

# Structural Analysis and Validation of a 1U CubeSat Frame Using Finite Element Analysis

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**Abstract**—CubeSat satellites are used extensively to perform inexpensive space missions and technology tests due to their compact sizes. Structural integrity during launch operation, which is characterized by extreme mechanical loading, is essential to ensure successful CubeSat missions. In this work, the structural integrity of a 1U CubeSat satellite frame (100 mm × 100 mm × 100 mm) was analyzed and validated numerically using finite element method. The findings were compared to previous CubeSat studies to prove the numerical reliability. The CubeSat satellite structure was modeled in three dimensions using the software package ANSYS Mechanical, material properties of aluminum alloy were applied, and load of acceleration was imposed under the condition of fixing its base surface, simulating the deployment process. Numerical results revealed maximal displacement value of  $2.474 \times 10^{-6}$  m and a value of maximum von-Mises stress of 0.556 MPa, which both fall well below the material strength values. Mesh independence analysis was carried out in order to confirm the numerical stability of results.

**Index Terms**—CubeSat, Finite Element Analysis (FEA), Structural Analysis, Nanosatellite Structures, Launch Acceleration, Aluminum Alloy, Mesh Independence Study.

## I. INTRODUCTION

CubeSats are tiny satellites with a common modular form of construction, originally defined as measuring 1U or ten cubic centimeters in volume. CubeSats have evolved since their introduction as an important vehicle for performing low cost space operations, conducting academic research, and for quickly prototyping new technologies. Because of their size and low cost, CubeSats can be built more efficiently and launched from a standardized vehicle. Because of the above reasons, universities, businesses and research institutions can now conduct experiments in space using CubeSats that previously could only be conducted using much larger, expensive satellites. Some examples of applications that currently exist for CubeSats are: Earth imaging, communication experiments, atmospheric research and testing technology for future space applications.

CubeSats are subjected to an austere mechanical environment during launch even though they are a small structure. During ascent of the launch vehicle (LV), CubeSats experience very high acceleration, vibration and dynamic loading. Because of these forces, there is the potential for structural deformation, stress concentrations and hence possible mechanical failure if the structural frame of the CubeSat is not adequately designed. Consequently, the integrity of the structural frame of a CubeSat is an essential consideration in the CubeSat design and mission reliability process. The structural frame of the CubeSat provides structural support for electronics and payloads, and it also provides geometric stability of the CubeSat during launch and deployment.

Aerospace engineers most commonly use Finite Element Analysis (FEA) as one of the means to numerically evaluate structural performance under various loading conditions. Engineers are able to model the mechanical environment in which the CubeSats will reside after launch and analyze the distribution of stresses, displacements and amount of structural stability through FEA without the need to conduct expensive physical tests. Thus, designers who use numerical simulation tools such as FEA are able to detect and evaluate a possible structural weakness and predict the reliability of the design before the CubeSat is manufactured.

A number of existing studies have used numerical simulation methods to investigate the structural behaviour of CubeSat frames. Results from past studies confirm that finite element modelling is a useful method for predicting structural performance and

validating CubeSat designs via simulated launch conditions. This project evaluates and validates the structural integrity of a 1U CubeSat frame (100 mm x 100 mm x 100 mm) through finite element analysis, using ANSYS Mechanical to create a 3D model and perform the necessary analyses. The results will evaluate the deformation and distribution of equivalent stress throughout the CubeSat frame when subjected to launch acceleration loading combined with a mesh independence study that will demonstrate the numerical stability and accuracy of the simulation results. Ultimately, through this work, the structural capabilities of the CubeSat frame will be established and confirmed to be appropriate for launch environments.

