Material Selection,Design and FEA of CubeSat

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1 Introduction

CubeSats are small satellites with a standard cubic form factor of 10 cm x 10 cm x 10 cm, weighing about 1 kg, known as 1 unit(1U).

1.1 Problem Statement

The project focused on selecting the most suitable material for CubeSat by evaluating mechanical and thermal properties. Performed Finite Element Analysis to assess performance under space conditions. Emphasizing weight management and cost analysis, ensured that materials meet strength, thermal stability, and cost-effectiveness criteria, providing valuable groundwork for future CubeSat development.

1.2 Why is it required?

The space environment is characterized by low pressure (vacuum), atomic oxygen (causes erosion of materials), ultraviolet (UV) radiation, charged particles, extreme temperatures, and electromagnetic radiation [11] Therefore, meticulous attention must be paid to material selection and structural integrity when designing and developing a CubeSat.

2 Primary CubeSat Constraints

2.1 Mechanical Properties

- To endure different loads during launch and orbit: Modulus of elasticity and Poisson's ratio.
- Possess Strength and stiffness to maintain its structure: Yield strength, density and fracture toughness.

2.2 Thermal Properties

- A CubeSat experiences significant temperature fluctuations in space environment which ranges between -20°C to +80°C [10], causing expansions and contractions. This leads to thermal stress, making it essential for the structure to handle deformation due to thermal stress.

Property	Accepted Value
Thermal Expansion Coefficient	$\leq 0.0001 strain/C$
Yield Strength	$\geq 5.1 MPa$
Elastic Modulus	$\geq 2.5 GPa$

Table 1: The essential criteria for selecting a material to be used [10]

3 Selected Materials

3.1 Aluminum (AL6061-T6)

Chosen for its corrosion resistance, ease of manufacturing, lightweight, and good thermal conductivity despite lower strength and higher thermal expansion.

3.2 Aluminum (AL7075-T6)

Selected for its high yield strength and low outgassing, although it requires additional corrosion protection and is difficult to machine.

3.3 Stainless steel (AISI 304)

Used for its high strength, corrosion resistance, and thermal stability despite its higher density and poor thermal conductivity.

Property	Aluminum(AL6061-T6) [6]	Aluminum(AL7075-T6) [7]	Stainless steel(AISI 304) [8]
Modulus of elasticity	68.9 GPa	71.7 GPa	193 GPa
Poisson's ratio	0.33	0.33	0.29
Yield Strength	276 MPa	503 MPa	215 MPa
Density	2.70 g/cc	2.81 g/cc	8.00 g/cc
Fracture Toughness	29.0 MPa-m$^{\frac{1}{2}}$	17.6 MPa-m$^{\frac{1}{2}}$	90.9 MPa-m$^{\frac{1}{2}}$
Coefficient of Thermal Expansion	23.6 µm/m-°C	21.6 µm/m-°C	17.3 µm/m-°C

Table 2: SI values of properties of selected materials

4 Design Considerations

4.1 Over all Dimensions

- Size: 10x10x10 cm
- Panels Thickness: 2 mm
- Inside Spacing for hardware: : 9.5x9.5 cm
- Solar Panel Mounting Hole: Diameter: 2 mm
- Central Hole Radius:7.5 mm

