Origami Solar Arrays for Small Space Systems

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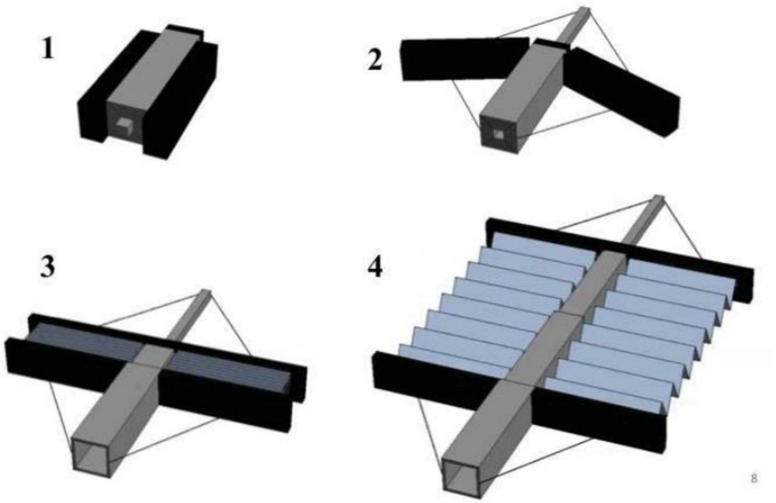
Traditional and Novel Solar Arrays

- Traditional silicon solar panels are rigid and occupy a large volume which could be used for other mission components

- Polymer based panels can be easily deployed but are susceptible to wrinkling and environmental damage

- Flexible Origami Solar Arrays can minimize both the total mass and volume of a system but are reliant upon complex mechanical systems



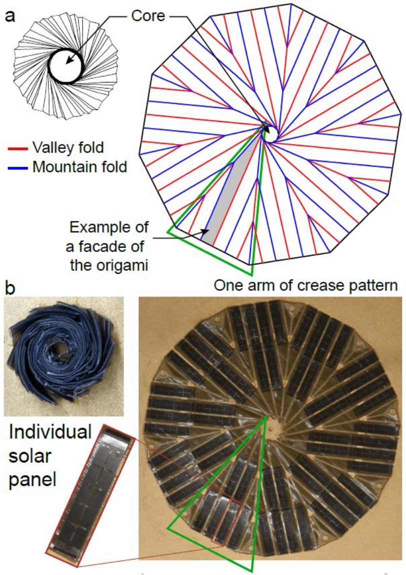
(1) Nasa, Telescoping Solar Array Concept for Achieving High Packaging Efficiency

Literature Review

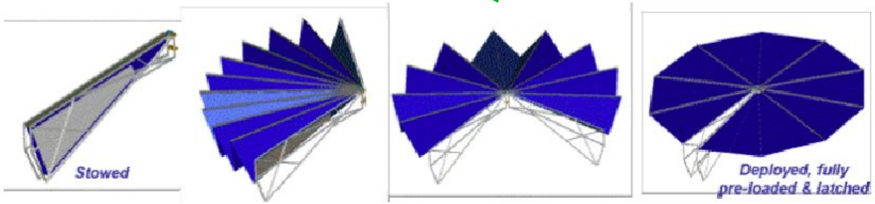
- Two new methods to deploy silicon panels are the Hannaflex and Ultraflex designs which involve collapsing panels on top of each other

- New Shape Memory Alloys and Polymers have been used to minimize mechanical and electrical equipment used to deploy these systems

- The main challenge when creating an origami system is preserving the structure of the solar panels without deformation



(3) Chen, Autonomous Deployment of a Solar Panel Using an Elastic Origami and Distributed Shape Memory Polymer Actuators



