

Abstract

Compliance in mechanics refers to a purposeful lack of stiffness. Large satellites such as the International Space Station employ compliant elements that bend to stow and deploy their solar arrays for the reduction of size and mass that it allows (among other benefits). While compliance provides advantages during stowage and deployment of systems, stiffness is often still required during operation. Mechanisms that stiffen compliant components typically add significant mass to the system, which can outweigh the benefits for small satellites. To overcome this issue, a lightweight, low-profile stiffening mechanism is proposed for application on the compliant deployable solar arrays of three 1U cube satellites, Binar 2, 3, and 4. The proposed stiffening mechanism is embedded in the solar array and increases the second moment of area of the array in the deployment direction. Shape memory alloy hinges are employed for actuation. The system is designed for deployment from the ISS and is expected to be launched in 2023.

Binar 2, 3, 4 Compliant Deployable Solar Array

Each deployable solar array of the Binar Space Program’s upcoming 1U CubeSats (Binar 1, 2, and 3) are a single rigid-flex PCB. The deployment is facilitated by the flexible regions of the PCB, which constitute the compliant hinges. The deployment of the hinges is initially prevented by a burn-wire system and is actuated by joule heating the Nickel-Titanium Shape Memory Alloy (SMA) strips.

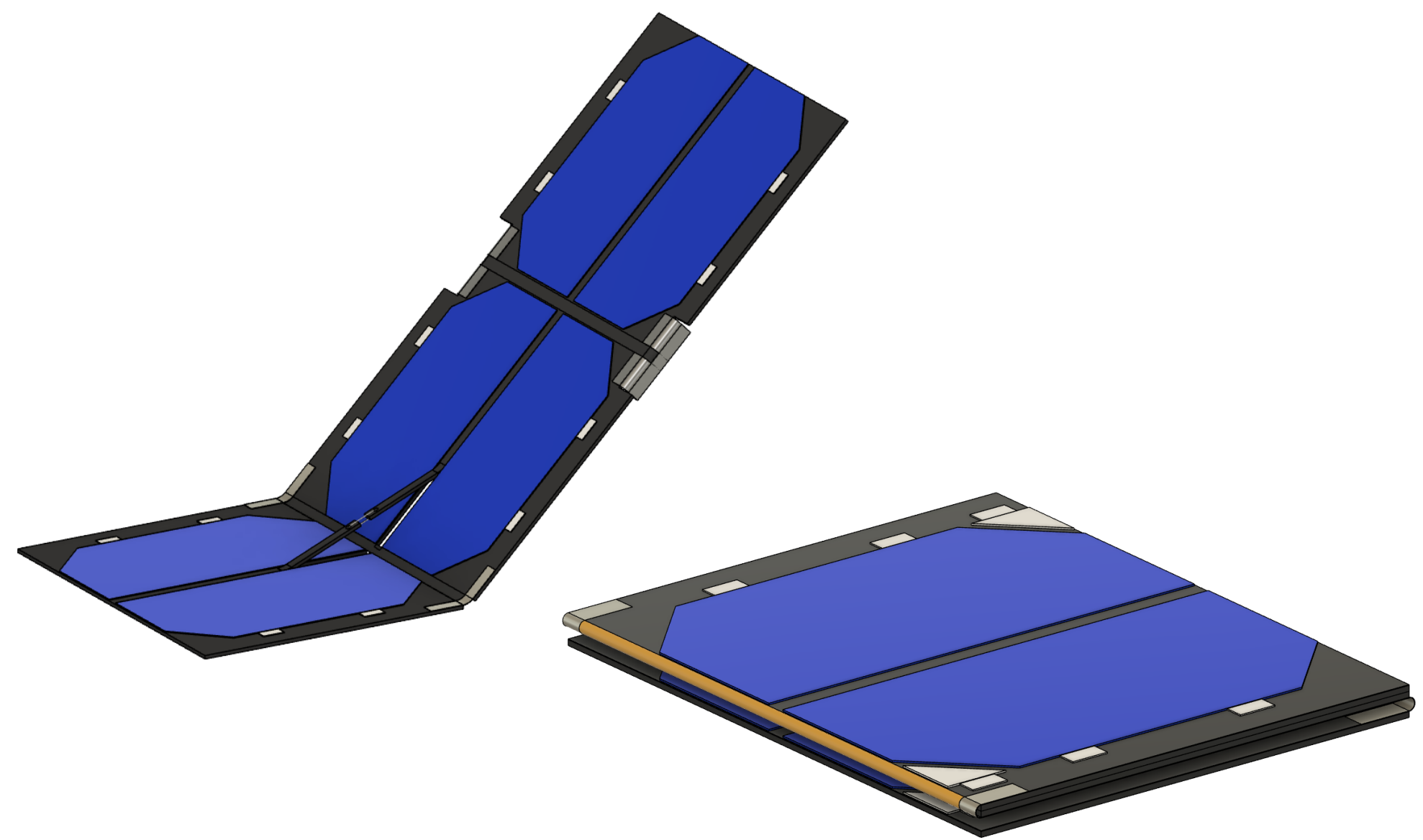


Figure 1: Binar Compliant Deployable Solar Arrays Deployed (left) and Stowed (right)

For adequate power generation, a maximum hinge deflection of 10° was targeted. Due to the strict SWaP constraints of the CubeSat formfactor a light-weight, low profile stiffening mechanism for the linear hinges is proposed to achieve this.