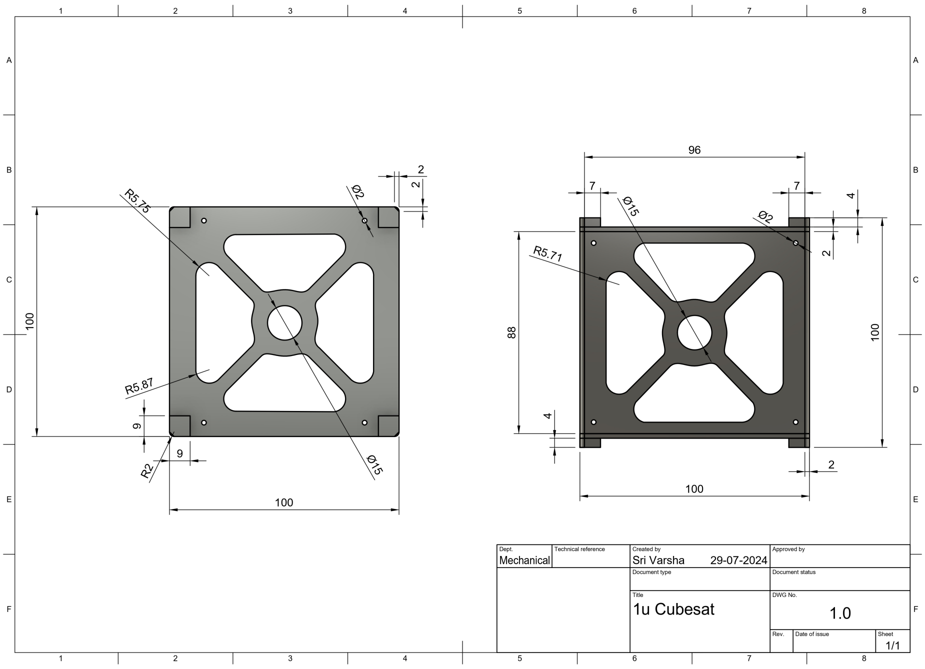

Figure 1: Design of CubeSat

4.2 STAINLESS STEEL FASTENERS , MOUNTING AND BASES

- Corner Bracket, 1 per corner: 1088A31
- Flat head Screw, 6 per corner: 90585A019
- Base: 8 (4 top, 4 bottom)
- Dimensions: 9x9x4 mm

4.3 Functionality and Reasoning

- 'X' Configuration of 6 frames: Even stress distribution, enhanced structural integrity
- Fillets in Joints: Reduce stress concentrations
- Central Hole: Weight reduction and Thermal management (airflow, thermal straps/heat pipes)
- Why circular : Even stress distribution and minimize crack risk
- Bases: Eight square bases for stability and spring deployment mechanism.

5 Finite Element Analysis (FEA)

5.1 Stress Analysis

5.1.1 Calculation of Impulse Force

Impulse (J) is defined as:

$$J = F \times \Delta t \tag{1}$$

where F is the force and Δt is the time interval over which the force is applied. Alternatively, impulse is also the change in momentum:

$$J = \Delta p \tag{2}$$

For a constant mass system:

$$J = m \times \Delta v \tag{3}$$

Therefore, the force F can be calculated as:

$$F = \frac{m \times \Delta v}{\Delta t} \tag{4}$$

Consequently, for $m = 1.33\,\mathrm{kg}$ (assumed), $\Delta v = 1.5\,\mathrm{m/s}$, $\Delta t = 0.3\,\mathrm{s}$ [3]

$$\therefore F = \frac{1.33 \times 1.5}{0.3} \approx 6.65\,\mathrm{N} \tag{5}$$

For conservative design purposes, we approximate the impulse force to a higher value of 7 N

- Applied boundary conditions simulate launch environments: 10g acceleration [2] in three directions, 83N [3] spring force on bottom stands, and 7N impulse force opposite to spring force.
- The analysis showed a maximum stress of 8.28 MPa and maximum deformation of 3×10^{-6}m, indicating the structural response under specified conditions.

