DEVELOPMENT OF A DEPLOYABLE 3U CUBESAT SOLAR PANEL ARRAY

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ABSTRACT

The primary goal of this project is to design, fabricate, and test a deployable solar array for a 3U CubeSat. The deployable mechanisms will adhere to the design restrictions of the standardized 3U CubeSat. The mechanisms will consider the capabilities of the Attitude Determination and Control System (ADCS) to ensure a smooth deployment. A crucial aspect of this project is based on the material selection and design to ensure safe operating throughout the life of the CubeSat. To achieve an effective design, structural analysis methods was applied in addition to failure criteria methods.

The design process was broken down into three main phases: Parameter definition, Design Concept, Design Analysis. Parameter Definition provides data and background research defining the parameter constraints. By defining all the working parameters an effective design envelope can be established so the mechanism does not interfere with other subsystems. The Design Concept, outlines the deployment design and the how the constraints were taken into consideration. The Design Analysis section provides data on the static analysis using finite element analysis.

The final hinge mechanism meets all design requirements with a safety factor greater than 2.5. From the integration to the structure to the deployment angle, the panel deployment system has been designed to meet a wide range space missions. The resulting design provides an efficient product that attaches to a 3U CubeSat with the ultimate goal of increasing power generation.

INTRODUCTION

CubeSats have eased the way for space accessibility and payload development. The primary goal of this project is to design, fabricate, and test a deployable solar array for a 3U CubeSat. Increasing the power generation capabilities of the CubeSat will help to provide on future missions. This project will provide a product that increases the potential of the 3U CubeSat through a more effective means of solar collection.

CubeSats are a class of pico-satellites typically deployed into low Earth orbit. The primary advantages of CubeSats are the low cost, standard infrastructure and quick launch capabilities.

CubeSats make space accessible to a larger audience that originally could not participate. Payload variance and development increases when platforms are easily available and cost
effective. Systems that previously required mating to a piggyback satellite have the option to utilize the CubeSat standard as the structure.

Standardization of the CubeSat makes it possible to create a highly flexible bus that serves as a multi-purpose testing platform. Through the use of CubeSats, academic institutions, the private industry, and government entities can test preliminary payloads to determine space worthiness. Standardization also enables quick exchange of payload modules, ease of interchangeability and lower cost due to volume production.

As microprocessors and computing technology continue to shrink in size, the power requirements for components remain steady. More data processing can therefore be done onboard prior to data transmission. Payload and data transmission capabilities are also limited if power generation is insufficient. Deployable Solar panels increases the capacity of power generation. Orientating the panels to face perpendicular to the sun significantly increases output power from the solar cells. By increasing the power generation on a CubeSat can increase its potential. Consequently, the power capacity of a CubeSat is as important as ever for a given CubeSat.

In the realm of satellites, solar panels are often the sole source of power generation. Expanded capacity of power generation significantly increases the capabilities of a CubeSat bus. Processing power, data transmission, and data collection potential are all dependent on the power capacity. With an increased power generation capacity, missions have the potential to accomplish more.

**METHODS**

**Background Research**

Background research was first conducted to ensure sufficient understanding of the project. The research explored existing panel deployment systems, deployment configurations and defined the deployment parameters for this project. The proposed deployment system shall be in accordance with CubeSat standards. CubeSats are strictly by Cubesat Design Specifications published by California Polylethnic State University [1].

Deployment angle and configuration varies one spacecraft to another depending on the power capacity required, orbit orientation, and payload. While deployment systems are available commercially, they are often custom systems and therefore expensive. They can also be difficult to integrate onto a generic off the shelf CubeSat because of the specialized mounting brackets.

With a better understanding of the design problem, the parameters and requirements of the project were then established. This included defining mass and volume budgets, and the deployment configuration. Figure 1 illustrates the physical dimensions required of 3U CanSats.
Since the panel deployment configuration can vary from mission to mission, the deployment system will be designed to be versatile. This is accomplished by sizing the mechanism to fit along the short side of the CubeSat, while being deployable on all four sides. The hinge can be adapted to fit either face by changing the torsion spring. For the purposes of this project, the system will accommodate a deployment angle of 90 degrees.

Due to the possibility of jitter disturbing other subsystems or the payload, the design shall attempt to avoid introducing excessive jitter into the spacecraft. A complete understanding of what is expected of a deployment system and how it’s integrated onto the bus is crucial to the success of the system and the overall success of the mission.

**Conceptual Design**

The Conceptual Design process began with brainstorming ideas and researching current designs that would satisfy all parameter requirements. Despite the wide variety of commercially available deployment systems, I was unable to find or configure one that fit the requirements for this project. Faced with designing a custom deployable, it took many attempts before a design emerged that fit all parameters.

There are many deployable systems that were reviewed. A rubric was created to list all the attributes and design features the deployable must meet. Some of the main attributes the deployment mechanism must have was light weight, low profile, simple movement and versatility. A versatile deployment design was priority for this project. A versatile design encompasses ease to adapt the system to various structure types, configurable deployment angles, and ease of integration.

