

Solar Panel Deployment Mechanism for Nano-Satellite



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Abstract A new solar panel deployment mechanism for nano-satellites is developed and successfully deployed on-orbit with an objective of achieving modularity and optimization in terms of mass and volume. The modular hinge mechanism simplifies ground testing and can be operated in Earth's gravity, thereby eliminating the need for gravity compensation system for solar panel deployment. The miniature hinge is configured without locking linkages and holds the panel by ensuring positive spring torque at the end of deployment. Similar existing miniature hinge mechanisms either lack indication switch or use fragile elements like tape springs. Hinge design presented in the paper addresses all such limitations. After hold down release, panel rotates by 90° , hits the stopper bracket of the hinge and rebounds. The panel oscillates few times before eventually settling down in the deployed state. Deployment dynamics of the solar panel is modeled in a multi-body dynamics tool, MSC ADAMS and analyzed to evaluate settling time. It is important to evaluate settling time as it governs the timeline of the sequence of mission critical events to be executed by satellite's on board computer. The peak angular velocity of the satellite during deployment is evaluated using the developed dynamics model. The evaluated peak reaction body rates and deployment settling time are compared with the actual on-orbit observations for the nano-satellite.

Keywords Solar panel · Deployment · Dynamics · On-orbit and hinge mechanism

1 Introduction

Solar panels are the primary source of power generation for the satellite. The configuration of the solar panel is governed by satellite configuration and power requirements. Panels are stowed during launch to meet the launch vehicle constraints and

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stiffness requirements. On reaching the intended orbit, the panels are deployed into their final deployed configuration.

The panels are held in stowed condition using a hold-down mechanism, which resists the launch loads. Spring driven hinges are employed to drive the panels after hold-down release. Conventionally, the hinges are positively locked after the panel reaches deployed orientation. Due to extremely small size and mass constraints, the miniaturized hinges for nano-satellite are not designed with lock mechanism.

This paper presents the configuration of the new hinges, with higher spring torques for deployed stiffness and for deployment tests under Earth's gravity conditions. It also studies the deployment behavior of solar panel in absence of an active locking mechanism, and evaluates the impact of the solar panel deployment dynamics on the nano-satellite. The hold-down mechanism is under patent and is not addressed in this paper.

2 Literature Survey and Option Studies

Solar panels for nano-satellites have been employed in body-mounted [1] and deployable [2] configurations. The concept of extendible solar arrays for nano-satellite has also been explored [3]. In addition, work is being carried out on origami based solar array deployment concepts [4].

For deployable solar panels, a variety of hinges have been developed for Nanosat/CubeSat class of satellites ranging from torsion spring based to tape spring based hinges with or without locking provisions. Hodoyoshi Project [5] of Japan employed helical spring for deployment and locking. Single spring was used for deployment and engaging of the latch for locking. Xatcobeo mission [6] used torsion spring based single hinge for the deployment and flat spring for latching of the hinges at the end of deployment. Tape spring based single component hinges with self-locking capabilities as proposed in [7] are an optimized solution. The work in [8] discussed the deployment analysis of tape spring hinge in detail. The deployment hinges of Kufasat [9] and IMT 3U [10] incorporate torsion spring based hinges. The hinges after deployment butt against the hard stopper without latching. In [11], the work presented the verification of solar panel deployment in microgravity conditions in parabolic flight path.

Hinges for Hodoyoshi Project and Xatcobeo mission deployed multiple panels in a single array and used latch mechanism which invariably introduces friction. The main disadvantage of tape springs is that they are prone to cracking due to mishandling as they are made up of thin sheet metals. Hinges for Kufasat lacked inbuilt deployment indication switches. Absence of a single optimized solution resulted in the design of a new hinge and deployment mechanism.

Most fundamental requirement for the mechanism for nano-satellites is the optimization of mass. Moreover, in order to make the overall testing proposal simple, hinges are required to be designed to deploy under Earth's gravity (1 g) condition. This requires increased hinge torque and thus improves the deployed stiffness of

the panel and allows the elimination of a dedicated latch mechanism resulting in a compact mechanism. Considered options for the hinge mechanism are shown in Fig. 1.