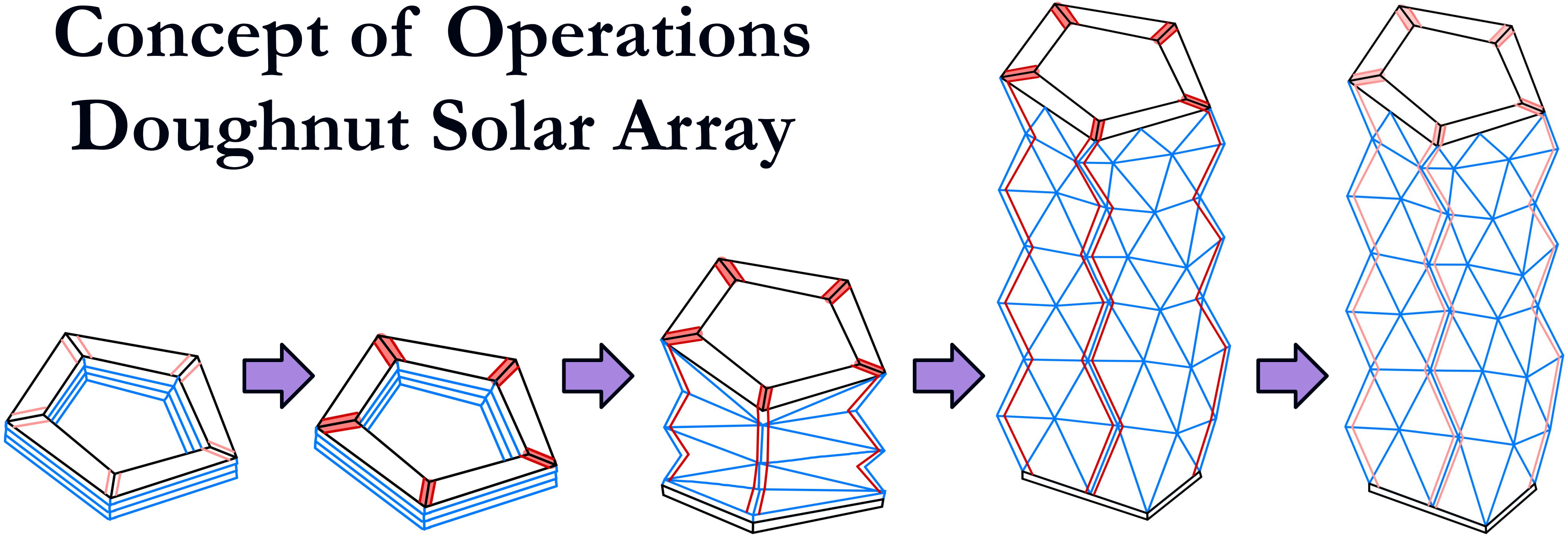
(2) Nasa, Next Generation UltraFlex Solar Array for NASA's New Millennium Program Space Technology 8

Motivation and Application

- Small scale missions require novel forms of power generation which are rigid and compact
- Miniaturized solar arrays can be utilized on lunar or interplanetary rovers as well as satellites
- A "Doughnut" shaped design can utilize both external and internal space in order to generate power

(4) Jong-Eun Suh, New Approach to Folding a Thin-Walled Yoshimura Patterned Cylinder

Concept of Operations
Doughnut Solar Array



Stowed State: Solar Array in collapsed state until surface is sunlight

Solar Array heats up copper lining to activate Shape Memory Polymer Actuators (SMPA)

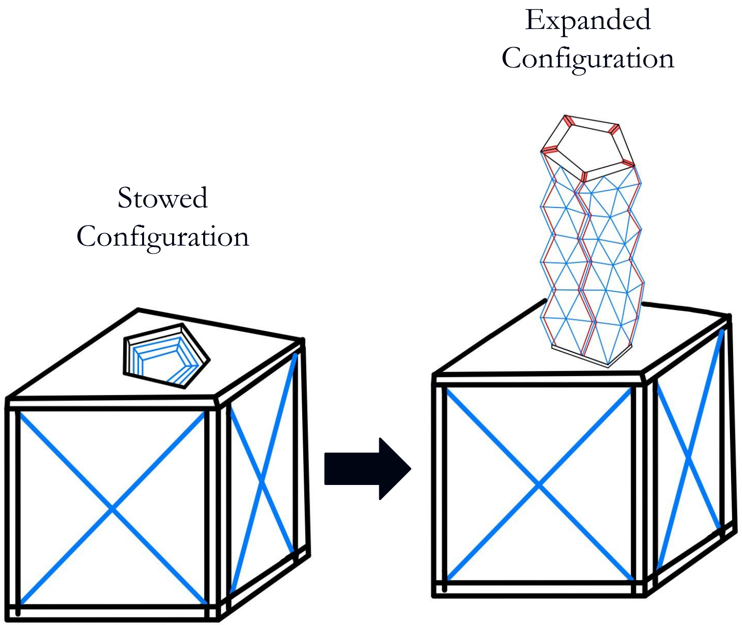
Solar Array expands using Hobberman structure and separates from pentagonal base

