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DESIGN and VIBRATION ANALYSIS of a 2U-CUBESAT STRUCTURE USING AA-6061 for AUNSAT – II

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ABSTRACT: *The design and analysis of modular 2U Cubesat structure based upon the Cubesat standard for the exploration of the lower thermosphere were carried out in this project. The structure composed of many sub components and multiple mounting configurations, giving maximum flexibility in the design process. The stack of PCBs and other flight modules could be build up first in the secondary structure and integrated with the load carrying frames at the end of the process, ensuring accessibility of the flight avionics. A suitable high strength aluminium alloy 6061 as per the Cubesat standard was selected for structure. The CAD model of the various parts and their assembly were made using SOLIDWORKS 2014 cad software and subjected to FE analysis using ANSYS 14 in a static load of 9g and 13g. In addition buckling and vibration analysis were also performed to find the deformation of structure at various natural frequencies in order to ensure that the Cubesat could withstand the various conditions while the launch. These results of FE simulation indicated that the natural frequency of 718.04Hz. By the static analysis the maximum deformation of 0.0049mm and maximum von mises stress is 21.27MPa while subjected to 250N load, the maximum deformation of 0.0039mm and maximum von mises stress is 17.02MPa while subjected to 200N load. The CubeSat structural members and other assemblies are fabricated using high strength lightweight Aluminium alloy. The entire assembled CubeSat will be subjected to Vibration testing to find the deformation of structure at various natural frequencies in order to handle the vibrations occur when the launch of rocket.*

Keywords - *Cubesat structure, AA-6061, Vibration analysis.*

1. INTRODUCTION

Anna University, Chennai is one of the participants in the QB50 mission co-ordinated by von karmann Institute, Belgium. As a participant, Anna University has been assigned with the task of design, develop, analyze, fabricate and test the various system of the 2U cubesat named as ANUSAT – II. The responsibility of the team assigned for structure is to design, analyze, fabricate and test the cad, engineering and flight model of the Anusat - II for its structural compliance. In this project a part of the structural compliance was analysed. In this project the structural design of the 2U cubesat with the volume of 100*100*200 mm3 with the structural mass of 400g by the given specification of the QB50 was attempted. Structural design of satellite undergoes the selection of the material which is not only consideration of weight factor, but also strength, stiffness, thermal conductivity, thermal expansion, manufacturability, and cost factor are considered during the satellite design.

By calculating the thickness for the budgeted mass of the satellite the CAD Modeling of the structure could be made using the SOLIDWORKS 2014. The CAD modeling of the structure could now tends for the FEM, free Vibrational and buckling load analysis test by the ANSYS 14 software. After this CAD modeling and software analysis, the structure could be fabricated by the high strength Aluminium alloy material and then the structure could be subjected to the vibrational analysis. By the results obtained by the software and real time analysis of the 2U cubesat structure, which will gives the difference between the two analysis processes and leads to the calibrations.

2. ANUSAT – II

The 2U cubesat satellite comprises of various components with the given specification of the QB50 cubesat. The components of the satellite with their mass, volume/area and power consumed details are shown in the Table I.

Table I. Components of the satellite

S.no	Card/ subsystem	Mass(g)	Volume/area (mm^3)	Power consumed (watt)
1	Structure(Incl,MLI)	400	100*1	-
2	Solar panal	400	98*98	-
3	UHF/VHF antenna	100	-	-
4	PC4(lono/tomo	80	80*80	.5
5	Payload(Main)	500	50*10	.5
6	PC2(ADCS)	100	90*90	.25
7	PC1(EPS+Batt)	200	90*90	.2
8	3*Torquer(AWG31,.12	120	80*80	.75
9	PC3(SDR	100	80*80	.4

Methodology

In this project the designing of the 2U cubesat satellite structure will undergoes varies steps such us selection of material, designing, analysis and results. The Flow chart of proposed methodology is shown in Figure 1.

