Flat-Fabrication of Progressively Self-Assembling Space Systems

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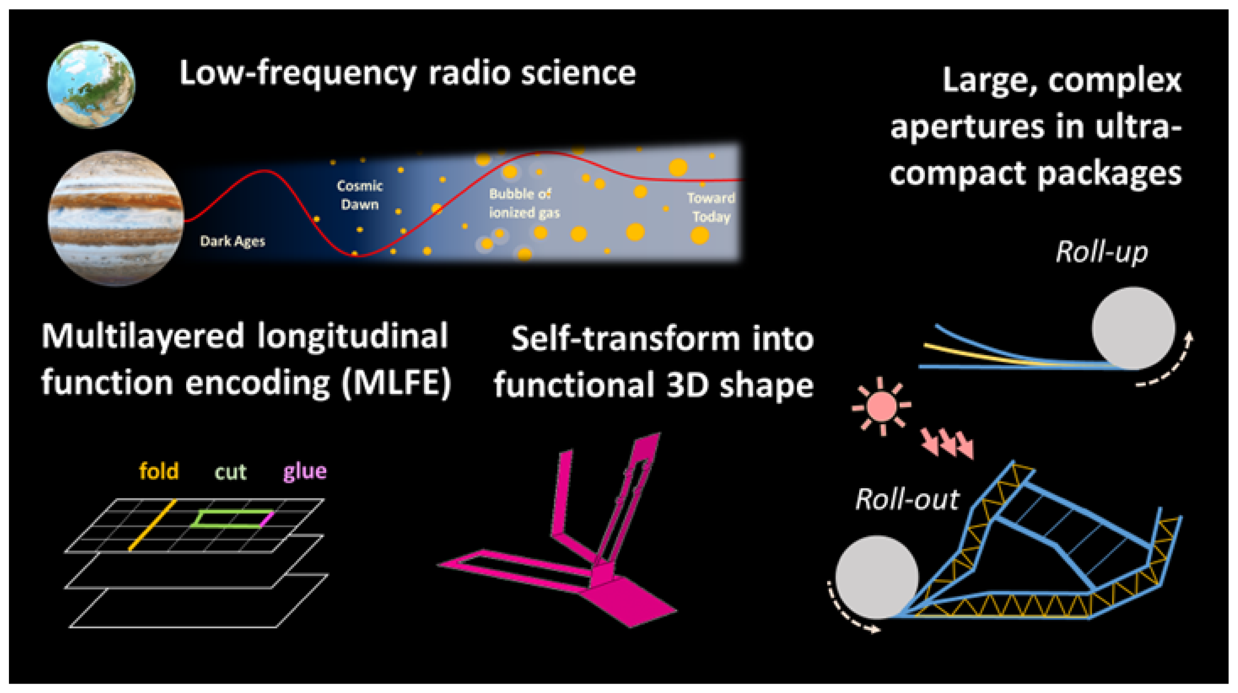
1. MISSION CONTEXT

Self-transforming roll-out structures offer a new scalable paradigm to realize large apertures for small satellites that are lightweight and can be carried in ultra-compact packages.