A miniaturized hinge using plain journal bearing as shown in option C is implemented which is deployed using a torsion spring. After deployment by 90° , the fork-end bracket butts against the stopper on eye-end bracket. The deployment indication is obtained by making use of a leaf switch wherein electrical contact is established when the outboard bracket touches both the live and return indication leaves.

3 Solar Panel Deployment Mechanism

The nano-satellite consists of two deployable solar panels mounted on two opposite decks of the satellite. The panels are held in stowed condition by a hold-down mechanism. After hold-down release, spring driven hinge mechanism rotates the panel about the hinge axis. The panel rotates by 90° , hits the stopper bracket on the hinge and rebounds. The panel oscillates a few times before eventually settling down in the deployed state. Positive spring torque by the deployment torsion springs holds the panel in the deployed state against folding back. The stowed and deployed view is shown in Fig. 2.

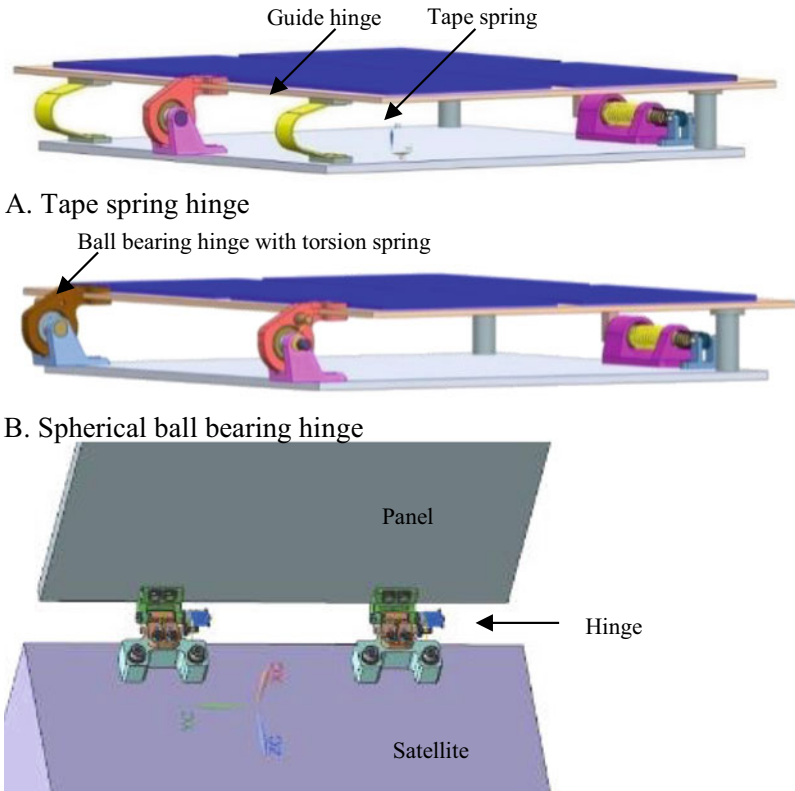
Two configurations of solar panels, as listed in Table 1, are analyzed and details are presented in Sect. 4.

4 Multi-Body Dynamics Analysis

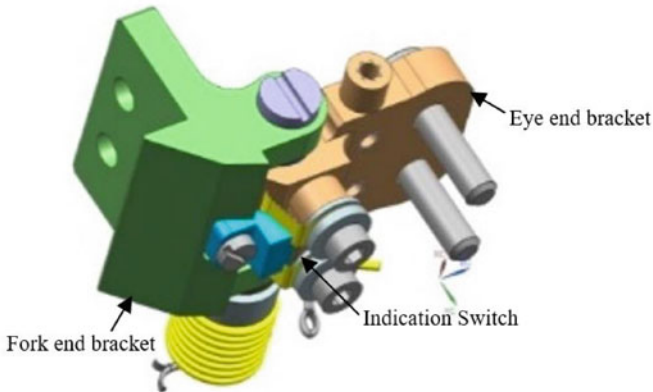
4.1 Settling Time Analysis for Single Panel

Time history for the panel oscillations to die-down is evaluated for configurations 1 and 2, for both ground and on-orbit deployment simulations. Analysis is carried out by developing the multi-body dynamics model in MSC ADAMS. Measured hardware characteristics viz., mass, inertia, torsion spring characteristics, dissipative forces etc. are modelled. Effects of 1 g forces are considered for ground deployment simulation. Contact is simulated at the hinge stopper interface to represent the physical behavior. Contact stiffness is derived using finite element analysis whereas the damping coefficient for the contact is obtained from the ground test results.