A spring loaded hinge design satisfied the majority of the attributes. A hinge was chosen because of its simplicity, low profile, light weight, and versatility. The simple movement of a hinge eliminates the need for gears, linkages, or any complex motion. This design features a low profile and incorporates a custom torsion spring. The spring characteristics, including spring constant, are determined by the weight of the solar panel, weight of the hinge, and the torsion required keeping the panel stable when fully deployed.

A unique feature of this design allows for the parametric adjustment of the hinge geometry and spring configuration for the final deployment angle. The configuration shown
above deploys the array to a final angle of 90 degrees as defined by the project requirements. The material selected for the hinge is 6061 Aluminum. Aluminum is a durable material that has a high strength to weight ratio. This alloy is commonly used and machinable, making it ideal for use in prototyping.

The other half of the array system is the release mechanism. The release mechanism is responsible for deploying the array from the initial launch configuration and is currently in the draft preliminary design phase. The current concept involves monofilament fishing line and nichrome wire. The panel will be secured in the launch phase using the fishing line. When the panel needs to be deployed, a current will be applied to the nichrome wire, causing it to heat up and cut through the fishing line. This releases the hinge-spring mechanism, effectively deploying the panel array. This type of release mechanism has been previously used in other CubeSats for a variety of deployables.

**Design Analysis**

Currently, static finite element analysis (FEA) is being employed to evaluate the design. FEA is a numerical method of evaluating how a component will react to loads and stresses. The FEA simulation tools packaged with SolidWorks are being used in this analysis.

Loading conditions for the solar panel were based off of the weight and dimensions for COTS 3U solar panels manufactured by Clyde Space (part number SP-L-S3U0016-CS) [2]. Additional factors considered in the analysis include the hinge material and torsion forces from the spring.

Figure 1 shows the stress gradient of the hinge at the final deployment angle. As shown, the greatest load would be on the material surrounding the contact faces of the hinge, thus creating the largest stress concentration. This is expected because it is where the torsion force
from the spring is applied. The maximum local stress is 97.9 MPa. The typical yield strength of 6061 aluminum is 276 MPa giving the component a safety factor greater than 2.5.

The material and thickness of the inner hinge is partially driven by the required fastener size and thread type that secures the panel to the hinge. The hinge must be thick enough to ensure that a sufficient number of threads are engaged. Fastener selection is in turn, driven by the required pullout load for the screw. However, thickness also affects the spring specification and overall profile. The material must not be too thick and overdesigned. The correct balance between the hinge thickness and the screw is essential for a reliable design. Highlighted in Figure 3 are the combinations that will satisfy the required loading and material thickness.

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<th>Diameter(mm)</th>
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<th>Pitch</th>
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Figure 3: #2-56 Screw and hinge thickness matrix. The shaded region highlights the material with sufficient pull-out strength that will allow for the stripping of the screw rather than the hinge material.

\[
A_{th} = 0.33 \times p \times d_p \times L_e \quad [1]
\]

\(A_{th}\) = shear area of threads

\(L_e\) = Thread Engagement

\(p\) = Pitch

\(n\) = Threads per unit length

\(D_n\) = Nominal shank diameter

\(D_p\) = Pitch diameter
Increasing the thread engagement of the screw allows for a larger shear area thus increasing the pull-out strength. Referencing Figure 3 and the estimated loading based on the Clyde panels a minimum thread engagement of 2 mm is required with a #2-56 UNC fastener. Analysis shows that three #2-56 UNC fasteners will be sufficient for a 2 mm thick inner hinge.

The panel release mechanism uses nichrome burn wire and monofilament fishing line to deploy the panels. Nichrome wire is a reliable, non-mechanical method of releasing deployments. Nichrome wire is a tested space standard for small scale deployments. The nichrome wire is placed across the fishing line, providing a slight contact stress for thermal conductivity. When a current is applied to the nichrome it heats up burning trough the fishing line triggering the deployment. The advantages of using a burn wire for deployment eliminates the possibility of a
freeze up of a mechanical moving part such as a motor or a spring loaded mechanism. Nichrome wire heats up quickly and effectively. Additional analysis of current draw must be researched to ensure proper integration to the satellite’s electrical system. Optimal sizing must be taken into consideration as well. The wire must be thick enough to be mechanically strong, but thin enough to reduce current draw. The most reliable method of fastening nichrome is through mechanical crimps. For these connections vibration and strength testing will need to be conducted.

CONCLUSION

This report provides the design for a panel deployment system, encompassing the deployment hinge and burn wire release mechanism. The final design meets all the design parameters required of a 3U CubeSat in accordance with the CubeSat Design Specifications [1]. Major attributes taken into consideration include: stand-off height, light weight, simple mechanical motion and adjustable deployment angles Static testing shows the design exceeds the loading conditions with a safety factor of 2.5. Additional work still needs to be done to continue the detailed analysis of the hinge under dynamic loading.

ACKNOWLEDGEMENTS

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REFERENCES