Stiffening Mechanism – Deployable L-Beam

In order to stiffen a hinge that is required to remain in a linear configuration, a deployable L-beam is proposed.

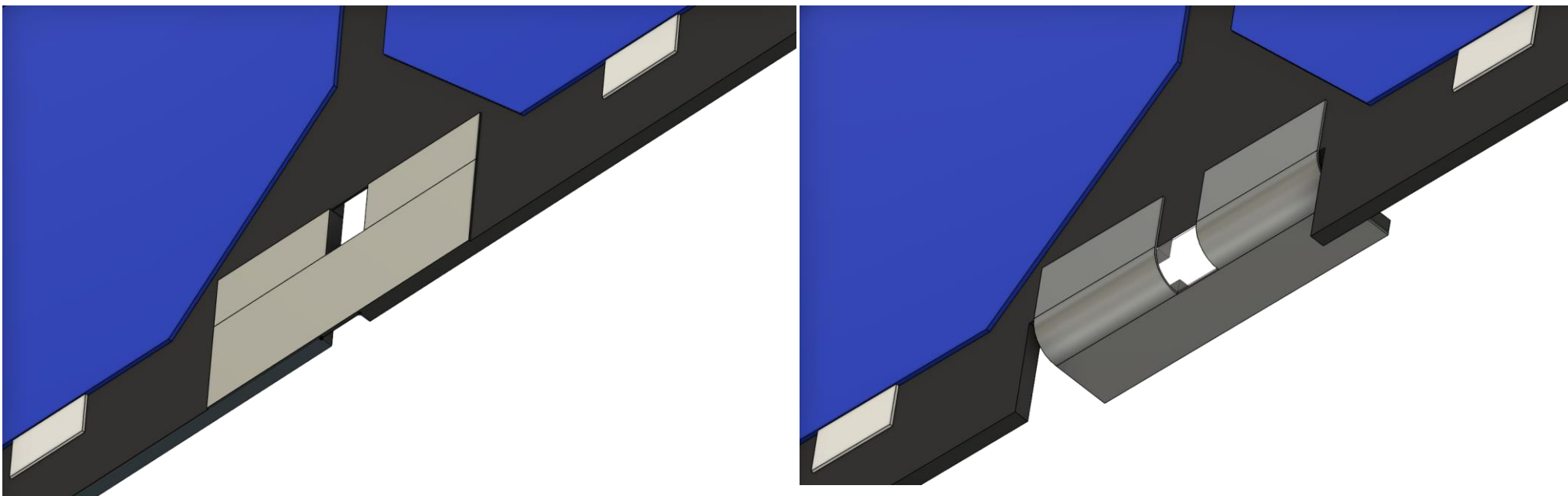


Figure 2: Deployable L-Beam Concept

This L-beam is actuated by similar shape-memory alloy hinges as the panel deployment mechanism, with the SMA trained into a 90° deflection configuration. This leverages the already existing shape-memory alloy heating system embedded into the compliant deployable solar array. Mechanically, stiffening is achieved by increasing the second-moment of area of the hinge by a factor of up to 2100. This mechanism also acts to enforce a 180° deployment angle at the hinge.

Compliant Array Stiffness

The primary performance indicator of this concept is its ability to reduce deflection at the compliant hinge. To demonstrate this ability, large deflection analysis was performed on the hinge, comparing a flex-PCB hinge and the L-beam stiffening mechanism under an expected 0.5N thrust.