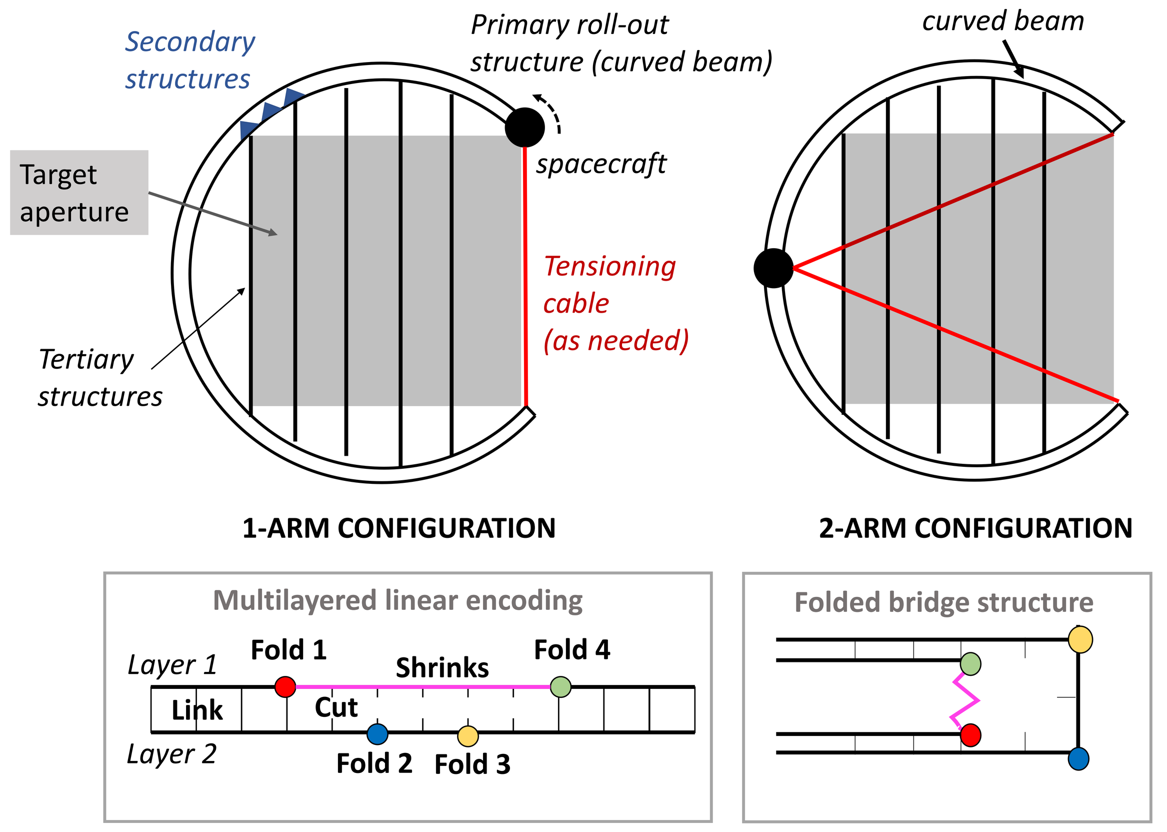
2. INNOVATION

Innovative **multilayered longitudinal function encoding (MLFE)** enables programmable actuation and self-deployment of complex roll-out structures with sensing functions. Thermally activated shape memory polymers (SMPs) encode the transformation of linear, flat structures into functional 3D shapes (including stiffness and curvature variation). Flexible, Hybrid Electronics (FHE) encodes sensing and service functions.

3. SMPs: SHAPE MEMORY POLYMERS

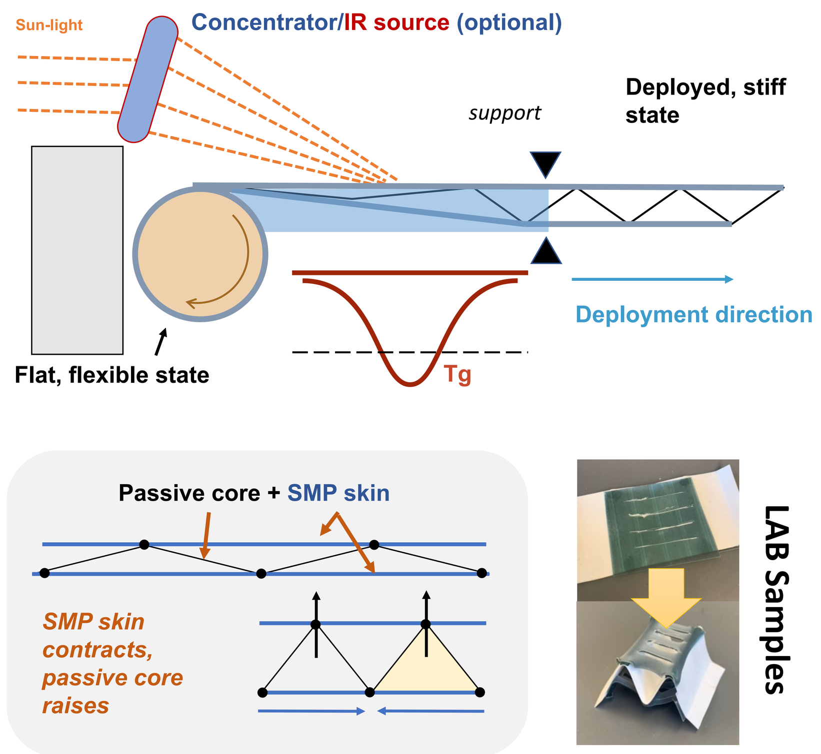
SMPs are smart materials that can change shape in response to external stimuli, including heat and, indirectly, infrared light absorption.

