# Structural Analysis of Thai Space Consortium-1 Satellite based on Falcon 9 Launch Vehicle Vibration Profile †

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**Abstract:** During the launch environment, dynamic loads are transmitted to satellites located within the payload fairing, leading to the failures of its structure. Therefore, the analysis of natural frequency can be utilized to observe the main structure's response and avoid interaction with launch vehicle dynamics. In this paper, the structural analysis for the Thai Space Consortium (TSC) satellite is presented through the concept of a Low-Earth Orbit Earth observation satellite. The Falcon 9 launch vehicle environment is applied as a primary reference. First, the different designs of the small satellite structure consist of horizontal and modular layouts are created. Second, the numerical simulation using the Finite Element Model (FEM) is accomplished to observe the structural analyses especially, the failure stress factor. The quasi-static and displacement are considered. Then, the vibration analysis is conducted for each load, such as natural frequency responses, random load to meet the launcher's requirements. The comparison of two designs is validated. The results show that the static load and the vibration are acceptable and not critical to the satellite's main structure.

**Keywords:** Dynamic loads, Horizontal layout, Modular layout, Finite Element Model, Quasi-static.

## 1. Introduction

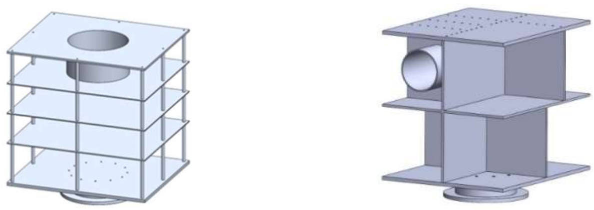
A micro-satellite is a small spacecraft that is classified by mass from 10-100 kilograms. Typically, the microsatellite can be established with many designs depending on their mission requirement. This work aims to compare two different layouts' structural design consisting of the horizontal layout and modular layout based on Beihang University micro-satellite (BUAA-SAT) and Flying Laptop satellite design respectively [1][2]. So, the suitable design for the TSC small satellite for its mission is determined. The material selection is also a challenge for the design. Materials used on exterior spacecraft surfaces are subjected to many environmental threats that can cause degradation. The design criteria selected for the material selection are mass; design, development, and test cost; ease of fabrication and assembly; ease of inspection and repair; availability of material; and thermal performance [3]. Mostly, satellite designers use machined aluminum, aluminum honeycomb, carbon fiber stainless steel, and graphite-epoxy laminates because of their light weights, low thermal expansion, low outgassing to prevent contamination of other spacecraft during integration, testing, and launch [4]. For this reason, aluminum 7075 with yield strength of 505 MPa is selected for the main structural material. Moreover, the Falcon 9 launch vehicle environment is used as a primary reference and determines the small satellite during the launch environment. In order to study the structural analysis, loads of subsystems and payload are applied and the results of the static load and dynamic loads are performed using Finite Element Analysis to ensure that the main structure can withstand during the launch environment period.

## 2. Methodology

This paper focuses on the static and dynamic loads analysis of two structure design layouts for the TSC-1 micro-satellite using Solidwork software. The scheme of method setup can be written as the following steps. Firstly, CAD of horizontal and modular layouts is prepared. Secondly, to obtain the optimal performance of the FEA model, mesh generation and convergent experiments are proposed. Finally, the simulation of two structure design layouts is established and the comparison result of two designs is determined.

### *2.1. Geometric Model*

The geometric models of the TSC-1 microsatellite structure are created. The designed layouts of horizontal and modular are selected to study and compare the results of static analysis and dynamic loads analysis. The size of two designed layouts is set as 730 $mm$×700 $mm$×600 $mm$ as showed in the Figure 1.



(**a**) (**b**)

**Figure 1.** Illustration of the TSC-1 structural models. (a) Horizontal layout; (b) Modular layout.

### *2.2. Mesh Generation*

According to the geometry of the TSC-1 satellite's structure, the curvature-based mesh is applied. In order to verify the independence of meshing for the simulation results, the mesh convergent experiment is conducted by setting maximum and minimum mesh size [5]. The effects of stress and displacement are a plot to define the convergence as shown in Figure 2. Therefore, to reduce the computation time, the optimal mesh type and maximum mesh size are obtained.

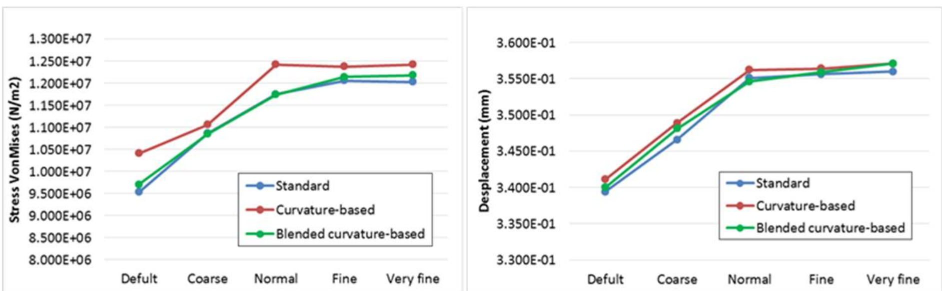



**Figure 2.** The mesh convergent experiment.

## 3. Result and Discussion

### *3.1. Static Analysis*

The comparison of the static analysis of horizontal and modular layout is showed in the Figure 3. The result shows that the maximum Von-Mises stress of two designed layouts is 59.512 $MPa$ and 13.631 $MPa$ near the spacer axis of second tray and at the bottom screw respectively which does not exceed material properties or failure values of the yield strengths of aluminum 7075. The displacement values are observed at the center of second tray and an upper section with 1.437 $mm$ and 0.5789 $mm$ respectively. The results show that the material used for the satellite's main structure is able to withstand under the static load.