Solar Array's Copper lining cools down increasing rigidity

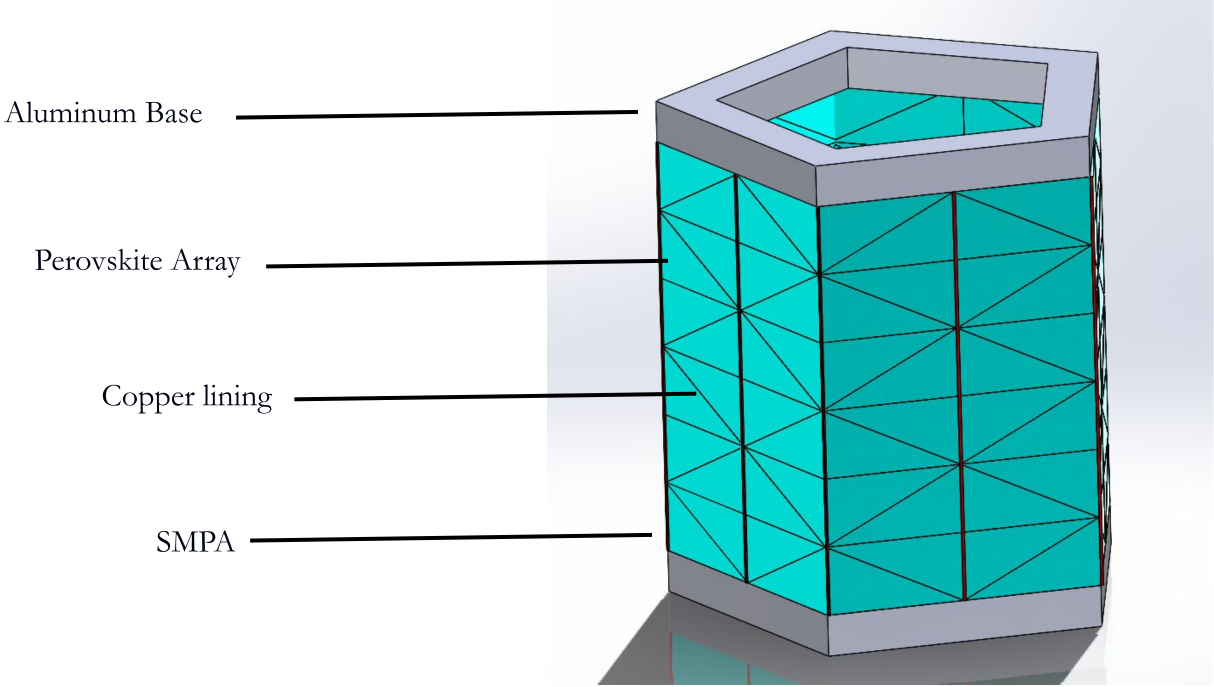
Expanded State: Solar Array generates energy utilizing external perovskite structure

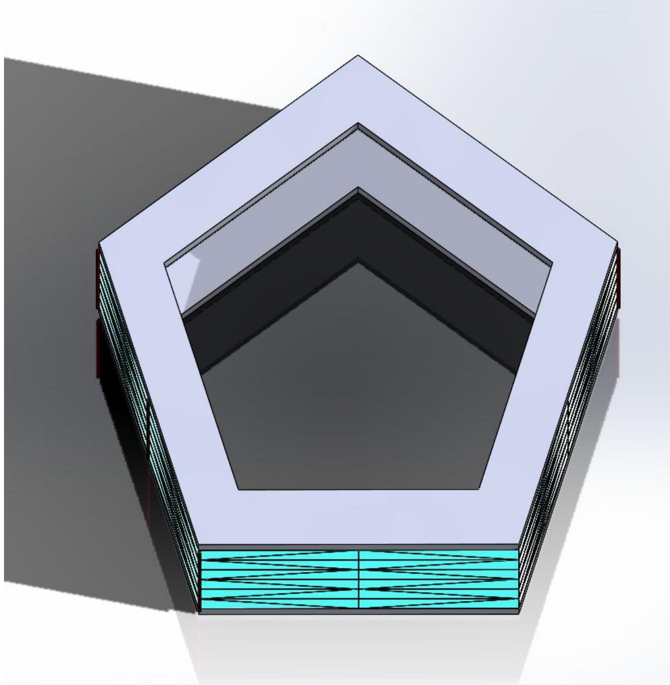
CubeSat Deployment

- The Solar Array is stored along the exterior top face of the CubeSat which extends outward utilizing Shape Memory Polymer Actuators
- Initially the panels are stowed in between two aluminum sheets with a plastic covering



System Design

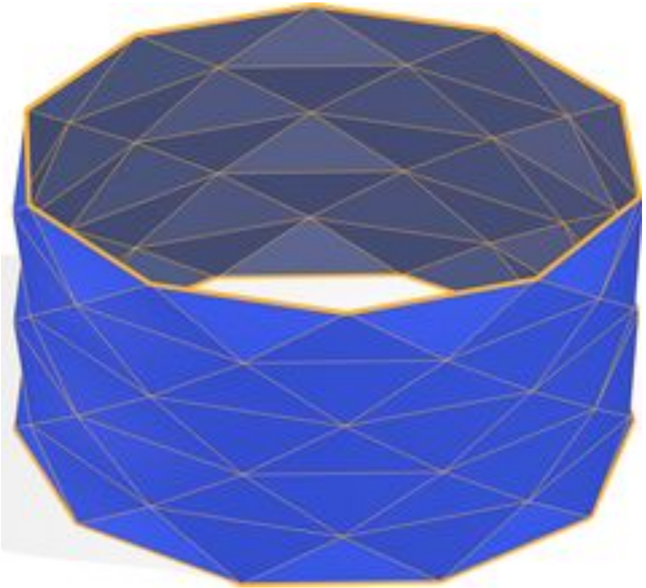




Yoshimura Pattern

- Isosceles triangles create a diamond pattern which can compress vertically while withstanding radial forces

