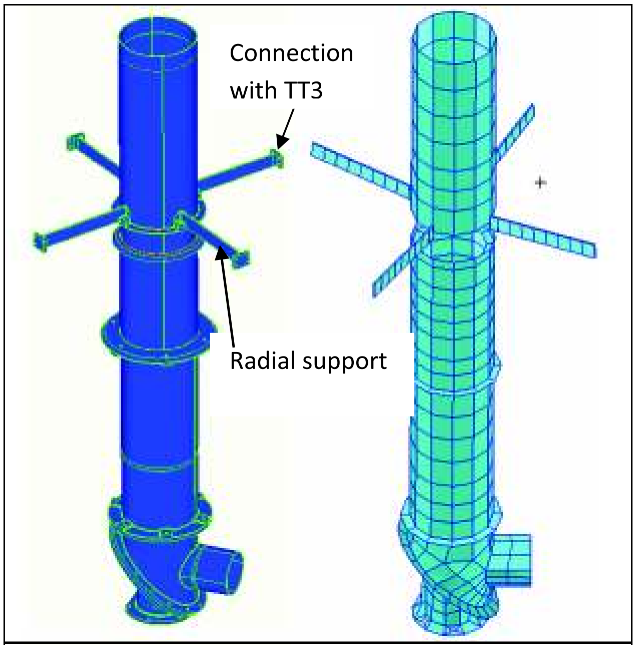


Fig 2: Second support for primary baffle

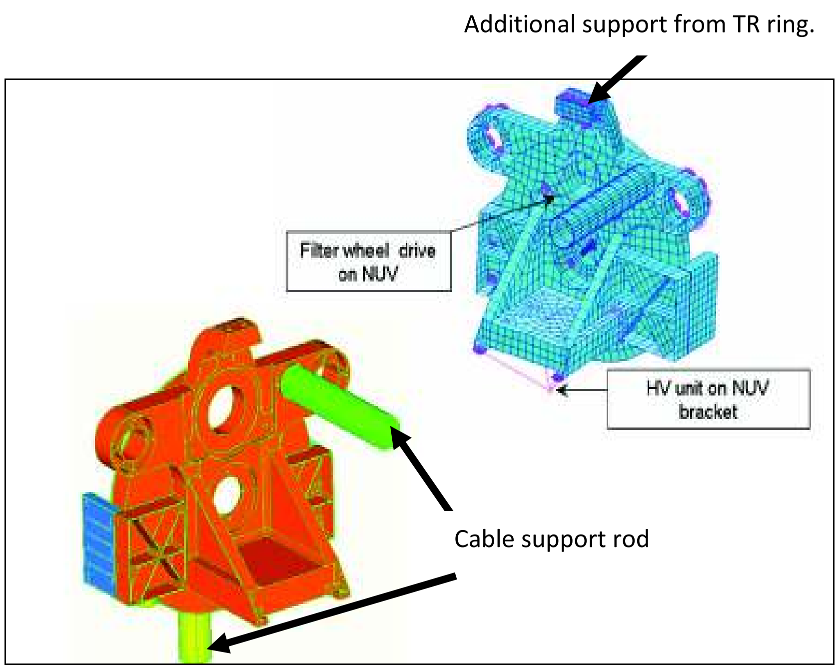


Fig 3: Additional support for NUV bracket

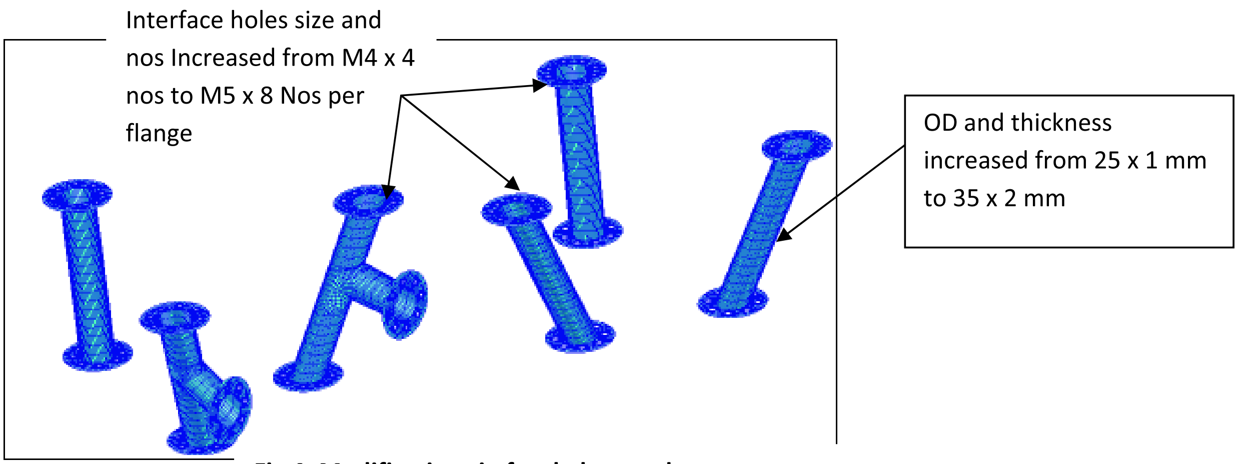