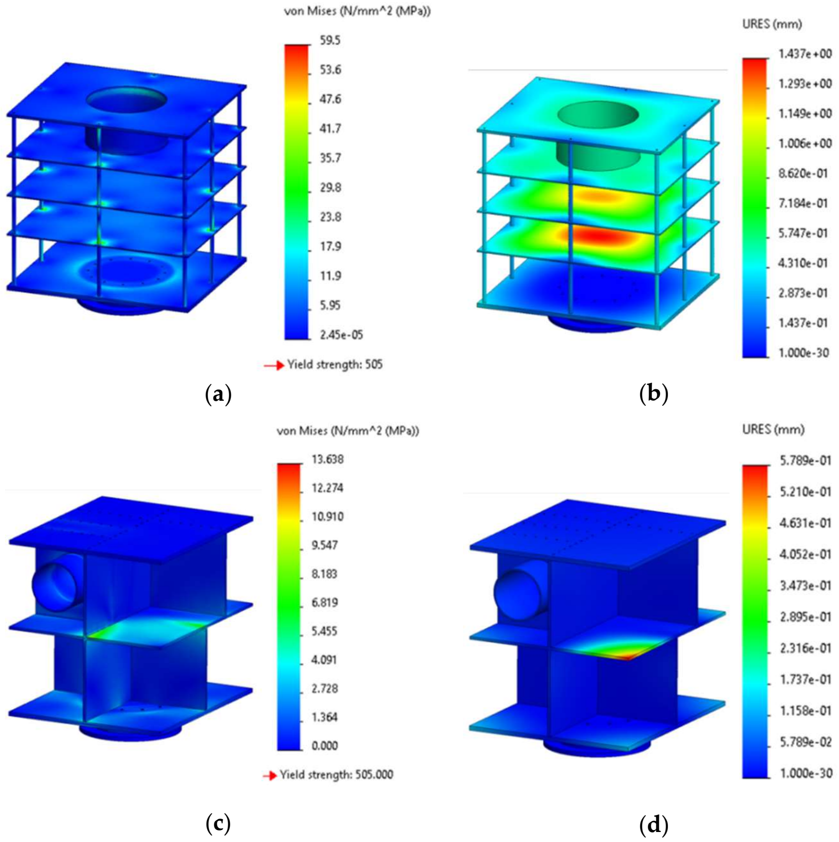



**Figure 3.** Illustration of the static analysis of horizontal layout and Modular layout. (a) Von-Mises stress for horizontal layout (MPa); (b) Displacement for horizontal; (c) Von-Mises stress for modular layout; (d) Displacement for modular layout

### *3.2. Modal Analysis*

The modal analysis is used to study the natural frequency and prevent the resonance with launch vehicle dynamics. Taking Falcon 9 launch vehicle environment as a primary reference, the structural design should maintain a minimum fundamental frequency above 35 $Hz$ [6]. Figure 4 shows the comparison of 12 modes for modal analysis with range between 0-350 $Hz$. The results show that the horizontal design has resonance in modes 1, 2, and 3, leading to the failure of the satellite structure. However, the modular design performs an acceptable result with all values are higher than the limit of launch vehicle requirement.

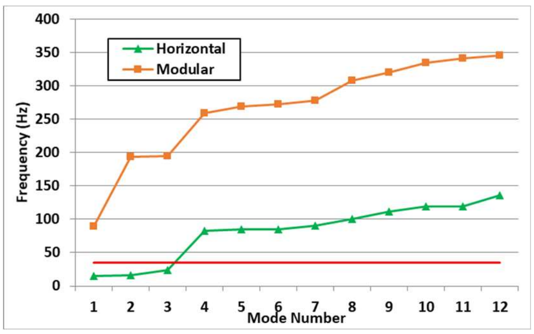



**Figure 4.** The comparison of 12 modes for modal analysis.

*3.3. Random Vibration Analysis*

Random vibration is used to study the response of structures due to non-deterministic loads. The loads are provided by the launcher requirement and are described statistically by power spectral densities (PSD) in $g^2/Hz$. The simulation is performed on the three axes. The result of horizontal layout shows that the maximum Von-Mises stress value of 41.25 $MPa$ is occurred in Y-axis at the screw on the first try and the displacement is found at the center of the second tray with 0.41 mm. In the same way, the modular layout has Von-Mises stress value of 1.942 $MPa$ is occurred in Y-axis at the panel of the bottom section and the displacement is found near the panel of the payload section with 0.081 $mm$.

## 4. Conclusion

The structural analysis of two design layouts consist of horizontal layout and modular layout for TSC-1 satellite is constructed using Finite Element Analysis. From static and random vibration analyses, the Von-Mises stress of both designs is satisfied and can withstand under the static load. However, the high value occurs to the horizontal design more than the modular design is discovered. The natural frequency of the horizontal layout has resonance in modes 1, 2, and 3, leading to the failure of the satellite structure. In contrast, the modular layout's result is higher than that of the limit of launch vehicle requirement. It can be concluded that the design of modular layout has satisfying results of static load and the vibration are acceptable and not critical to the satellite's main structure.

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