SMP sheets can be patterned with light-absorbing ink hinges that enable controlled shape transformation. In addition, the folded SMP bus maintains the folded state when cooled below the glass transition temperature.



4. CONCEPT SOLUTION

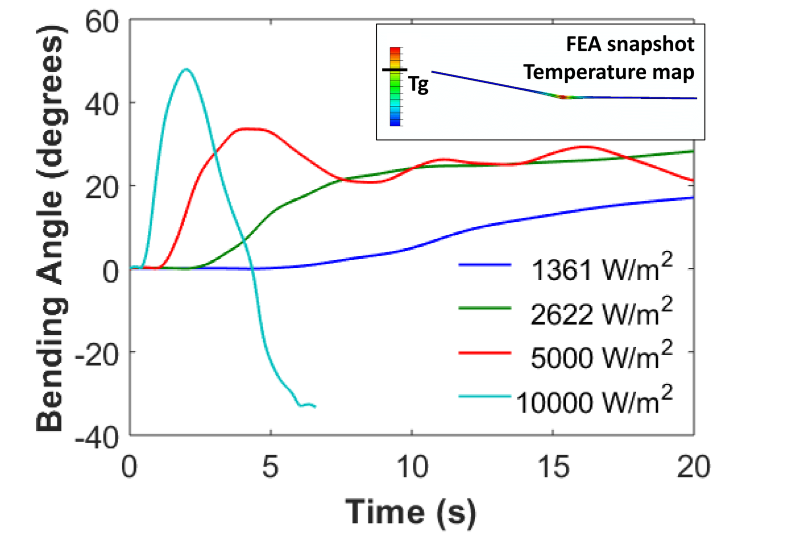
MLFE of roll-out SMP structures promises to enable a new class of large aperture payloads for small satellites, such as the proposed **roll-out harp antenna array**. The roll-out harp antenna array comprises a curved supporting beam. Curvature and stiffness of the supporting beam are achieved via the formation of secondary Miura-Ori structures. From the primary beam, tertiary bridge structures are deployed that carry integrated radio frequency receivers, and effectively form the antenna array. One or more tensioning cables may be added to the design to actively control deployment and the shape of the array. **This design, demonstrated for a radio instrument, can be adapted to different missions by swapping the payload.**



4. STRUCTURE DESIGN

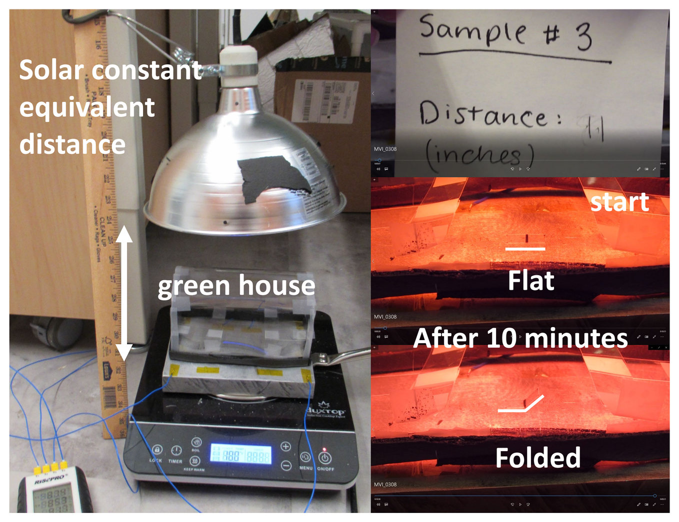
- SMP skin and passive core rendering a 1-DOF folding pattern (e.g., miura-ori).
- SMP arm transits through an activation region where absorption of sun light raises the internal temperature of SMP layer above glass transition.
- As a result of the SMP layer activation, the contraction of the SMP skin triggers the folding of the passive core which is driven to raise and increase the moment area of inertia of the cross section, and thus, bending stiffness.