## II. METHODOLOGY

### ANSYS SOFTWARE

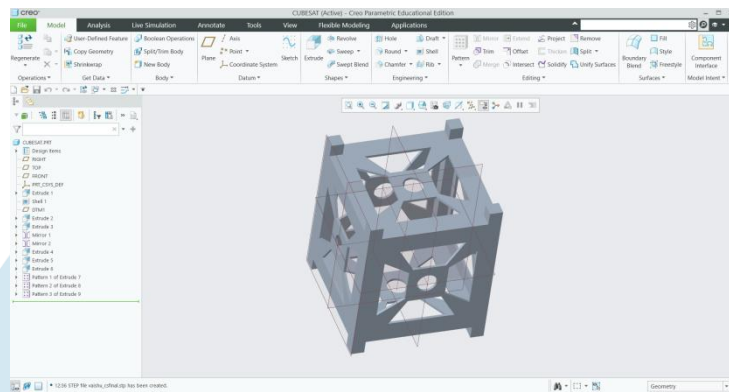
In this research project on finite element analysis, ANSYS Mechanical was used as the analysis tool. ANSYS Mechanical is highly recognized and has large amounts of historical usage in structural, heat transfer and fluid mechanics analysis due to its ability to perform engineering simulations for the above mentioned types of analysis. ANSYS Mechanical is also a very intuitive software and will allow an engineer to model very detailed geometries and apply suitable boundary conditions and loading scenarios to those models. ANSYS Mechanical allows the user to create 3-dimensional geometric models, create finite element mesh, assign material properties, apply constraints and loads and then use established finite element methods to derive the solution to the governing PDEs that define the structural behavior of the CubeSat frame. ANSYS also has post processing capabilities in that it allows the user to create visual representations of the stress, displacements and strains a CubeSat frame would experience in order to accurately assess the structural performance of the CubeSat frame. ANSYS numerical solvers have been subjected to large scale validation efforts and have very significant historical use within the aerospace engineering community, which makes its use for analysis of CubeSat frames under launch conditions appropriate. Using ANSYS Mechanical will also ensure the accuracy, repeatability and consistency of the analysis completed in this research project to similar analyses and results published in the literature regarding the validation of structural performance of nanosatellites., etc.

### MODELLING

The design of the 1U CubeSat frame was created in three dimensions following the CubeSat specification to produce a frame that measures 100 mm on each side. Four long rails, four corner posts, and multiple panels connect together to form the frame and are typical to the commercial CubeSat kit under design now. The three-dimensional representation of this CubeSat frame was designed with ANSYS SpaceClaim, which allows for parametric solid modeling and can provide accurate control over geometric tolerances.

To ensure accurate representation of structural behavior, the various features critical to the structure of the frame are included in the ACAD drawings: rail thickness, corner fillets, load-bearing edges, and mounting holes, etc. The only component omitted from these models is small internal electronic components as they are not the focus of this study; models focus on creating a structural load-carrying framework. The material for the CubeSat's structure is Aluminum Alloy; this is a common material for use in nanosatellites due to its excellent strength-to-weight ratio, good machinability, and compliance with the requirements of a launch provider.

The design is kept with all symmetrically located features, but small, micro-detailing such as surface screws, chamfers, and deployer grooves, etc., after confirming that they do not impact overall stiffness, has been removed. This results in a simple but accurate, mechanical model for finite element analysis. The final solid model is also exported directly from ANSYS Mechanical for future mesh and simulation.



*Figure 1: 1U CubeSat CAD Model*

## MESHING

Importing the CubeSat geometry into ANSYS Mechanical requires that the geometry be discretized with finite element meshing tools before performing finite element analysis. The process of meshing is a key step in a finite element analysis, as the size, quality, density, and type of mesh elements used in the analysis directly affect how accurately the numerical results will be produced. Tetrahedral solid elements were used in this study due to their ability to provide good meshes for very complex three-dimensional geometries, particularly those with slim edges, small features, and interconnected structural members commonly found in CubeSat frames.

The automatic mesh that is generated during the meshing process in ANSYS uses a default setting of the software for automatic generation of an initial automatic mesh; however, since the CubeSat frame has thin walls, and slender rails, and the need for refinement of the mesh to capture the stress gradients, an adjustment was made to the ANSYS settings to refine the mesh and eliminate the areas of too much variation in the mesh size, making use of the same element size throughout the structure to provide a uniform discretization.

The final size of the elements selected for the refined mesh was 1 mm, which was adequate for providing a trade-off between numerical accuracy and computational costs. To evaluate the sensitivity of the simulation results to the mesh density, a mesh independence study was performed. Two additional mesh configurations were generated using element sizes of 3 mm (coarse mesh) and 2 mm (medium mesh). Each mesh was solved independently under identical loading and boundary conditions. The maximum deformation values obtained from the coarse, medium, and fine meshes showed negligible variation—demonstrating convergence toward a consistent solution. This confirms that the selected fine mesh (1 mm) is sufficient for accurate structural analysis without unnecessary computational overhead.

The final mesh consisted of a high number of tetrahedral elements with good aspect ratios and smooth element transitions across the frame. No skewed or distorted elements were detected, verifying mesh quality. This meshing approach ensured reliable stress and deformation predictions for subsequent static structural analysis.

