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Structural Response and Thickness Sensitivity Analysis of a Dual-Panel CubeSat Solar Array under Different Incident Flow Angles in Low Earth Orbit

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Abstract. This study investigates the structural response of a dual-panel CubeSat solar array under different deployment angles in low Earth orbit. Deployable solar arrays are critical components for CubeSats and must maintain sufficient structural integrity under rarefied aerodynamic loading conditions. A simplified three-dimensional model is developed in SolidWorks, and finite element analysis is carried out using ANSYS Mechanical. The aerodynamic load at approximately 400 km altitude is simplified as an equivalent static pressure, and five deployment angles together with four panel thickness values are considered in a parametric study. The structural performance is evaluated in terms of von Mises stress. The results show that the deployment angle has a significant influence on structural response, with the fully deployed configuration identified as the most critical case. In addition, increasing panel thickness effectively improves structural stiffness and reduces deformation and stress. The findings provide preliminary design guidance for CubeSat solar array structures in low Earth orbit.

Keywords: CubeSat, Dual-Panel Solar Array, Structural Response, Angle of Attack, Equivalent Static Load

1. Introduction

Low Earth orbit (LEO) has become one of the most practical operating regions for CubeSats, largely because missions can be launched at relatively low cost while still supporting a wide range of applications, including communications, Earth observation, and scientific research. As CubeSat missions become more ambitious, however, their power requirements and intended lifetimes are also increasing. Body-mounted solar cells are often no longer sufficient, which makes deployable solar arrays an increasingly important part of the onboard power system. The drawback is that these arrays must remain thin and lightweight. As a result, even the weak aerodynamic forces present in the rarefied LEO environment may cause panel deformation or localized stress, particularly near hinges and attachment points.

A considerable amount of research has already examined CubeSat structures, deployable solar-panel arrangements, and finite element modeling under idealized loading conditions. Aerodynamic and environmental effects in LEO have also been discussed in several studies. Even so, one issue

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has received relatively little attention: the way deployment angle and panel thickness jointly affect the structural behavior of dual-panel solar arrays when aerodynamic loading is treated as quasi-static. These parameters deserve closer examination because they affect the solar array in different ways. Changing the deployment angle changes how the panel is positioned relative to the incoming flow, whereas increasing the panel thickness primarily improves its stiffness and therefore changes the resulting stress and deformation.

Based on this, a 3U CubeSat equipped with a two-panel deployable solar array was selected for the study. A simplified 3D model was created in SolidWorks and analyzed in ANSYS Mechanical. Rather than simulating the full rarefied-flow environment in LEO, the aerodynamic load was represented by an equivalent static pressure applied to the exposed panel surfaces. Five deployment angles and four panel thicknesses were considered. The resulting stress and deformation were compared to identify the most demanding configuration, examine the influence of panel thickness, and provide practical guidance for CubeSat solar-array design in LEO.

2. Numerical modeling, aerodynamic loading, and structural response analysis

2.1. Geometric model, material properties, and thickness design

A 3U CubeSat with two deployable solar panels was simplified. From Fig.1 we can see the spacecraft is composed of mainly three parts: a core satellite bus and two solar array wings. The simplification leaves aside irrelevant details but keeps those necessary for judging how the panels react when hit by air resistance.