Fig 4: Modifications in focal plane rod

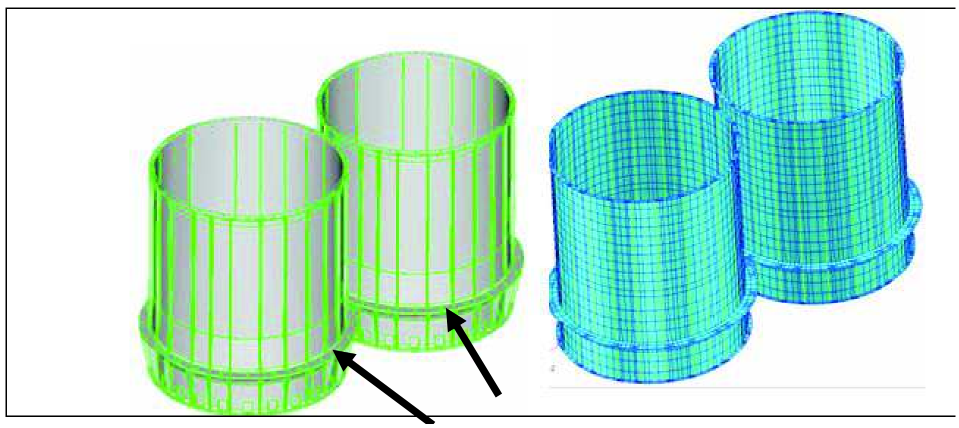


Fig 5: Flange modified, 5 mm at the tip and 20 mm at the root, with as large fillet radius of 20