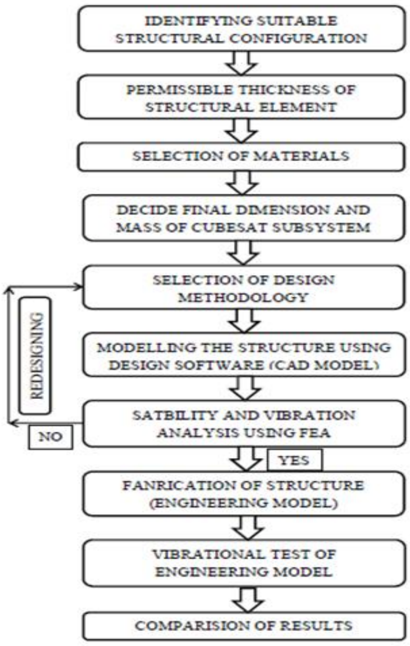

Figure 1. Methodology

Cubesat Standardization

Cubesat Design Specifications drive a significant number of constraints and requirements of the design. Some rules about the structure design must be implemented to provide compatibility with interface adaptor. The mechanical requirements were:

1. All parts of satellite shall remain attached during launch, ejection, and operation.
2. Risky materials shall not use on cubesat.
3. Each double cubesat mass should be low in 2.66 kg.
4. Center of gravity shall be located within a sphere of 4.5 cm from its geometric center.
5. For cubesat main structure, AA 6061 or 7075 should be used. Since, the material of satellite should be similar properties with the material of adaptor.
6. The cubesat's contact areas with the adaptor should be hard anodized.
7. The cubesat's wide should be 100+- 0.1 mm for X and Y directions. In addition, a double cubesat's tall should be 227+-0.3 mm for Z direction.
8. No components should exceed 6.5 mm normal to the surface of the 100 mm cube.
9. Exterior surface of the cubesat should not contact with the interior surface of adaptor such as deployable panels and antennas.
10. Rails should have a minimum width of 8.5 mm.

3. SELECTION OF MATERIAL

The selection of material is one of the significant steps on design of satellite structure. Since weightiness is an important factor for on-orbit object. Specially, for a 2U cubesat, small changes on the structure can result in valuable space for other subsystems and components. Not only weight factor, but also strength, stiffness, thermal conductivity, thermal expansion, manufacturability, and cost factor are considered during the satellite design. Material requirements, in line with the space environment, are given below:

1. All materials that will use in satellite should be selected from list that NASA determined.
2. Thermal expansion coefficient of the selected material should be similar with the material of deployment mechanism.
3. Yield strength of the selected material should be bigger than max Von Misses stress.
4. The material should be easy manufacturability.
5. To minimize the mass the material that has low density should be selected.
6. The material that has low out-gassing property should be selected.

CDS provides AA 6061 and AA 7075 as the mainstream two alternatives for cubesat structure materials. By considering weight, strength, coefficient of thermal expansion, manufacturability, cost criteria and availability, AA-6061 is selected for the ANUSAT II structure. Even though AA 6061 is lighter than AA 7075, we selected AA 6061 because of the fact that it has easier manufacturability and availability. The material composition and material properties of the AA 6061 is shown in the Table II and properties in Table III.

Table II. Material compositions

Element	Al	Mg	Fe	Cu	Si	Zn
Weight %	95.8	1.2	0.7	0.4	0.8	0.25

Table III. Material properties

PHYSICAL PROPERTIES	
DENSITY (g/cc)	2.7
MECHANICAL PROPERTIES	
Hardness Brinell (Hb 500)	95
Ultimate Tensile Strength(MPa)	310
Tensile Yield Strength(MPa)	276
Elongation at Break(%)	12
Modulus of Elasticity(GPa)	68.9
Poisson's Ratio	0.33
Fatigue Strength(MPa)	96.5
Machinability(%)	50
Shear Modulus(GPa)	26
Shear Strength(MPa)	207
Thermal Properties	
Specific Heat Capacity(J/g-°C)	0.896
Thermal Conductivity(W/m-K)	167
Melting Point(°C)	582 - 652