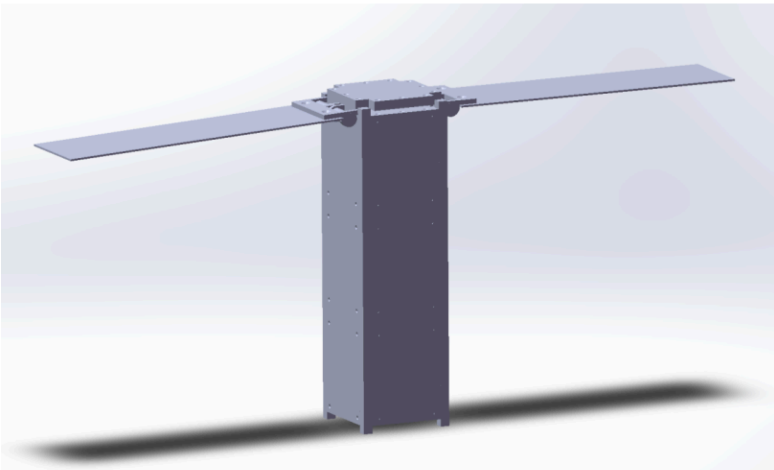

Figure 1. Model of 3U CubeSat

The satellite bus was represented by a 3U rectangular body measuring 100 mm × 100 mm × 330 mm [1]. Two solar panels, each 320 mm × 10 mm × 2 mm [1], were attached symmetrically to its sides to represent a typical CubeSat solar array. The panel connections were simplified as hinges [2], since modeling the individual hinge components would add unnecessary computational cost. Each panel root was therefore defined as a revolute joint, allowing rotation about the hinge axis while still transferring loads to the bus. In Figure 1, the 90° position corresponds to the fully deployed state. Friction and backlash were ignored.

The materials were selected with strength, mass, thermal stability, and suitability for space use in mind. Aluminum 6061-T6 was used for the satellite bus because it offers good specific strength and thermal stability and is widely used in spacecraft structures [3]. The assigned density, elastic

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modulus, and yield strength were 2700 kg/m³, 69 GPa, and 276 MPa, respectively. FR4 was chosen for the panels, with a density of 1850 kg/m³, an elastic modulus of 22 GPa, and a tensile strength of 150 MPa. Since FR4 is lighter and less stiff than aluminum, it is suitable for studying thickness-dependent deformation under aerodynamic pressure [2]. This material combination also reflects the transfer of loads from flexible panels to a relatively rigid satellite bus [4].

Panel thickness affects stiffness, mass distribution, stress, and deformation. Although 1.6 mm is often used in CubeSat designs as a practical balance between manufacturability and rigidity [5], four thicknesses were considered in this study: 1.0, 1.5, 2.0, and 2.5 mm. Each panel was modeled as a single FR4 plate without reinforcement or additional material layers [6]. In this way, the effect of thickness on the panel's structural response could be examined more directly.

2.2. Incident flow load estimation, equivalent static loading, and numerical setup

The analysis is based on a representative LEO environment similar to the ISS orbit, at an altitude of about 420 km. Although the atmosphere is extremely thin at this height, the resulting aerodynamic force on the deployed solar panels is still considered. An orbital velocity of 7.67 km/s and a drag coefficient Cd of 2.2 are used [7]. Atmospheric density is taken from the NRLMSISE-00 model [8] as approximately 5×10^{-12} kg/m³. The aerodynamic load is then calculated from the dynamic-pressure equation:

The calculated load is applied as a constant equivalent static pressure. Because the atmospheric density is extremely low, fluid–structure interaction, transient loading, and rarefied-gas effects are not included in the analysis.

The solar-panel deployment angles are set to 0°, 22.5°, 45°, 67.5°, and 90°, covering conditions from nearly aligned with the flow to fully exposed to it.

A 6 mm global mesh is used for the CubeSat body, while the solar panels are meshed more finely with a 3 mm element size. Additional refinement is introduced around the hinges and panel roots, where stress concentrations are expected.

The panel–bus connection is represented by a rigid hinge, with the hinge base fully constrained to ensure that the applied load is transferred completely to the satellite structure.

The aerodynamic pressure of 3.23×10^{-4} Pa is applied uniformly on the upper surface opposite to the orbital velocity direction.

2.3. Structural response under different working conditions

2.3.1. Effect of deployment angle

Figures 2 and 3 show the variation of maximum von Mises stress with deployment angle for a 2 mm panel thickness. The results indicate a monotonic increase in stress with increasing angle. At 0°, the stress is 0.323 Pa, corresponding to the stowed configuration with minimal projected area.

As the deployment angle increases, both the projected area and bending moment at the root increase, resulting in higher aerodynamic loading. The stress rises from 11.227 Pa at 22.5° to 28.543 Pa at 90°, showing a nonlinear trend with a stronger increase at lower angles.

The maximum stress is consistently located at the root near the hinge due to the cantilever-like configuration. The fully deployed state (90°) is therefore identified as the critical condition.