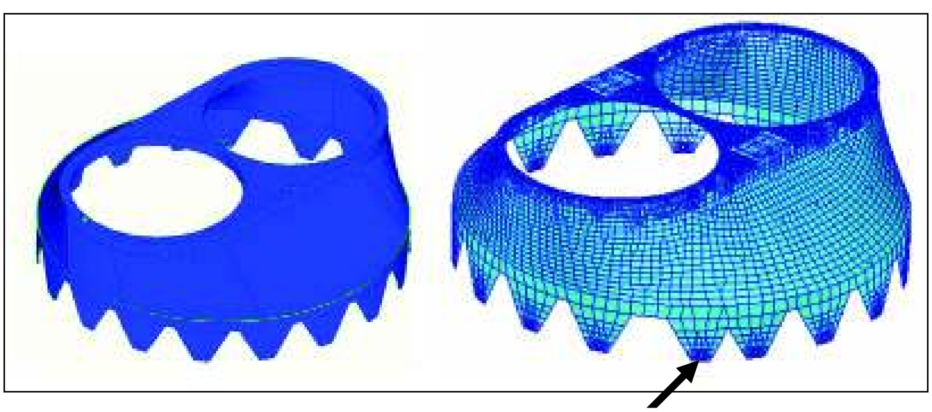


Fig 6: This Tab position shifted by 6 deg

3. MATERIALS USED IN UVIT: The following are the structural material (and its properties) used in UVIT.

Sl. No.	Material Properties	Material Name		
		Aluminium (Al-6061)	Invar	Titanium Ti-6Al-4V (Grade 5), Annealed)
1	Young's Modulus 'E' (MPa)	68900	148000	115000
2	Density 'ρ' (tonne/mm^3)	2.70E-09	8.05E-09	4.30E-09
3	Poissons Ratio 'ν'	0.33	0.29	0.3
4	Tensile Yield Strength (Mpa)	320	240	880
5	Co-efficient of Thermal Expansion 'α' (μm/m-°c)	2.36E-05	1.30E-06	8.60E-06
	Acceptable Stress Limits			
6	Tensile (Mpa)	213.33	160.00	586.67
7	Shear (Mpa)	106.67	80	293.33

4. MASS of UVIT PAYLOAD:

The mass of UVIT has two parts, UVIT mass attached to central cylinder of satellite is 202 **Kg**, and UVIT packages mass on satellite equipment panels is about **28 Kg** amounting the total UVIT mass as **230 Kg's**. The details of mass break ups are given in the document "UVIT Mass break up table, Ver 4.0, Date: 10-11-2009" which is shared with project office.

5. LOAD SPECIFICATIONS:

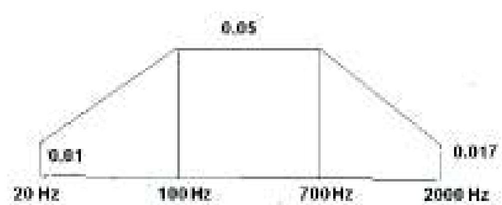
Longitudinal to spacecraft

Frequency (Hz)	Amplitude	
	Qualification level	Acceptance level
5 – 16	9.7 mm	6.5 mm
16 – 50	10 g	6.67 g
50 – 80	6 g	4 g
80 – 100	3.5 g	2 g
Sweep rate	2 oct. / min.	4 oct. / min.

Lateral to spacecraft

Frequency (Hz)	Amplitude	
	Qualification level	Acceptance level
5 – 11	10.3 mm	6.9 mm
11 – 60	5 g	3.3 g
60 – 100	3 g	2 g
Sweep rate	2 oct. / min.	4 oct. / min.

Frequency (Hz)	PSD (g^2 / Hz)	
	Qualification level	Acceptance level
20 – 100	+ 3 dB / oct.	+ 3 dB / oct.
100 – 700	0.05	0.02
700 – 2000	- 3 dB / oct.	- 3 dB / oct.
Overall RMS	8.3 g	5.5 g



6. FINAL ANALSYIS RESULTS AND DESIGN MARGINS: Subsequent to the review of structural analysis data by analysis review committee, the payload model was updated by incorporating the modifications suggested by the committee and structural analysis was carried out. The bolt forces at the telescope tube joints, tube attachments with the adaptor, and in the focal volume support structure were brought down to allowable limits. The final analysis results were again reviewed and accepted by analysis review committee.

6.1 QUASI-STATIC MARGINS: UVIT is analyzed for static loads to explore the maximum stress and to find the available design margins. The allowable yield stress of the material is computed considering a factor of 1.5. The maximum stresses experienced by the UVIT structure under static loads are much below the allowable stresses limits.

Maximum Stress experienced by UVIT

Load case	Max. Von Misses Stress, MPa	Tensile Yield Stress, MPa (σ_y)	Allowable Yield Stress , MPa ($\sigma_y/1.5$)	Location	Design margin on allowable stress
15g X-dir	**54.17**	**240**	**160**	At bolt area of TR ring connected to Thermal cover	~3
15g Y-dir	**114.66**	**880**	**586.67**	At bolt area of Adaptor tab	~5
15g Z-dir	**168.6**	**880**	**586.67**	At bolt area of Adaptor tab	~3.5

6.2 DYNAMIC CHARECTERISTICS OF UVIT SYSTEM: The UVIT system is modeled completely with a finite element model. The system has six frequencies below 100Hz. The Natural frequencies, modal mass and inertia participation for different frequencies are listed in the tables. It may be noted that the mass and inertia participation for frequency above 100Hz is not listed as they are not relevant.