1) TO FIND THICKNESS ON EACH RAIL

Density of AA 6061 = 2.7g/cc
= 0.0027g/mm3
Mass = 400 g
Thickness of the rail = t mm
Volume = volume of (horizontal column + vertical column)

Volume of vertical column = l*b*h*(no. of column) = 200*t*t*4
= 908t2
Volume of horizontal column = l*b*h*(no. of column)
= (100- 2t)*t*t*10 = 1000*t*t – 20t3

Volume = 908t2 +1000*t*t – 20t3 = 1908t2 – 20t3

So, DENSITY = MASS / VOLUME
0.0027 = 400 / 1908t2 – 20t3
5.1516t2 – 0.054t3 = 400
t = 8.246, -8.056, 8.928
We take t = 8.928 = 9 mm

2) LOAD FACTOR CALCULATION

From NASA GEVS (General Environmental Verification Standard),

$$Ni = Si \pm \sqrt{(Li2+Ri2)}$$

Where, Ni = Combined Load Factor
Si = Steady State Load Factor
Li = Low Frequency dynamic Load Factor
Ri = High Frequency Random Vibration factor

Worst Case Factor (so far) is Minotaur 1 (numbers from Launch Vehicle user's guide)\'

Slongi = 13 g
Slati = ± 3.3 g
Li = 5g
Ri = 14.1 g (From NASA GEVS)
Nx =Ny = ± Slati ± √(Li2+Ri2)
= ± 3.3 g ± √((5)2 + (14.1)2)
= ± 18.26 g
Nz = Slongi ± √Li2+Ri2
= 13 g ± √(5 g)2 + (14.1)2
= 1.96g or 27.96 g
N = √ (Nx2+ Ny2+Nz2)
= √ (2 (18.26)2 + (27.96)2)
= 38.06 g

3) DESIGN FORCE CALCULATION

Fapplied= Fsatelites + Fsprings

Where,
Fsprings includes the force of the main spring and spring plunger from the P-POD

Fsatelites = 9.81 * Mass * 2 * N
= 9.81 * 2 *2 * 38.06 = 1493.44 N
FMain Spring = 44.5 N (Nominal Satellite Velocity of 1.8 m/s)
FSpring Plunger = 57.8 N (Max Force)
Fapplied = 1493.4 + 44.5 + 57.8
= 1769.1 N = 1595.7
F.O.S = 2.5 = 2.5 (1769.1)
= 4422.75 N
F load on each rail = 4422.75 / 4
= 1105.6 N.

4) CRITICAL BUCKLING LOAD

Pcr = π2EI / Leff2

Where,
Pcr = Critical Buckling Force
E = Modulus of Elasticity for Al 6061 = 68.9 GPa
E = 70.278GPa (2% Greater Than tension Modulus)
I = Moment of Inertia,
Leff = Effective length for a fixed and free Situation

I = bh3 / 10
= (0.009) (0.009)3 / 10
= 6.561x10-10 m4
Leff = 2 * length
= 2 * 0.2
= 0.4 m
Pcr = $\pi 2\ (70.278 * 10^{9})\ (6.561 \times 10^{-10})\ /\ (0.4)2$
= 2443.47 N

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CAD MODELLING

We have designed an innovative highly modular 2U main structure for cubesat satellites structure around structural columns, which support for our ANUSAT II nanosatellite. The envisioned structure provides the much-needed flexibility to the satellite designers during the design, development and test cycle. Specifically, the structure allows the designers to change the location of subsystems or perform design modifications to the subsystems without the need and the necessity to re-design the main structure.

The sizing of the satellite in the main three dimensions, the design of rails in corners and solar panels, and protrusions for the six sides of the satellite are decided according to the "Cubesat Design Specifications" constraints. Also, by considering material criteria, the material selection of AA-6061 is made for the structure of the cubesat. SOLIDWORK 2014 is used for modeling of ANUSAT II structure.

The CAD model of the Subsystem Assembly and the fully assembled of the structure in Figure 2.