5. NUMERICAL STUDIES

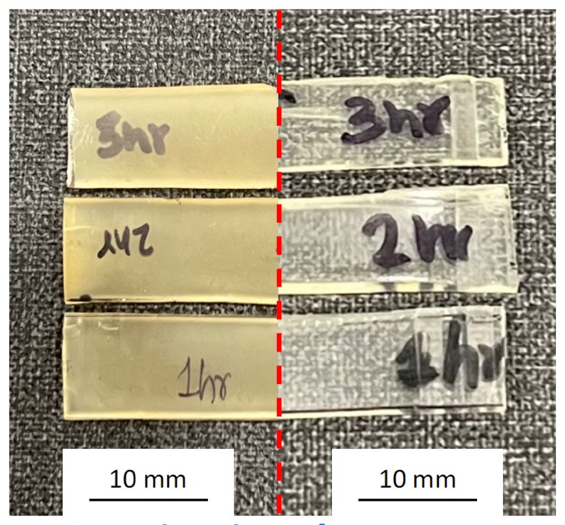


SMP activation at 1AU was demonstrated in finite element analysis experiments

6. EXPERIMENTAL STUDIES

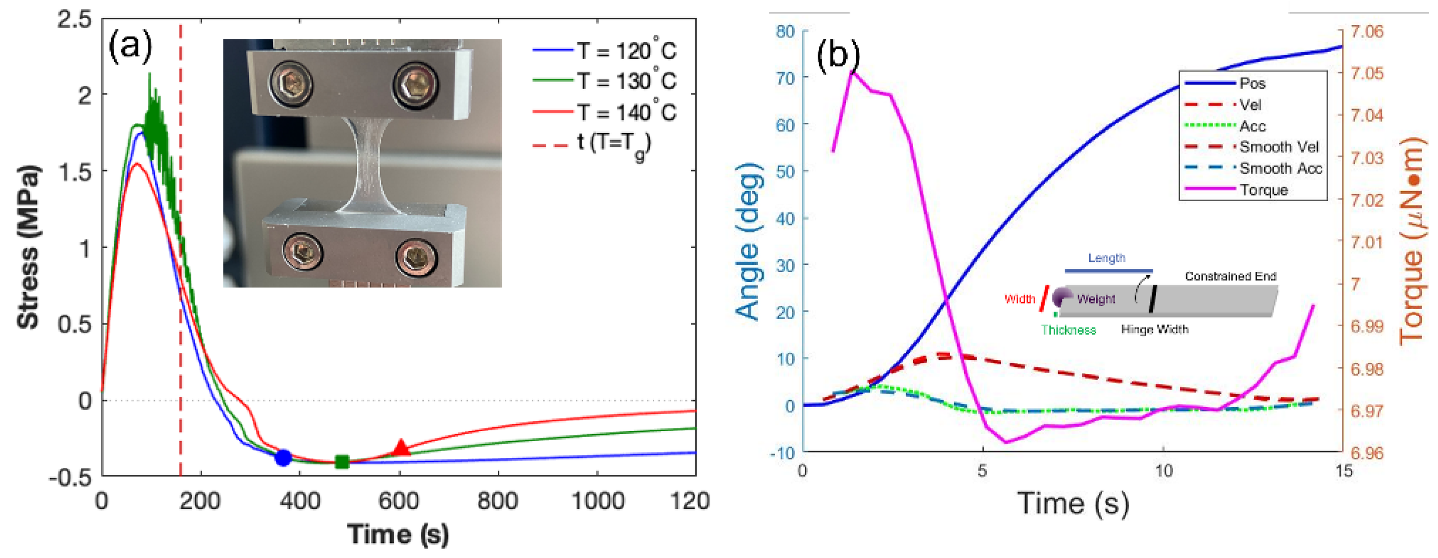


SMP activation at 1AU was demonstrated in controlled laboratory experiments



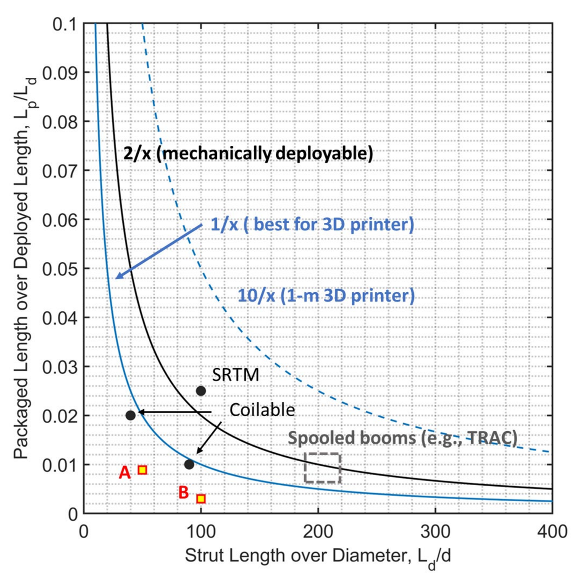
SMP activation demonstrated after 2.3 hr of **exposure to UV radiation** at ~253.5 nm in a 10 nm bandwidth with radiation flux > 100 times larger than the space environment value.