Natural Frequencies and Modal Effective Mass

MODE No.	FREQUENCY, Hz	T1 (tonne)	T2 (tonne)	T3 (tonne)	R1 (tonne-mm^2)	R2 (tonne-mm^2)	R3 (tonne-mm^2)
1	45.4397	2.00E-06	0.006	8.00E-06	6.627	0.31504	**87679.4**
2	67.821	7.00E-06	1.00E-05	0.01	3.6	**98439**	3.55069
3	75.9874	1.00E-06	0.084	7.00E-04	11.36	0.97426	**10403.4**
4	86.2978	4.00E-05	1.00E-05	0.117	71.8	1298.29	0.63039
5	93.4816	2.00E-05	0.024	0.002	15.26	44.5869	1143.93
6	94.2693	3.00E-06	0.01	0.004	3.418	90.4428	459.623
7	111.961	7.00E-06	3.00E-07	4.00E-05	76.75	1.61672	0.00156

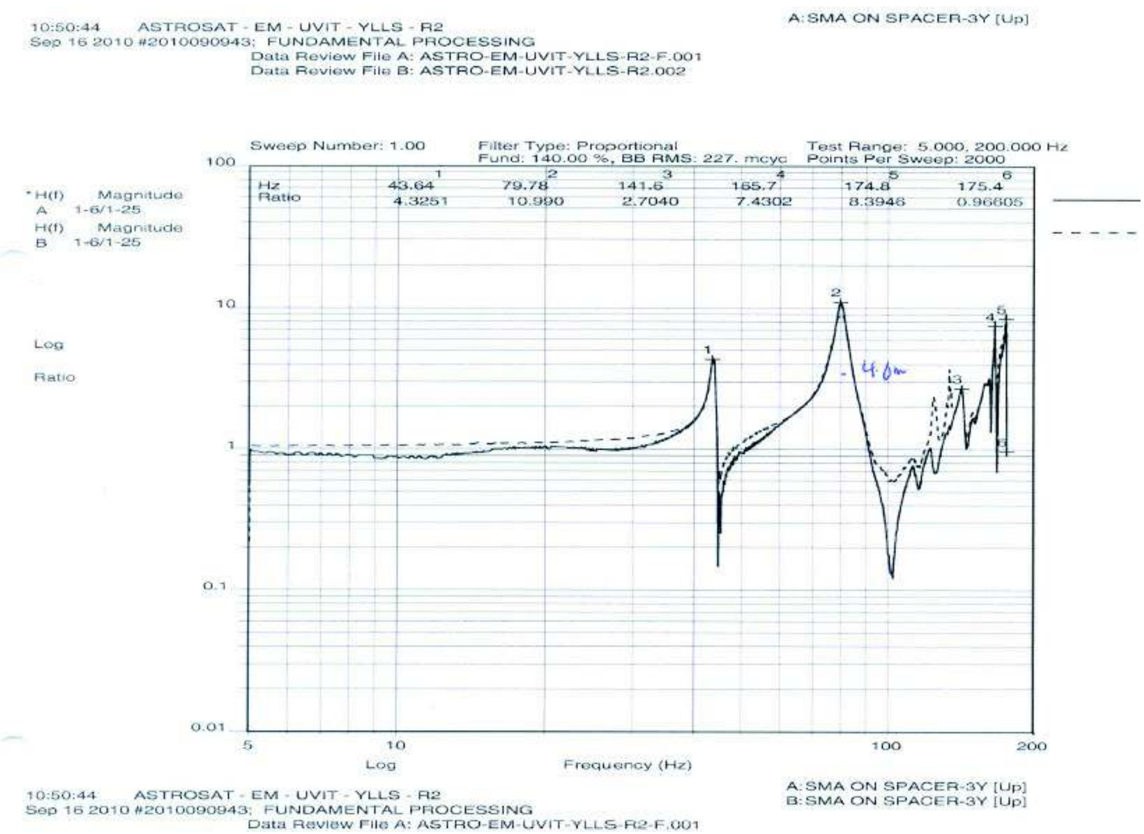
From the above table it can be seen that inertia participation is high for frequencies of 45.4 Hz and 67.8Hz. The mass participation is high for frequencies 76 Hz, 86.3 Hz and 93.5 Hz. In case of frequency at 76 Hz the inertia participation is also high. Hence the modes for the above mentioned five frequencies are considered as global modes. At the frequency 94.3 Hz the mass participation is only 5% and this mode is considered as local.