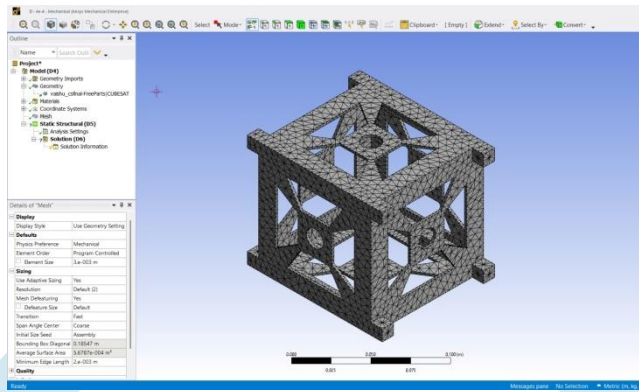


Figure 2: Coarse mesh (3mm element size) generated for the CubeSat frame.

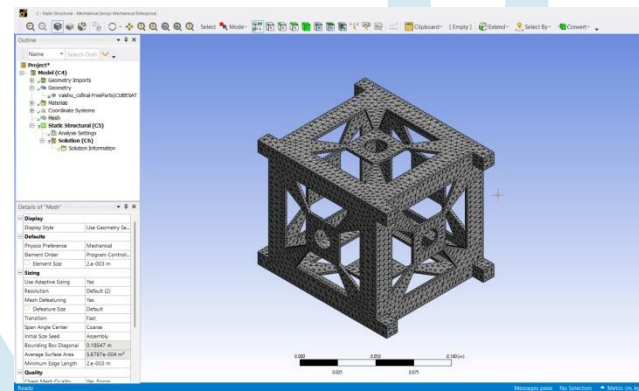


Figure 3: Medium mesh (2mm element size) generated for mesh convergence analysis

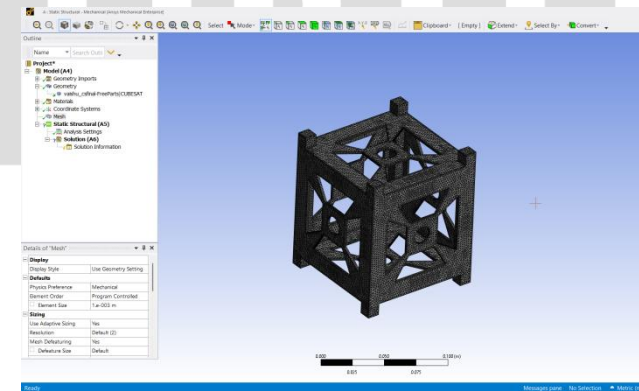


Figure 4: Fine mesh (1mm element size) selected for final structural simulation.

Table 1: Mesh independence study confirming convergence of deformation values

Mesh Size	Max Deformation
3mm	$2.2762 \times 10^{-6}$
2mm	$2.3908 \times 10^{-6}$
1mm	$2.474 \times 10^{-6}$

## SOLVER SETUP

The finite element model was solved using the Static Structural analysis module in ANSYS Mechanical, which is appropriate for evaluating structural response under steady loading conditions such as launch acceleration. Although launch environments involve dynamic effects, the primary objective of this study was to assess the structural capability of the CubeSat frame under the equivalent static loads commonly used in preliminary satellite structural validation.

### Boundary

To simulate realistic constraints during launch, the bottom face of the CubeSat frame was fixed in all translational and rotational degrees of freedom. This represents the attachment of the nanosatellite to the Poly-PicoSatellite Orbital Deployer (P-POD) or similar deployer systems, where the satellite is held firmly at the base until orbital release. Fixing this surface ensures that the reaction forces and stresses are computed correctly under applied launch loads.

