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# Advanced Deployable/Retractable Solar Panel System for Satellite Applications

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***Abstract*—**Modern low earth orbit (LEO) satellites that require multi-mission flexibility are highly likely to be repositioned between different operational orbits. While executing this process the satellite may experience high levels of vibration and environmental hazards, exposing the deployed solar panel to dangerous stress levels, fatigue and space debris, hence it is desirable to retract the solar array before satellite repositioning to avoid damage or failure.

A novel concept of deployable/retractable hybrid solar array system composed of both rigid and flexible solar panels arranged within a petal formation, aimed to provide a greater power to volume ratio while dramatically reducing mass and cost is proposed.

***Keywords*—**Deployable Solar Panel, Satellite, Retractable Solar Panel, Hybrid Solar Panel.

## I. INTRODUCTION

OVER the last four decades satellite solar array systems have evolved from body-mounted panels supplying a total power output of less than 1 watt, to a multi-panel deployable system supplying a total power output of over 75kW [1]. The constant demand of satellite power growth has been driven by the evolution of technology, culture, and science. Furthermore due to the diverse range of satellite missions and environments, a large variety of rigid and flexible solar array configurations, and deployment mechanisms have been designed and employed on previous and current satellites [1].

Taking advantage of the new lightweight technology in solar panels [2], a mechanical system composed of both rigid and flexible solar panels arranged within a petal formation is proposed to yield a stowed to deployment area ratio up to at least 1:7, which improves the power density dramatically.

The system consists of five subsystems, the outer ones based on a novel eight-petal configuration that provides a large surface and supports the flexible solar panels. A single cable and spool based hinge mechanism was designed to synchronously deploy/retract the panels in a safe, simple and efficient manner, while the mass compared to the previous systems is considerably reduced. The system was designed, simulated and tested using the CAD package Solidworks [3], and a half system prototype was fabricated.

The relevant challenge to assure a smooth movement is resolved by a proper minimization of the gearing system, optimization of the resistive inertial loads and the use of a micro-controller system.

## II. DESIGN DESCRIPTION

The present design status outlines the requirements, geometry and operation of the solar panel's structural platform and deployment/retraction mechanism. The main design specification is:

- Lightweight, strong, reliable and durable
- Stowed to deployed area better that 6:1
- Protect the solar panel by any damage when stowed
- Use of material space qualified
- Endure high stress and fatigue
- Low power, low mass and energy efficient.

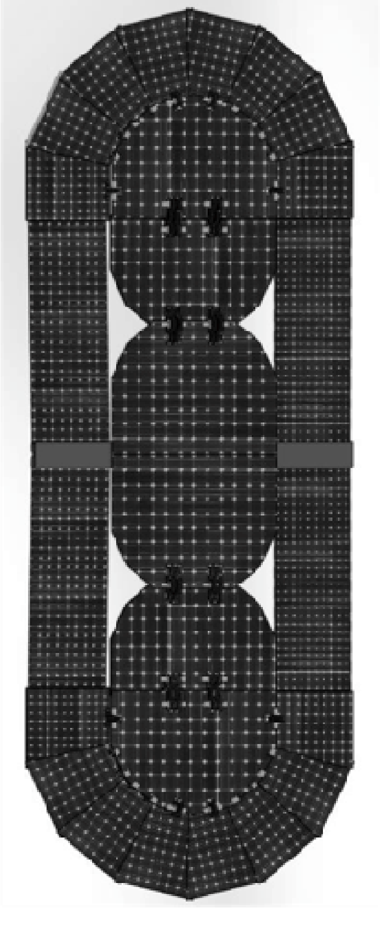

Fig. 1 Fully Deployed Configuration

The overall configuration of the deployed solar panel system is illustrated in Fig. 1. It is notable the wide area obtained with combining the rigid and the flexible solar panels.