Natural Frequencies and Modal Effective Mass/ Inertia Fraction

MODAL EFFECTIVE MASS/INERTIA FRACTION (FOR TRANSLATIONAL DEGREES OF FREEDOM)							
MODE	**FREQUENCY**	**T1**		**T2**		**T3**	
NO.	**[Hz]**	**FRACTION**	**SUM**	**FRACTION**	**SUM**	**FRACTION**	**SUM**
1	45.4	0%	0%	3%	3%	0%	0%
2	67.8	0%	0%	0%	3%	5%	5%
3	76.0	0%	0%	43%	45%	0%	6%
4	86.3	0%	0%	0%	45%	59%	65%
5	93.5	0%	0%	13%	58%	1%	66%
6	94.3	0%	0%	5%	63%	2%	67%

MODAL EFFECTIVE MASS/INERTIA FRACTION (FOR ROTATIONAL DEGREES OF FREEDOM)							
MODE	**FREQUENCY**	**R1**		**R2**		**R3**	
NO.	**[Hz]**	**FRACTION**	**SUM**	**FRACTION**	**SUM**	**FRACTION**	**SUM**
1	45.4	0%	0%	0%	0%	81%	81%
2	67.8	0%	0%	85%	85%	0%	81%
3	76.0	0%	0%	0%	85%	10%	90%
4	86.3	0%	1%	1%	86%	0%	90%
5	93.5	0%	1%	0%	86%	1%	91%
6	94.3	0%	1%	0%	86%	0%	92%

6.3 COMPARISION of ANALYSIS RESULT with TEST RESULTS: From the frequency response curve shown below, at secondary mirror interface in Y-axis test, we can notice that the first frequency of the system is **43.44 Hz,** which is very close to **45 Hz** as estimated from analysis.



6.2.1 Frequency response analysis: A detailed analysis of the payload has been carried out. The frequencies of the system have been computed. Nearly six modes are below 100 Hz. A response study has been carried out for the levels specified. Below table gives the response of the UVIT system for unit g load at the base.

Response of the UVIT for unit acceleration at various interfaces

Sl No.	Accelerometer location	X	Y*	Z**
1	Interface of door subsystem on main baffle	1.3	41.3	21.0
2	Secondary mirror assembly interface on spacer	1.46	13.6	8.1
3	Primary mirror assembly interface on TR ring	1.32	7.5	19.2
4	HVU interface on FUV detector bracket	1.32	14.2	31.0
5	HVU interface on VIS detector bracket	1.48	16.2	38.4
6	HVU interface on NVU detector bracket	1.58	18.6	43.0
7	FUV Detector interface on its mounting bracket	1.32	13.8	30.0
8	VIS Detector interface on its mounting bracket	1.38	15.6	37.8
9	NUV detector interface on its mounting bracket	1.46	13.2	32.2
10	Filter wheel drive interface on FUV bracket	1.32	13.6	29.5
11	Filter wheel drive interface on VIS bracket	1.38	15.0	36.0
12	Filter wheel drive interface on NUV bracket	1.44	13.8	33.6
13	FUV primary baffle interface on FUV detector bracket	1.34	13.2	28.5
14	VIS primary baffle interface on VIS detector bracket	1.38	14.6	33.8
15	FUV unit telescope interface on satellite adapter	1.16	2.9	6.8
16	VIS/NUV unit telescope interface on satellite adapter	1.16	2.9	6.6
17	Focal plane rod interface with FUV bracket	1.32	13.0	28.0
18	Focal plane rod interface with NUV bracket	1.38	14.6	33.6
19	Focal plane rod interface with VIS bracket	1.46	12.0	29.0
20	FUV Focal Plane Rod Interface with TR Ring	1.38	8.4	21.0
21	VIS Focal Plane Rod Interface with TR Ring	1.32	8.0	20.4
22	Thermal Cover Base/ Focal Volume Cover	2.46	69	39.2

*** Most of the responses occur at approximately 76 Hz and 93-94 Hz**

**** Most of the responses occur at approximately 86 Hz**

As can be seen in the table the X axis responses are low whereas, the response in Z axis is high. In the Y axis the response at two places is quite high namely the thermal cover and at the door interface. Of all the locations/interfaces the critical accelerometers for Go/No Go accelerometers are mounted on High voltage unit of NUV, CPU of NUV, thermal cover and door, which are highlighted in the table.