8. WORK CAPACITY



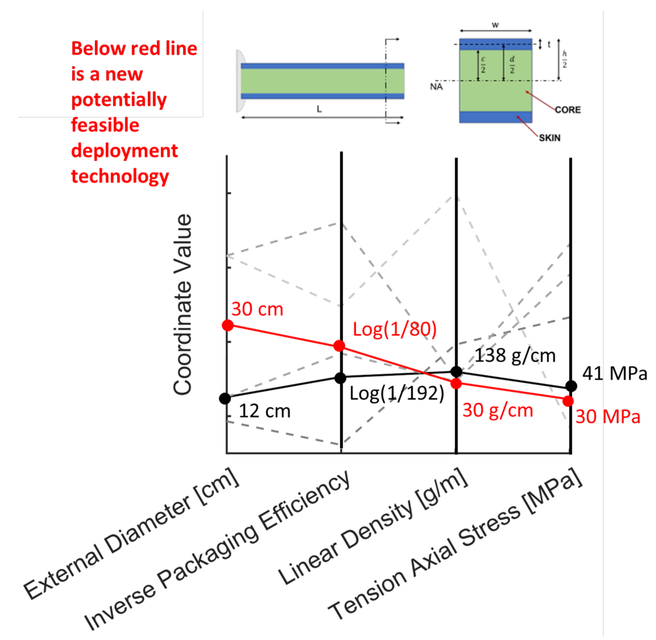
We conducted experiments to estimate the work capacity of self-folding polymer origami and maximum inertial load that is tolerable during deployment

(a) Uniaxial contraction of sample. Inset: sample in test fixture. (b) Representative torque results for a sample with a 2.2 mm wide hinge (inset: Sample geometry. Weight at end provides higher inertia which must be folded against).