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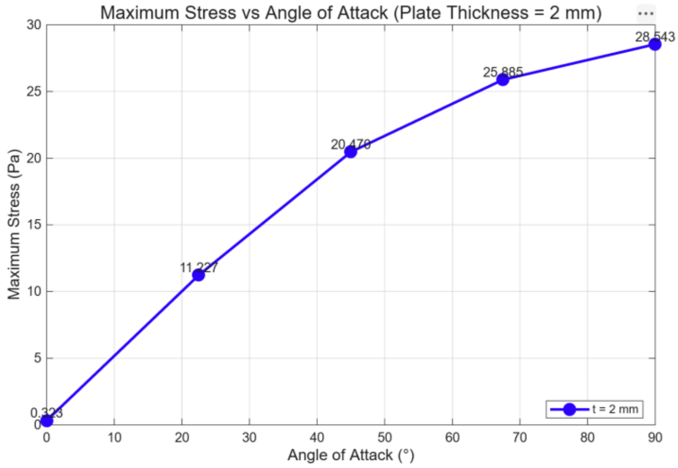

Figure 2. Stress variation with deployment angle (t = 2 mm)

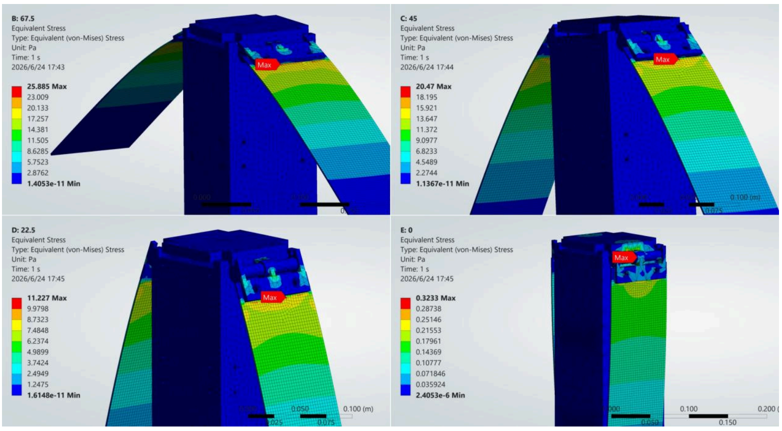

Figure 3. Simulation results for different angles of attack

2.3.2. Effect of panel thickness

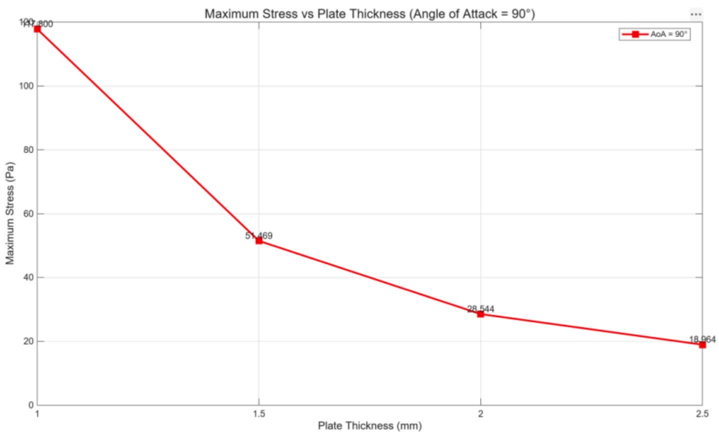

Figure 4. Stress variation with panel thickness (AoA = 90°)

Figures 4 and 5 show the thickness effect under the 90° deployment case. The results indicate that stress decreases significantly with increasing thickness, from 117.8 Pa at 1.0 mm to 18.964 Pa at 2.5

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mm.

A sharp reduction occurs between 1.0 mm and 1.5 mm, while further increases show progressively smaller improvements. This indicates a clear nonlinear dependence and diminishing return behavior.