6.3 RANDOM RESPONSE OF THE SYSTEM: For Random Loading (in all x, y and z direction), all the bolt forces of each interface between flanges are within the allowable bolt load. RMS stresses of UVIT assembly are also within the allowable limits

Max RMS stress in X-direction	49 Mpa.	At VIS.TR tie interface.
Max RMS stress in Y-direction	260 Mpa.	Interface of NUV.HVU on NUV detector bracket.
Max RMS stress in Z-direction	212 Mpa.	Interface of NUV.HVU on NUV detector bracket.

6.4 BUCKLING FACTOR/FIRST EIGEN VALUE OF THE SYSTEM: Buckling analysis is carried out for 15g static load in X, Y and Z direction respectively and corresponding buckling Eigen values are shown in **Error! Reference source not found.**.

For load in X-direction, the buckling has occurred in the telescope tie between Main baffle 2 and Telescope tubes TT1.

For load in Y-direction the buckling occurred in the bottom of telescope tube TT3.

For load in Z-direction the buckling occurred on the primary baffle support

Eigen Values from Buckling Analysis.

Sl.No	**Eigen Values of Buckling load case**		
	X	**Y**	**Z**
1	14.36	8.21	3.15

7. SUBSYSTEM and UVIT INTERFACES.

7.1 UVIT subsystem interfaces: UVIT structure has the following subsystem interfaces.

1. DOOR (Also called as SUN shield) (ISAC)
2. Secondary mirror interface (LEOS)
3. Primary mirror interfaces (LEOS)
4. Filter wheel drive electronics. (IISU)
5. Filter wheels (IIA)
6. Detector system (CSA/Routes/Photeck)
7. High voltage units (MSSL/Photeck/Routes)
8. Processing electronics unit called EU (CSA/routes)

All subsystem interfaces are frozen ICD's documented well before EM test and stands qualified on the structure.

7.2 UVIT-ASTROSAT interface: The titanium satellite adapter on the UVIT structure will provide the interface between UVIT and spacecraft (ASTROSAT). The attachment is through 18 nos tabs on the titanium adapter, which are held against satellite cylinder by M6 bolts, which get engaged in to the plate nuts riveted in the tabs. The satellite cylinder is provided with two cut outs to take the cable harness in to the spacecraft. The titanium satellite adapter also has a master ref. cube fitted on it, to serve as a ref while integrating with spacecraft. Definite ICD's exists stating all the above requirements and are also met.

8. CONCLUSIONS:

- Mode shape of natural frequencies up to 100 Hz show global behavior and the local modes of the primary baffle (where primary baffle vibrates much more than the rest of the telescope) were removed by providing additional support

- For 15g static loading (in all direction) **stresses in all components** of UVIT assembly are **within the allowable limits**. A buckling analysis also shows that the margin on buckling is greater than one.

- For 15g static load case all the bolt forces of each interfaces between flanges are within the allowable bolt load.

- For sine excitation loading (in all direction): The investigations on dynamic response due to prescribed g-level excitations at the resonant frequencies indicate that some of the bolts at the flange interfaces of the telescope tubes are exceeding the allowable loads. The frequency at which this happens corresponds to global modes, it was recommended by test committee to reduce the input **(notching)** to keep the resulting stress within allowable limits.

- For Random Loading (in all direction), all the bolt forces of each interface between flanges are **within the allowable bolt load.**

- For Random Loading (in all direction), RMS stresses of UVIT assembly are **within the allowable limits.**

- **VIBRATION AND THERMOVAC TESTS OF UVIT ARE SUCESSFULLY COMPETED, SUBSEQUENT PERFORMANCE TESTS OF UVIT CONFIRMS THE GOOD HELTH OF INSTRUMENT, AND SO THE <u>DESIGN STANDS QULIFIED</u>.**