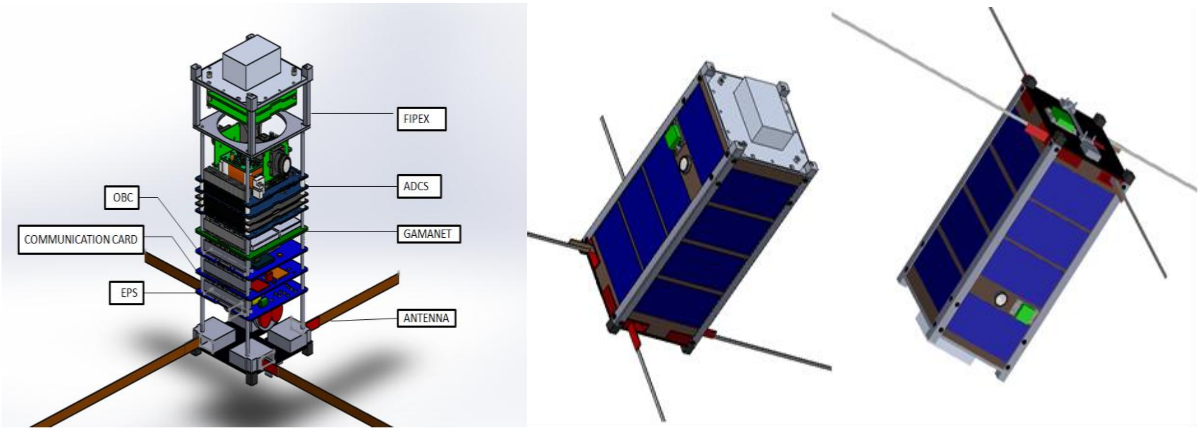

Figure 2 ANUSAT - II fully assembled view

4. RESULTS AND DISCUSSION

The CAD model of 2U cubesat structure was subjected to various analyses such as Static, Frequency and Buckling Analysis to find the Deformation, Von Misses Stress, Strain and Natural Frequency by applying Loads and Fixture on the structure after meshing the parts in to the number of nodes using the FEM analysis in ANSYS 14 software. The FE analysis was obtained by the two different loads of 200N and 250N at the top plate after triangular meshing of the parts by fixed the four legs at the bottom.

Static Analysis

The first step in static analysis of 2U cubesat was meshing the structure. The meshing was performed with satisfying the solid meshing the element size, on obtaining the fine mesh size the structure was meshed into Elements: 131625 and Nodes: 239711 with Number of D.O.F: 714491.

On analyzing for a maximum load of 250N which was applied as the longitudinal force after the structure was fixed at its four legs, a maximum deformation of 0.0049mm was observed (Figure 5.3) and a maximum Von Misses stress of 21.27MPa was observed (Fig. 3).

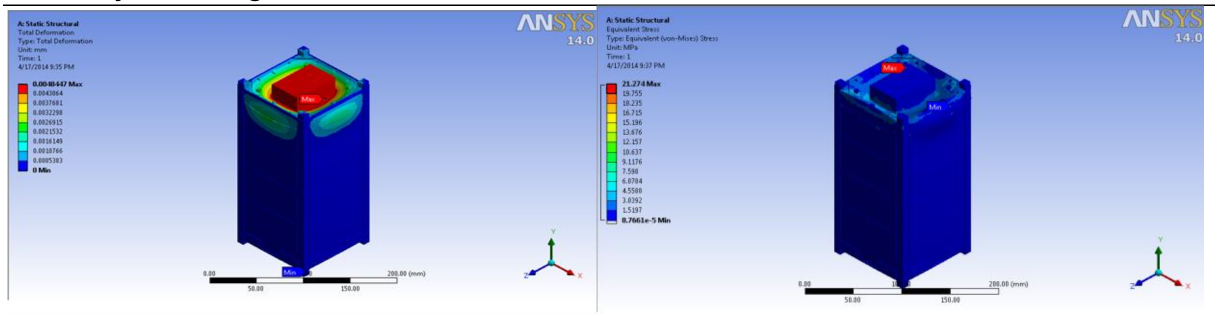

Fig. 3 Maximum deformation and maximum von mises stress

Frequency Analysis

On performing model analysis, the natural frequencies for the structure with respective with to modes were listed in the Table 5.3 and the graph of natural frequencies at each mode was shown in Figure IV.