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### *A. Structural Platform*

A purposely designed solar array structural platform is required to create a secure and reliable framework, providing strength, protection and mounting points for the relevant solar cells and subsystems. Furthermore, the structural platform determines the stowed and deployed panel architecture. It is crucial the mechanism travels between the deployment and the stowed status.

Rigid panel solar arrays are most commonly made from a lightweight aluminium honeycomb core, which are hinged together and deployed via a pulley based system or a pantograph structure. Considering high efficiency multi junction solar cells (MJ), rigid platforms have the advantage of a high areal power density (W/m2). On the other hand, the disadvantages include a high specific mass (kg/m2), high specific cost ($/W) and a low specific power (W/ kg). These characteristics are desirable for when a low power supply is required. Due to the high areal power density a compact solar array can be designed allowing for a decrease in deployment volume, weight and cost [1], [4]-[20].

Flexible planar arrays are most commonly made from a lightweight composite structure consisting of graphite fiber reinforced plastic (GFRP), which is either rolled or folded out via a series of rigid deployable booms. Flexible planar arrays film platforms have the advantage of a low specific cost ($/W), low specific mass (kg/m2) and a high specific power (W/ kg). On the other hand, the system has a lower power density (W/m2) than rigid systems; hence a larger panel area is required. These characteristics are extremely desirable for high power supply applications, where the reduced mass of the solar blanket outweighs the heavy deployment mechanisms. Due to the thinness and flexibility of the solar cells the array can be folded into a compact volume for launch [1], [21]-[41].

Fig. 2 compares the various component masses upon the rigid and flexible structural platform systems. Rigid structural platforms generally have a much heavier solar panel substrate and overall system mass than flexible arrays. However, flexible planar solar arrays require a heavier deployment mechanism [42]-[69].

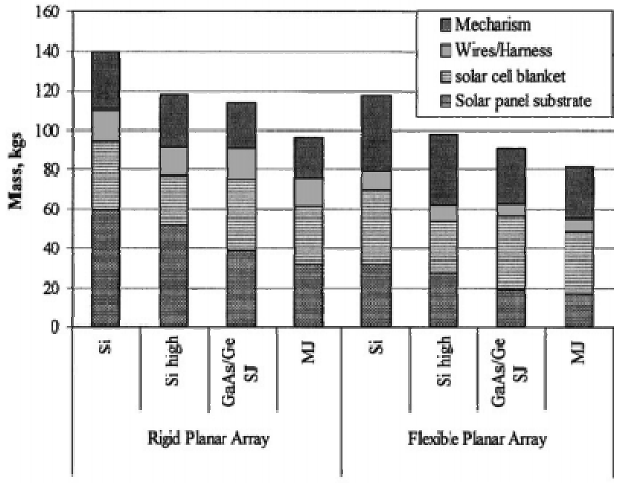

Fig. 2 Primary Structural Platform Retraction Sequence [1]

Once flexible solar cells reach a higher efficiency, and greater progress is made into lighter deployment mechanisms, flexible solar arrays will dominate the satellite solar array market. However, a more current solution would incorporate a hybrid design, combining the advantages of the rigid array's structural integrity as well as the flexible array's compact stowage volumes and lower mass [70], [71].

In Fig. 3 it is shown the aperture mechanism with the details the novel deployable/retractable structural platform. It incorporates both rigid and flexible panels arranged within three distinct sections to form an efficient, effective and reliable lightweight solar panel structure that proposes to increase the power density dramatically. The architecture of the system is mirrored around the centre axis of panel 1 and the deployment/retraction of each side is could be independent or synchronized with the other section.

The primary structural platform consists of panels 1, 2 and 3, which could be made with a corrosive resistant, lightweight aluminium honeycomb sheet with a carbon fibre shell [72], [73]. The panels are hinged adjacently to neighbouring panels and follow a concertina style deployment/retraction sequence [73], which consequently constructs the backbone of the complete solar panel system. The bottom of panel 1 is mounted to the satellite and upon retraction panel 2 folds flush upon the topside of panel 1, and panel 3 folds flush upon the underside of panel 2, as shown in Fig. 2.