Results. Time taken for the panel to settle in the deployed state is presented in Fig. 3 for on-orbit scenario. The actuation of hold-down initiates at $t = 0$ s and hold-down release is assumed to occur nominally at $t = 1$ s. It can be observed that deploying solar panel touches the mechanical stopper at 90° of deployment, bounces back and forth several times and finally settles down in intended deployed condition. The time for ground deployment is more as the hinge friction due to self-weight of



C-1: Configuration of plain journal bearing hinge



C-2: Detailed design of plain journal bearing hinge

Fig. 1 Options considered for hinge design

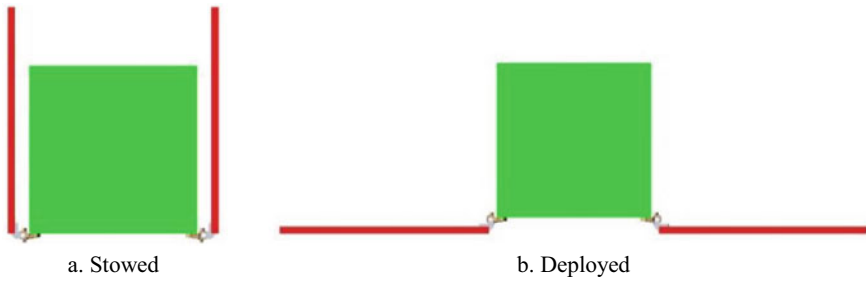


Fig. 2 Stowed and deployed view of nano-satellite solar panels

Table 1 Two configurations of solar panels

Configuration	Solar panel		
	Dimensions	Mass	Inertia (about hinge)
1	250 × 235 × 20 mm	250 g	0.6E-2 kgm ²
2	335 × 250 × 20 mm	399 g	1.4E-2 kgm ²

the panel influences the ground deployment. The results for both ground and on-orbit deployment are summarized in Table 2.

It is observed that the number of oscillations, corresponding time period and the final settling time for config-2 solar panel is higher when compared to config-1. This

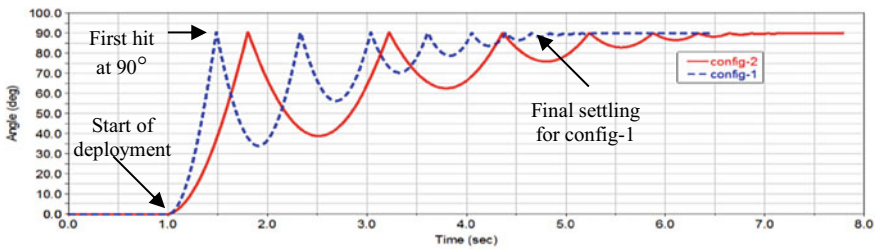


Fig. 3 Deployment angle (degree) versus time (s) for on-orbit deployment simulation

Table 2 Time line of events

S. No	Event	Ground time (s)		On-orbit time (s)	
		Config1	Config2	Config1	Config2
1	First hit at 90°	1.48	1.84	1.47	1.80
2	Final settling at 90°	4.0	5.2	4.8	6.7

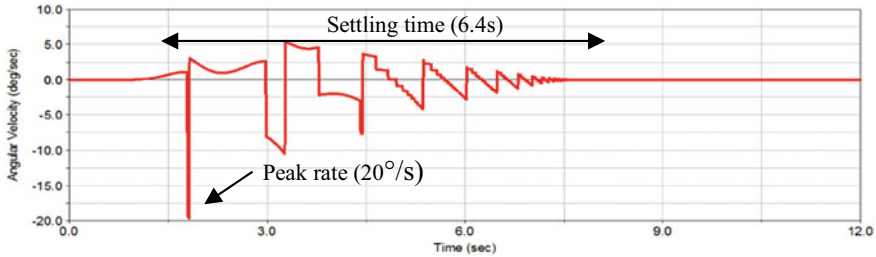


Fig. 4 Nano-satellite angular velocity during deployments—Analysis

is attributed to the fact that config-2 has a higher mass moment of inertia, resulting in lower frequency and hence longer time period of oscillation.