### Conditions

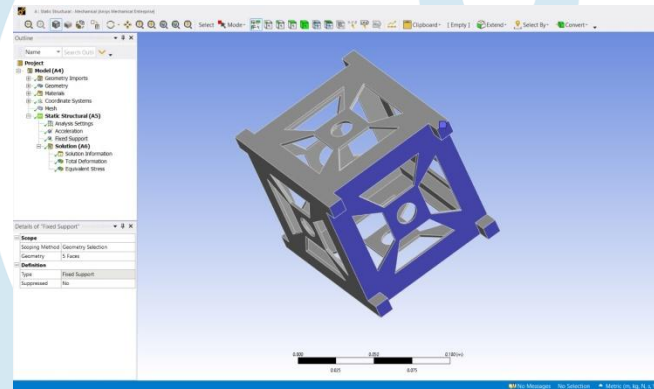


Figure 5: Boundary condition showing fixed support applied to base surface

### Applied Loads

The CubeSat frame was subjected to a launch acceleration load applied as a body force in the global vertical direction. A load of 10 g (98.1 m/s<sup>2</sup>) was selected based on typical acceleration magnitudes experienced during launch vehicle ascent. This acceleration was applied uniformly to the entire structure to represent inertial loading conditions encountered during launch. This approach is consistent with standard preliminary structural assessments for small satellites.

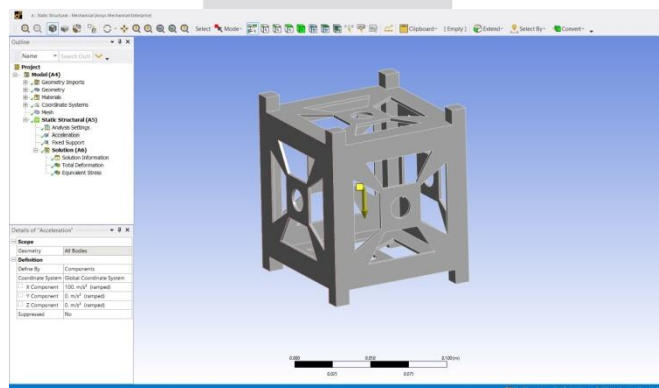


Figure 6: Launch acceleration (10g0 applied in vertical direction.

### Solver

The ANSYS solver computed structural deformation, equivalent (von-Mises) stress, and strain fields using the finite element governing equations. Default solver settings were retained, as they provide stable and accurate solutions for linear elastic problems. The analysis was performed assuming:

### Parameters

1. Linear elastic material behavior
2. Small deformation theory

3. Isotropic properties of aluminum alloy
4. Static loading with no time-dependent effects

The combination of these assumptions is justified because CubeSat frames are typically well within the elastic region under expected launch loads.

### **Convergence Criteria**

The solver used residual-based convergence checks for force and displacement fields. All results converged well within allowable tolerances. No numerical instabilities or divergence issues were observed during the simulation runs. The mesh independence study further confirmed the stability and reliability of the computational model.

## **GOVERNING EQUATIONS**

The static structural analysis performed in this study is governed by the fundamental equations of linear elasticity and finite element discretization. The structural response of the CubeSat frame under applied launch acceleration is described by the equilibrium equation:

$$[K] \{u\} = \{F\}$$

where

[K] = global stiffness matrix,  
 u = nodal displacement vector,  
 F = applied nodal force vector.

The stiffness matrix is assembled from element matrices computed using material properties and element geometry. The behavior of the aluminum alloy used in the CubeSat frame was modeled as a linear elastic, isotropic material, governed by Hooke's Law:

$$\{\sigma\} = [D]\{\epsilon\}$$

where

$\sigma$  = stress vector,  
 $\epsilon$  = strain vector,  
 D = elasticity matrix for isotropic materials.

The strain-displacement relationship is given by:

$$\{\epsilon\} = [B]\{u\}$$

where

B = strain-displacement matrix derived from element geometry.

The inertial loading due to launch acceleration is represented through:

$$F = m \times a$$

where

m = nodal mass,  
 a = applied acceleration (10 g in this study).

ANSYS Mechanical automatically computes nodal forces from acceleration loading using the assigned material density and element volumes. These governing equations collectively form the basis of the finite element solution used to predict deformation and stress distribution in the CubeSat frame.

## VALIDATION

Validation is an essential component of any finite element-based structural analysis to ensure that the numerical results accurately represent real physical behavior. In this study, two levels of validation were performed: (1) methodology validation through comparison with previously published CubeSat structural analyses, and (2) numerical validation through a mesh independence study.

### *Validation with Published Literature*

The numerical approach used in this study, including the use of aluminum alloy material properties, static structural analysis, and acceleration-based loading is consistent with methodologies reported in earlier CubeSat structural research. Previous studies indicate that typical 1U CubeSat frames experience deformation in the order of  $10^{-6}$  to  $10^{-5}$  meters and stress levels far below the yield strength of aluminum under launch acceleration.