Table IV Natural frequencies

S.NO	MODE	NATURAL FREQUENCY(Hz)	S.NO	MODE	NATURAL FREQUENCY(Hz)
1	1	718.04	**9**	9	1078.8
2	2	725.36	**10**	10	1089.2
3	3	928.95	**11**	11	1089.6
4	4	953.73	**12**	12	1293.6
5	5	957.87	**13**	13	1338.7
6	6	962.33	**14**	14	1471.0
7	7	966.43	**15**	15	1522.7
8	8	1040.3	**9**	9	1078.8

Natural frequency at mode 1 and the mode 15 with the total deformation at first mode and 15th mode of 31.124mm and 166.19mm was shown in Fig. 4.

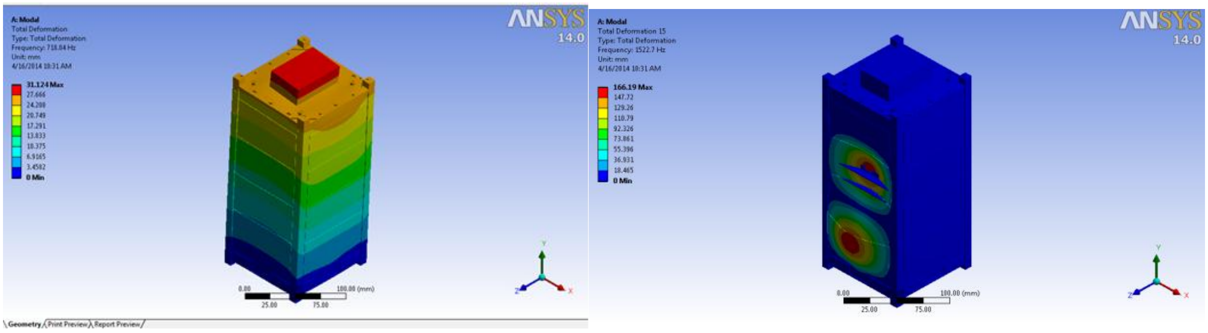

Fig. 4 Deformation at mode 1 and mode 2

5. CONCLUSION

In this project the structural design of the 2U cubesat structure with the volume of 100*100*200 mm3 with the mass of 400g using AA 6061 material which is not only consideration of weight factor, but also strength, stiffness, thermal conductivity, thermal expansion, manufacturability, and cost factor are considered during the satellite design. The project leads to the CAD Modeling using the SOLIDWORKS 2014 of the structure and subsystems in ANUSAT – II. It is then implemented to the FE analysis using ANSYS 14, for finding maximum deformation, maximum von mises stress, buckling load and the natural frequencies by static analysis, linear buckling analysis and modal analysis while the load of 200N and 250N is applied.

By the design calculation, the thickness of rail (9mm), load factor (38.06g) and the buckling load of 2443.47N have been calculated. The overall assembled 2U cubesat has the mass of 1.900kg with the CG at (x=0.022mm, y=-0.012mm, z=0.051mm) was founded. The FE analysis indicates that the structure can withstand the deformation and stresses acting on it while 2U cubesat is subjected to launch. This shows that the maximum von mises stress (21.27MPa) obtained was lesser than the yield strength (276MPa) of the aluminium alloy 6061 material. The maximum deformation (0.0049mm) while acting of load shows that the deformation is very less compare to the thickness of the structure (9mm), it gives us the structure can withstand the loads. The buckling analysis shows that the 2U cubesat structure can withstand vibration acting on it while 2U cubesat is subjected to launch.

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