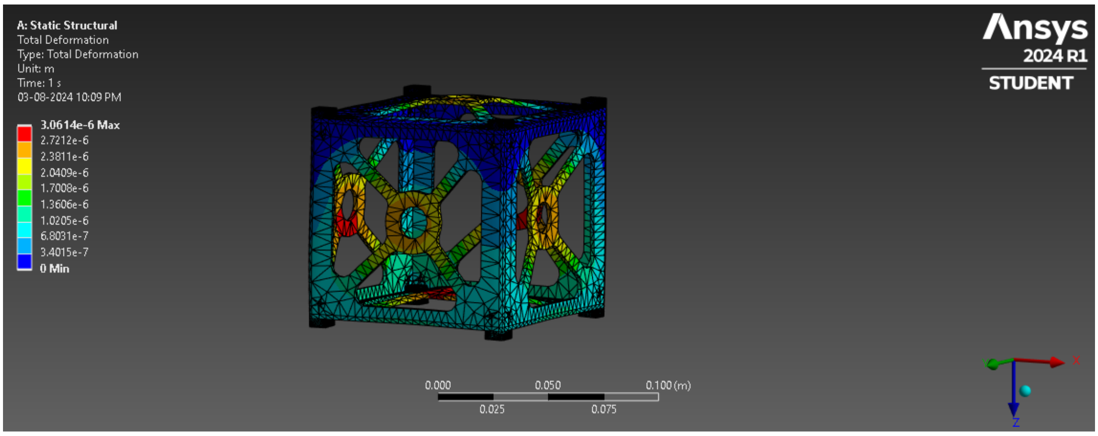

Figure 2: Total Deformation

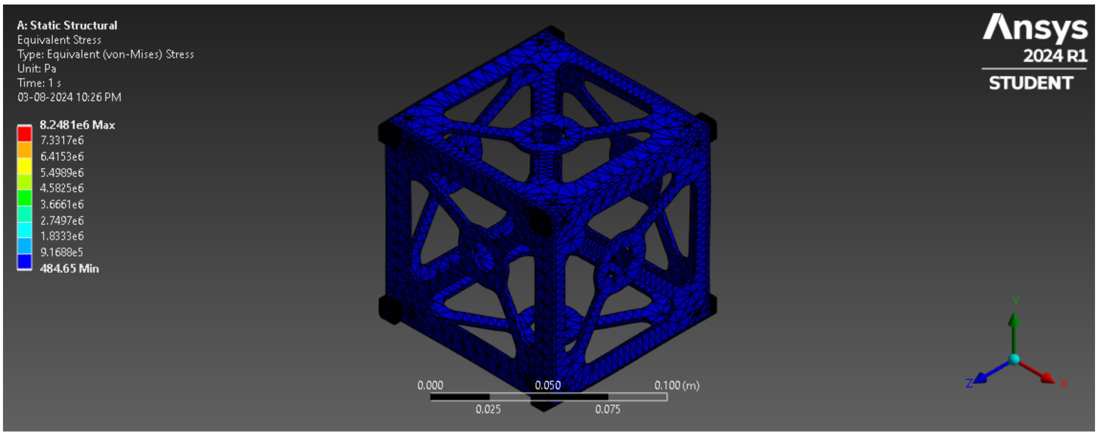

Figure 3: Equivalent Stresses

5.2 Thermal Analysis

- The CubeSat experiences 1366 W/m² solar flux, 237 W/m² from albedo, and 368 W/m² Earth IR [9], with 1.875W [1] from internal components, and an initial internal temperature of 298 K

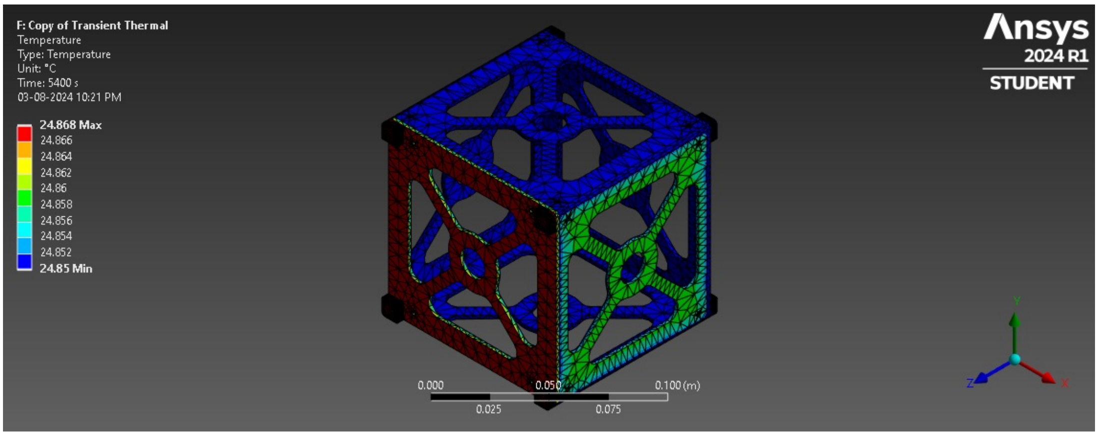

Figure 4: Temperatures

- The analysis revealed maximum and minimum temperatures of 24.868°C and 24.85°C, respectively, indicating temperature stability during the 90-minute orbit.

5.3 Modal Analysis

- The CubeSat's base is treated as a fixed end, and the analysis calculates the first ten natural modes to assess the structural response.

- The first mode frequency is 1160.3 Hz, significantly above the 100 Hz minimum [2] required for CubeSats, confirming structural resilience.

Mode	Frequency [Hz]
1.	1160.3
2.	1196.8
3.	1210.9
4.	1242.4
5.	1246.9
6.	1331.
7.	2708.9
8.	2721.9
9.	2786.1
10.	2819.4

Figure 5: Modal Frequencies

6 CubeSat Cost Analysis

Materials (per kg)

- Aluminium Plate 6061 : $3.28 [4]
- Stainless Steel 304 Coil: $2.99 [5]

Component	Quantity	Cost (Including Machining)
AL6061-T6 Frame	6	$390
Stainless Steel Bracket	8	$930
Stainless Steel Support	8	$425
Stainless Steel Screw	48	$5
Total Cost		$1750

Table 3: Cost Tally (Approximate)

Key Takeaways:

- High Cost: Stainless Steel Brackets
- Frame Material: Aluminium 6061
- Cost Reduction Opportunities: Optimize brackets usage
- Note: Component costs include manufacturing expenses as per online quotations and are approximated to next integer. (Website used :RapidDirect CNC Milling Quote)

7 Problems Incurred

- During the analysis of the 1U CubeSat frame, several meshing errors were encountered:
- Surface Mesh Intersection: The surface mesh is intersecting or close to intersecting especially at the corners and intersecting bodies, making it difficult to create a volume mesh.
- Entity Meshing Failure: One or more entities failed to mesh. The mesh of the bodies containing these entities may be incomplete.
- Surface Meshing Quality and Quantity: One or more surfaces cannot be meshed with acceptable quality. Had to try using a different element size or meshing method. But were restricted due to limited number of elements and nodes in Ansys student version.

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