The maximum deformation ( $2.474 \times 10^{-6}$  m) and maximum von-Mises stress (0.556 MPa) obtained in this study fall well within the expected range, confirming that the numerical response aligns closely with established results in literature. This agreement demonstrates that the modeling assumptions and finite element approach adopted here are valid for CubeSat structural evaluation.

### *Mesh Independence Study*

To further verify the reliability of the simulation results, a mesh convergence analysis was conducted using three different mesh sizes: 3 mm, 2 mm, and 1 mm. The corresponding maximum deformation values were  $2.2762 \times 10^{-6}$  m,  $2.3908 \times 10^{-6}$  m, and  $2.474 \times 10^{-6}$  m, respectively. The gradual and minimal variation between these results indicates strong numerical stability and confirms that the analysis is mesh independent. As shown earlier in Table 1, the deformation values for 3 mm, 2 mm, and 1 mm meshes showed minimal variation, confirming mesh convergence. The fine mesh (1 mm) was therefore selected for final evaluation, as it provides high accuracy without unnecessary computational cost. Together, the literature comparison and mesh convergence study demonstrate that the simulation methodology is reliable, and the results accurately capture the structural behavior of the CubeSat frame under launch loading.

## III. RESULTS AND CONCLUSION

The finite element analysis of the 1U CubeSat frame under a 10 g launch acceleration load yielded deformation and stress distributions that confirm the structural adequacy of the design. The maximum deformation obtained using the refined 1 mm mesh was  $2.474 \times 10^{-6}$  m, occurring near the upper edges of the frame where constraints are minimal. This displacement magnitude is extremely small, indicating that the overall structure exhibits high stiffness during launch-induced inertial loading.

The maximum equivalent von-Mises stress recorded in the frame was 0.556 MPa, concentrated around the fixed base where reaction forces are highest. This stress value is significantly below the yield strength of aluminum alloy (approximately 250 MPa), providing a substantial safety margin. The CubeSat frame therefore remains well within the elastic region under typical launch accelerations.

A mesh independence study using mesh sizes of 3 mm, 2 mm, and 1 mm demonstrated minimal variation in maximum deformation, confirming numerical stability and reliability of the finite element model. Furthermore, the obtained deformation and stress magnitudes are consistent with previously reported CubeSat structural studies, supporting the overall validity of the modeling approach.

Based on these results, it can be concluded that the analyzed 1U CubeSat frame possesses excellent structural integrity and is fully capable of withstanding expected launch acceleration loads without risk of yielding or excessive deformation. The simulation methodology presented in this study provides a reliable framework for evaluating preliminary nanosatellite structures and may serve as a reference for future CubeSat design and optimization efforts.

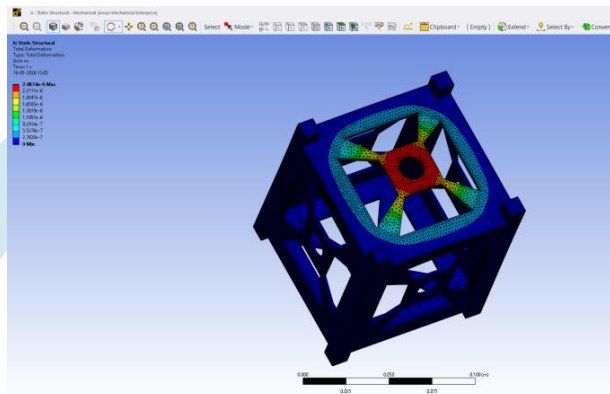


Figure 7: Total deformation contour of CubeSat frame under 10g acceleration.

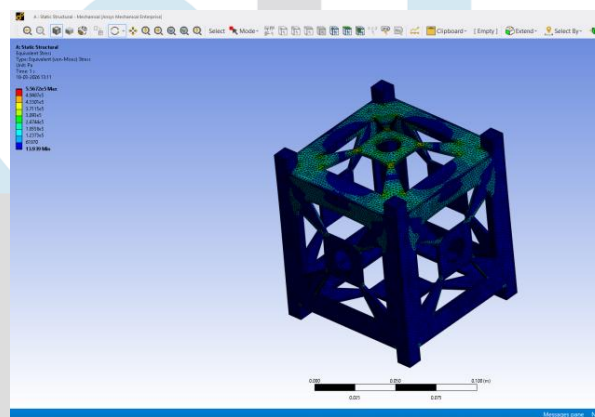


Figure 8: Equivalent von-mises stress distribution of CubeSat frame.

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