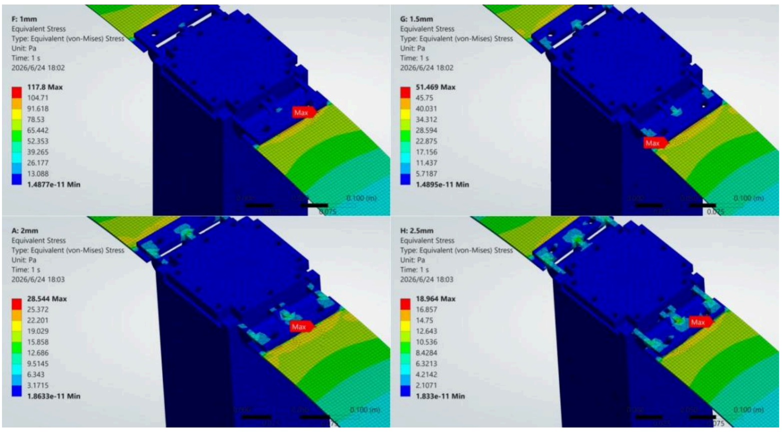

Figure 5. Simulation results of different thicknesses

2.4. Discussion

2.4.1. Effect of incident angle on structural response

The results show that von Mises stress increases monotonically with deployment angle, mainly due to the increase in projected area and the corresponding growth of bending moment at the hinge.

At low angles (0°–22.5°), the panel is nearly aligned with the flow, resulting in minimal aerodynamic loading and low stress. As the angle increases, both the projected area and the moment arm increase, leading to higher aerodynamic force and amplified bending at the root.

The fully deployed configuration (90°) is the critical case, where the load acts perpendicular to the panel and is fully converted into bending stress at the hinge, producing the maximum von Mises stress. Therefore, 90° is identified as the governing design condition.

2.4.2. Effect of panel thickness and structural improvement index

The influence of panel thickness shows a clear nonlinear trend. Increasing thickness reduces von Mises stress, but the improvement gradually decreases with further increases.

At 90° deployment, the stress decreases from 117.8 Pa at 1.0 mm to 51.469 Pa at 1.5 mm, then to 28.544 Pa at 2.0 mm, and finally to 18.964 Pa at 2.5 mm. This indicates a strong stiffness improvement at low thickness values.

The most significant reduction occurs between 1.0 mm and 1.5 mm, while further increases provide diminishing benefits. This behavior reflects classical plate bending behavior, where stiffness increases rapidly with thickness at small values but gradually saturates.

2.4.3. Limitations of the present model

Several simplifications were adopted to enable the parametric study. First, the aerodynamic load was represented as a steady equivalent static pressure based on a simplified dynamic pressure model, neglecting rarefied gas effects, transient fluctuations, and fluid–structure interaction. Second, the

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structure was assumed to behave in a linear elastic regime, and large deformation effects were neglected due to the low loading level. In practice, deployment dynamics and attitude variations may introduce additional nonlinear behavior. Third, a uniform pressure distribution was assumed on the panel surface, without considering local or attitude-dependent variations. Therefore, the results should be regarded as a first-order structural assessment rather than a fully coupled aeroelastic analysis.

3. Conclusion

This study investigated the structural response of a dual-panel CubeSat solar array under different deployment angles and panel thicknesses in a low Earth orbit environment. The aerodynamic loading was represented as an equivalent static pressure based on an ISS-like orbit at 420 km altitude, enabling a parametric finite element analysis.

The results show that the deployment angle has a significant influence on structural response. Von Mises stress increases monotonically with angle due to the increasing projected area and bending moment at the hinge region. The fully deployed configuration (90°) is identified as the most critical case, with maximum stress occurring at the root region.

The results indicate that thicker panels are stiffer and experience lower stress and deformation. However, the additional benefit gradually decreases as thickness increases. Based on the results, a thickness of 1.5–2.0 mm offers a practical balance between structural safety and mass, which is also in line with common CubeSat design practice.

There are several limitations to this study. Aerodynamic loading was represented by a constant equivalent pressure, so rarefied-flow effects, transient disturbances, and fluid–structure interaction were not included. The model also assumes linear elastic behavior and does not consider nonlinear deployment dynamics. Future work could use more advanced approaches, including DSMC or FSI, and combine numerical analysis with experimental testing to improve the reliability of the predictions.

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