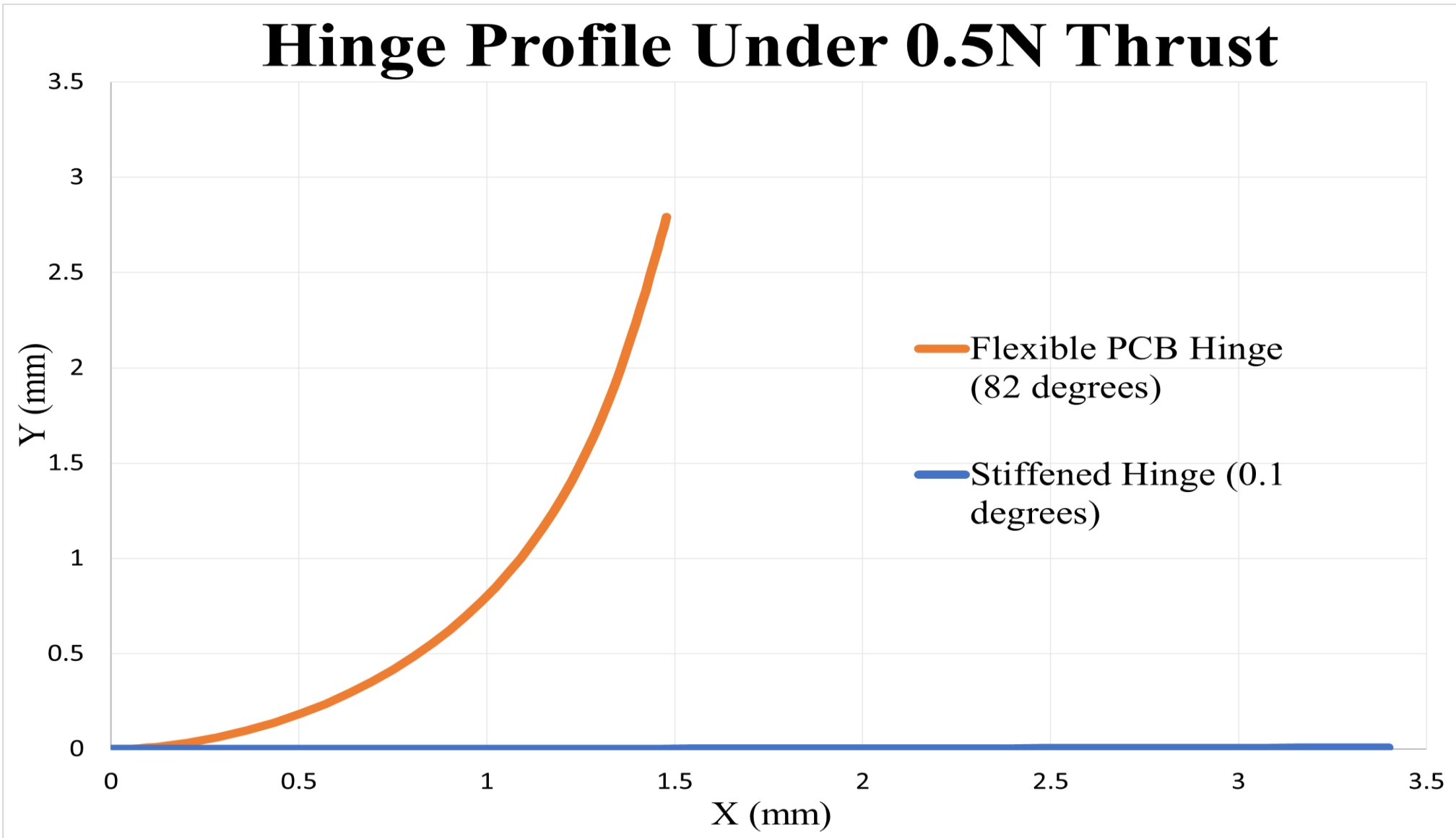


Figure 3: Hinge Profile Under 0.5N Thrust

As can be seen, the stiffening mechanism dramatically reduces deflection at the hinge, preventing the reduction in solar power collected as well as potential damage. Investigating the force required to deflect the panels by 10°, it was found that the unstiffened hinge required 0.02N, where the stiffened hinge required 31N to exceed the targeted maximum.

Key Parameters

The other key parameters are the increase in mass and volume as a result of the stiffening mechanism. For this concept to be successful, they must be light and have a low z-height. Other parameters of interest are the EPS requirements and increase in cost. These are presented in Table 1.

Table 1: Marginal Increase in key parameters over the Binar 2,3,4 Compliant Deployable Solar Array

Parameter	Increase per Panel
Z-Height	127 μ m
Mass	600 mg
EPS Requirement	800 μ Ah at 8.4 V *
Cost	\$20 (AUD)

*Calculated based on single deployment at 253K and Af of 318K

Applications

Vibration Reduction: The significantly higher stiffness and negligible increase in mass can be leveraged to raise the natural frequency and reduce the vibrational amplitude of other flexible components.

Differential Drag: As demonstrated in Figure 3, this design is able to withstand forces sufficient to alter the attitude and altitude of a 1U CubeSat. Longer chains of solar arrays and a stowage mechanism could be combined to facilitate attitude or re-entry control.

Compliant Manipulator: The inherent benefits of compliance make such mechanisms applicable to manipulators. This deployable L-beam can be directly translated for application on compliant manipulators. This would similarly overcome the issues associated with the size and weight of typical stiffening mechanisms.

Future Work

Reconfiguration: The current design of the solar array and stiffening mechanism allows for a single deployment. Reconfiguration of the L-beam to alter the stiffness as desired will have a wide range of applications.

Angled Hinge Stiffener: The hinge adjacent to the satellite is deployed at 135°. This stiffening mechanism is not applicable for such a hinge and so an alternate must be investigated. Preliminary investigation is being done into an embedded stop, as can be see in Figure 1 (left).

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