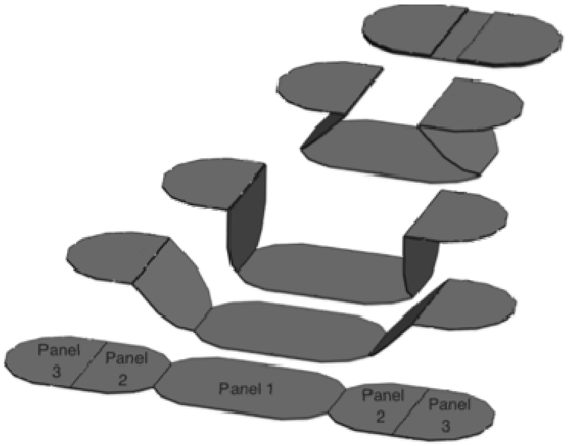

Fig. 2 Primary Structural Platform Retraction Sequence

The secondary structural platform contains an array of eight smaller 'petal' panels (labelled 4 and 5), which are hinged upon panel 3 in an overlapping circular staircase pattern. Like the primary structure, the panels could be made of an aluminium honeycomb sheet with a carbon fibre shell. Upon retraction the petals of panel 4 push and slide over the top of each other, retracting as a unit until flush against the topside of panel 3, as shown in Fig. 3. The sequence of folding clearly demonstrates the properties of the design solution based on a petal structure.

The tertiary structural platform entails four flexible panels, which are made from a super tough, exceptionally lightweight open weave fabric called Vectran that remains very flexible within a very cold environment as in the space. The flexible panels are fixed and tensioned between the edge of panel 4 and the stowage cover. Upon retraction the flexible panels are simultaneously rolled into the flexible stowage cover as the structural platform is retracted. Table I illustrates a possible design of a very compact stowed vs. deployed structural platform.