The hinge brackets are also analyzed for the latch-up loads due to deployment and it is observed that stress margin exists over yield strength of the bracket.

4.2 Spacecraft Body Rates During Deployment

Multi-body dynamics model of the nano-satellite along with both the solar panels is developed in MSC ADAMS and analysis is carried out for measured hardware parameters including the overall mass and inertia of the spacecraft. The simultaneous deployment of both solar panels is carried out which induces reaction rates on the nano-satellite. The rates induced on the spacecraft and the time taken by the rates to settle down are evaluated.

Results. The nano-satellite angular velocity (body rate) about the axis parallel to hinge axis of solar panel is presented in Fig. 4. A peak rate of nearly $20^\circ/\text{s}$ is observed with a settling time of 6.4 s.

4.3 On-Orbit Deployment Observations

The analysis results are compared with on-orbit performance data obtained through spacecraft telemetry. The actual body rates observed during on-orbit deployment of the solar panels are presented in Fig. 5. It is observed that the peak body rate change of nearly $14^\circ/\text{s}$ is observed with a settling time of nearly 5.6 s. The status indication changes of both solar panels from ‘stowed’ to ‘deployed’ is also presented. The comparison between analysis prediction and on-orbit observation is shown in Table 3.

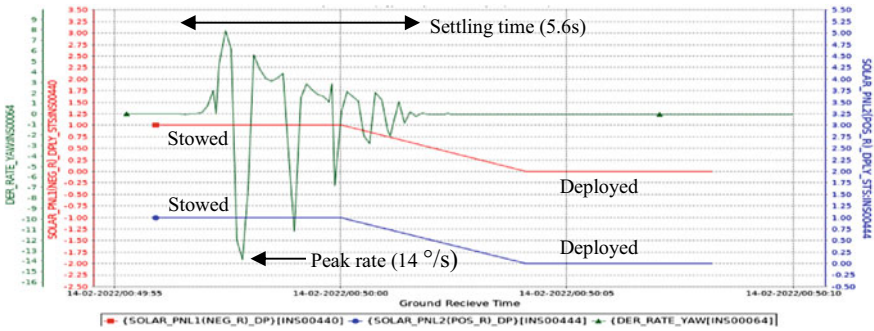


Fig. 5 Nano-satellite angular velocity during deployments—On-Orbit observations

Table 3 Comparison of analysis predictions and on-orbit observations

	Peak rate	Settling time
Analysis prediction	20°/s	6.4 s
On-orbit observation	14°/s	5.6 s

5 Conclusions

A compact hinge mechanism for solar panel deployment is developed to meet the mass and size constraints for nano-satellite. The miniature hinge is configured without an active lock mechanism. Torsion spring is designed to ensure margins for deployment in Earth’s gravity.

Behavior of deploying panels in absence of an active lock at hinge is analyzed together with its impact on the nano-satellite. Two configurations of the panel with different sizes are considered. It is observed that the config-2 panel takes 1.9 s longer to settle down after deployment due to its higher inertia and lower frequency. This calls for a longer monitoring time for deployment event by the on board computer (OBC). It implies that after deployment initiation, OBC must wait before other critical spacecraft events are executed. Even though the settling time increases, the clear advantage of using a bigger panel is the increased area for solar cells and hence more power for the satellite. The config-2 panel is implemented for the nano-satellite.

During the on-orbit deployment, both panels are commanded to deploy simultaneously. For this scenario, analysis results predict a peak body rate change of 20°/s and a total settling time of 6.4 s. Actual on-orbit observations indicate a peak rate of 14°/s and settling time of 5.6 s. The observed settling time is in good agreement with the analysis prediction. However, as the rate build up is very fast, the existing on-orbit data sampling rate may not be fine enough to capture the actual peak and this contributes to the observed difference in predicted and observed rate. The overall trend of the satellite body rate observed on-orbit also compares well with the analysis prediction as shown in Figs. 4 and 5.

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