- Each row can be contracted independently which can slightly angle the array away from the vertical



(5) Wikipedia

Deployment System Comparison

Deployment	Design(s)	Material	Benefits	Drawbacks	Weight/Density	Function	Energy Required
Shape Memory Actuators (SMA)	3U Cubesat	Nickel Titanium	Lightweight, operates between -140 to 500 C	Expensive manufacturing, precise folding	150-200g	Pin puller releases the solar array from hooks and hinges are rotated outward	18 W
Flexible Joints	Tape Springs	Copper Beryllium, Carbon Fiber	SMA compatible, inbuilt actuator, small volume	Difficult retraction, needs to be linked to a rigid structure	8.25 -8.36 g/cm^3 density, dependent on length of spring	Thin curved strips which fold elasticity and can lock into a straight position when attached to a plane	N/A
Electric Motor	Brushless DC, DC, Stepper	N/A	Large torque, precise, retractable	Large volume, complex, gears required	300-400g	Propels solar panels outward using a mechanical skeleton	5-15 W
Shape Memory Polymers	Experimental	Perovskite, AgNW/shape memory polyimide	Mechanical strength, optically transparent, extremely lightweight	Experimental, deformations, decreasing performance	0.061 g/cm3 density	Retracts into a pre folded shape once heated and expands upon cooling.	N/A

Solar Panel Comparison

	Cubesat Solar Panels (1800 μm thick) (1.8 mm)	Perovskite (1800 μm thick)	CIGS (Copper Indium Gallium Diselenide) (1800 μm thick)
Density (g/cm^3)	2.329002± (7x10^-6)	3.91	5.7
Mass (g)	50	82.8	102.8
Efficiency	30%	25%	14%
Benefits	Flight Heritage, high efficiency, inbuilt sensors	Mass of 0.046 g with a power per weight ratio of 26 W g^-1, with 2 μm thickness	Mass of~0.057 g, efficiency of 23.2% with thickness of 7.15 μm
Drawbacks	Heavy, inflexible, low absorption	Delicate, experimental, high toxicity	High manufacturing costs, experimental, abundant impurities in chemical structure

Conclusions & Future Work

- Different folding patterns can minimize deformation overtime
- The Yoshimura design can be reinforced by overlaying multiple patterns across the same sheet
- Additional Research:
  - Polymer Base
  - Structural Support
  - Architectural Characteristics

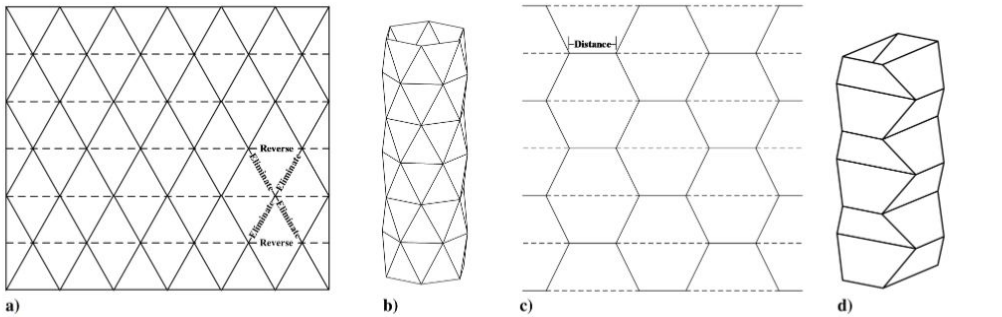
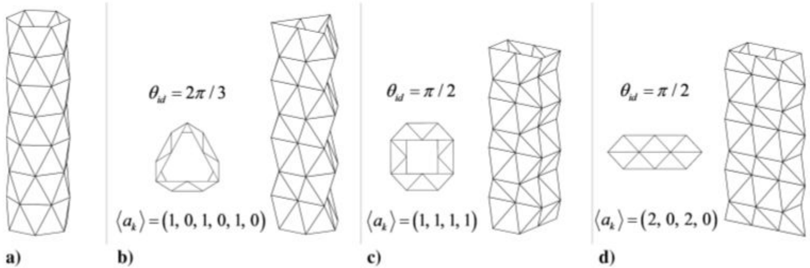


Fig. 2 Representations of a) Yoshimura pattern, b) cylindrical structure made with Yoshimura pattern, c) bellows fold pattern, and d) cylindrical structure made with bellows fold pattern.



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