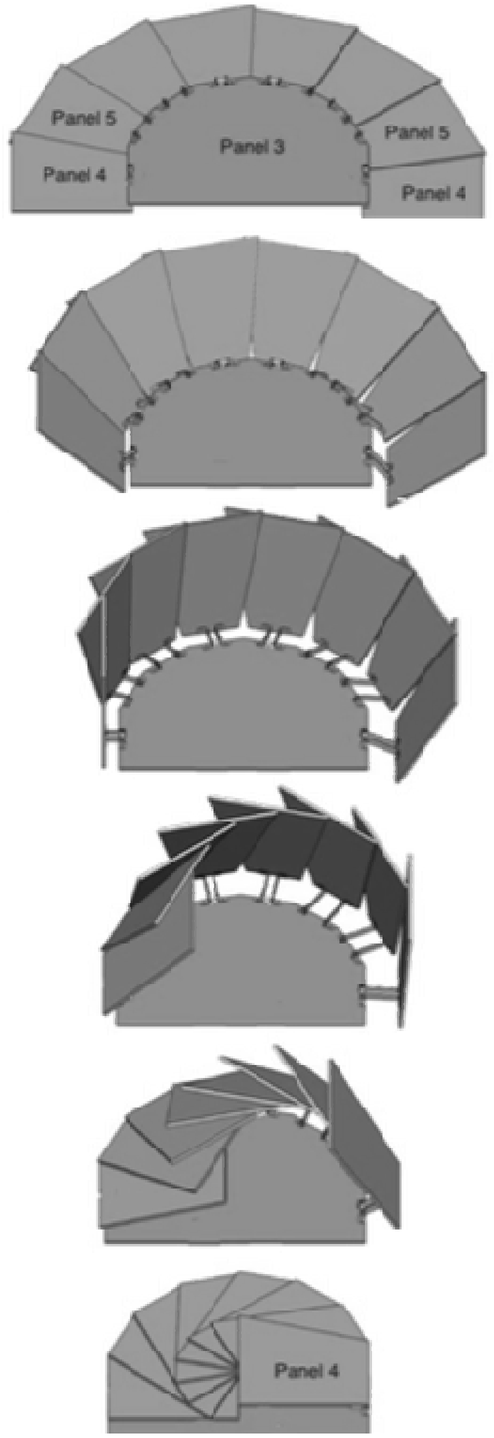

Fig. 3 Secondary Structural Platform Retraction Sequence

TABLE I
STRUCTURAL PLATFORM TEXT DESIGN

| Panel | Quantity | Total Area (m$^2$) | Mass (kg) |
|---|---|---|---|
| Panel 1 | 1 | 0.149 | 0.1043 |
| Panel 2 | 2 | 0.124 | 0.0868 |
| Panel 3 | 3 | 0.129 | 0.0903 |
| Panel 4 | 4 | 0.082 | 0.0574 |
| Panel 5 | 12 | 0.228 | 0.1596 |
| Flexible Panel | 4 | 0.263 | 0.0263 |
| Deployed Total | 26 | 0.976 | 0.5247 |
| Stowed Total | 26 | 0.149 | 0.5247 |

### *B. Deployment/ Retraction Mechanism*

A solar panel's deployment mechanism has to efficiently control and synchronize the movement of the structural platform between the stowed and deployed configuration. A simplistic, lightweight and minimalistic spool and cable based hinge mechanism, which controls both the deployment and retraction of the entire system with two cables is proposed.

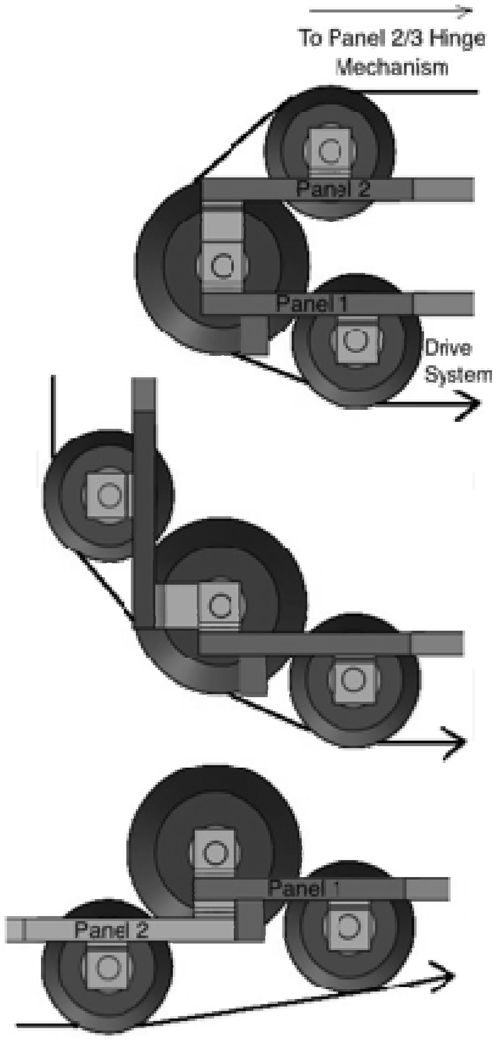

Fig. 4 Detail of the Hinge Mechanism for the Deployment Sequence

Both cables are fed through a series of spools throughout the primary and secondary structural platform. The paths taken by each cable respectively provide a clockwise or anticlockwise torque upon the hinge axel, which is dependent upon the cable tension.

Upon deployment, the deployment cable is drawn into the drive mechanism and the retraction cable is drawn out. Once the torque applied upon the hinge overcomes panel inertia and frictional forces, adjacent panels fold from the stowed to the deployed position. The retraction function is performed exactly replicating and reversing the deployment procedure. A locking block is positioned to prevent over rotation of the panels once the system is fully deployed/retracted. The cable system is driven using a lead screw mechanism. The deployment sequence is described in Fig. 4.

The order of deployment/retraction of the primary and secondary structural platform is dependent upon the inertial and frictional forces acting upon each hinge. Consequently, the hinge experiencing the lowest inertial and frictional forces will be the first to deploy/retract until restrained in the desired position by the locking block. Once locked in place, the mechanisms will deploy/retract the remaining hinges in order of resistance until the desired task is complete. Therefore, the synchronization of the system is dictated via the resistive torque forces. To prevent an unwanted catastrophic collision between the left and right side of the solar panel system, the system architecture has been carefully designed to deploy/retract the structural platform in a reliable and safe sequence. This has been achieved by optimizing the inertial loads acting upon each hinge, and introducing additional frictional forces to prevent any unwanted movement. Fig. 6 illustrates the position and operation of the deployment mechanism upon the system's structural platform.

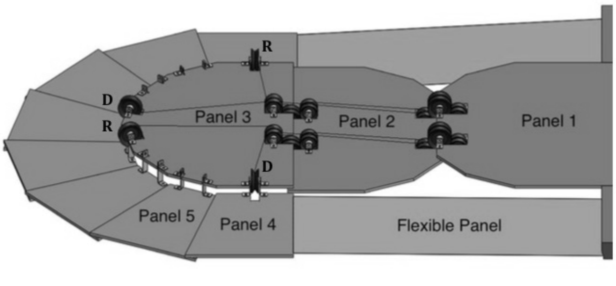

Fig. 6 Position of Hinges

Four deployment, D and retraction, R cables are necessary to efficiently and effectively control the movement of the full solar panel structural platform. The mechanisms operate simultaneously and share the load uniformly around the structural platform to prevent system damage. The deployment/retraction sequence is as follows:

- The deployment cable is drawn in and the retraction cable is drawn out. Vice versa for retraction.
- The primary structural platform deploys/retracts.
- The secondary structural platform deploys/retracts.
- Concurrently, the tertiary structural platform deploys/retracts.

## III. DRIVE MECHANISM

A motor-based drive system is required to draw and hold the deployment/retraction cables in/out in order to power, control and stabilise the solar array's deployment/retraction mechanism. A simplistic, reliable and effective lead screw mechanism is proposed.

As the motor rotates, the nut and carriage are moved along the lead screw, pulling or providing slack to either the deployment/retraction cable. A second rail parallel to the screw is used to guide the nut and carriage. When not in use, the lead screw holds the cables at their current position, therefore, locking the structural platform in place. A micro-switch is fixed to the limits at either bracket to stop the solar array from over extending/retracting. Fig. 7 illustrates the chosen design.

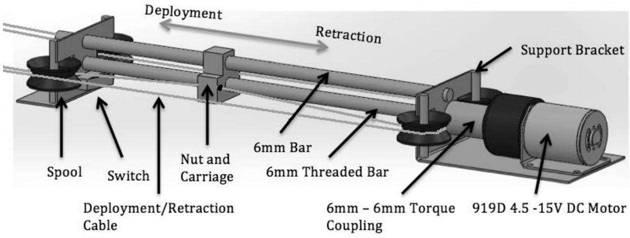

Fig. 7 Drive Mechanism

## IV. TESTING

A scaled down, half system prototype was constructed to test and analyse the performance of the primary and secondary deployment/retraction systems. The prototype was made from a combination of Correx and aluminium to mimic the real material for a full final prototype. The solar array system successfully completed full deployment and retraction throughout the testing procedure effectively and efficiently.

## V. CONCLUSION

The advanced structure of the presented solar panel system encapsulates a very high power to mass and power to volume ratio via the use of flexible solar panels, while eliminating the need for heavy and volume intensive deployment mechanisms. The simplistic lightweight spool and cable deployment/ retraction mechanism provides an effective deployment/ retraction method and further reduces the volume of the hybrid system.

The proposed system due to an effective and reliable mechanism provides a large active surface, whilst being very compact. It could be extremely advantageous for use as ground portable solar panel system.

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