8. PACKAGING EFFICIENCY

MLFE enables x2 to x4 larger cross-section diameter than current roll-out structures and x2 length packaging efficiency compared to coilable and 3D printed structures. This figure is a reproduction of Figure 7 in the paper "Truss Performance and Packaging Metrics" for the packaging length efficiency. The abscissa is the ratio between the deployed length and the deployed cross-section dimension, while the ordinate is the ratio between the packaged and deployed length (i.e., the packaging length efficiency). Markers A (10m x 0.2m x 0.2m beam) and B (20m x 0.2m x 0.2m beam) indicate theoretical packaging length efficiency that are achievable with MLFE deployment mechanism. Alternative deployment technologies are plotted for comparisons

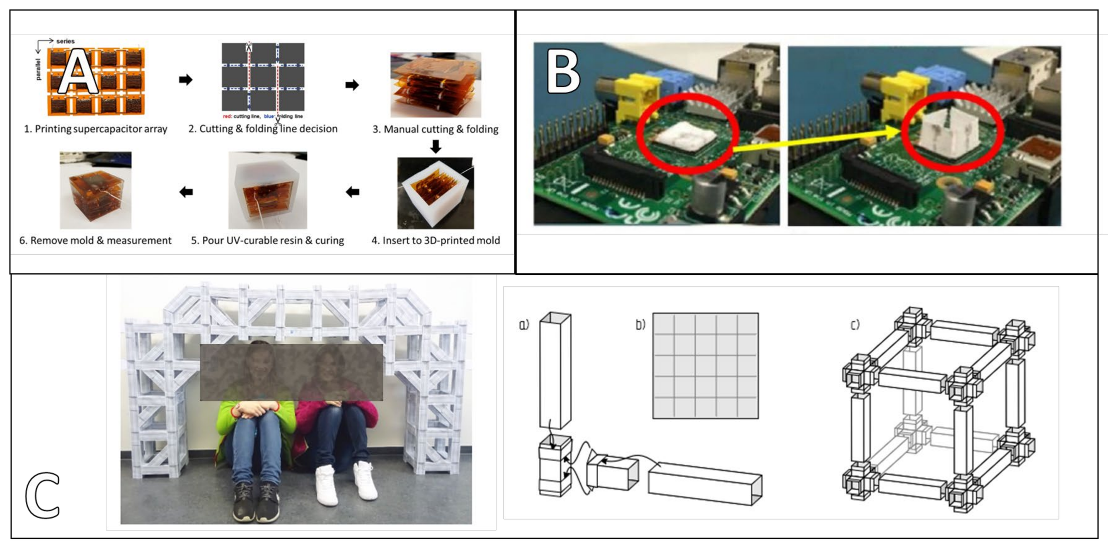


8. FIGURES OF MERIT

Considering a 20 m boom, selected figures of merit are estimated for varying skin thickness (0.01 mm to 2 mm) and cross-section dimension (1 cm to 20 cm). The current analysis elucidates the **unique capability of the current MLFE design to achieve very high packaging efficiency while being able to support a 20 kg tip payload on a 20 m boom.** Structure topology optimization is warranted for mass saving while maintaining structural and packaging performance

12. CROSS-CUTTING APPLICATIONS

Cross-cutting applications include (A) packaging for supercapacitor arrays, (B) miniature antenna deployment from circuit boards, and (C) construction of bridge structures from flat papers. Images (B) and (C) are not ours.



13. TECHFLIGHT 2022-2025

As SMP actuators are driven by the release of stored energy, understanding the building blocks of self-folding science will inform the design and development of SMP deployment mechanisms. Microgravity effects on self-folding can only be approximated in ground-based experiments for the simplest of fold patterns.

CONTRIBUTIONS

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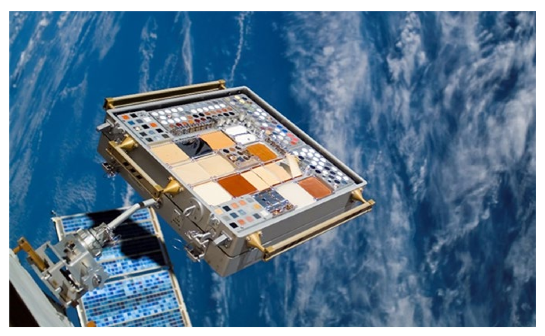
14. NASA MISSE-17



Sixteen SMP samples are currently flying on the NASA MISSE-17 experiment.

The primary objectives of this project are to (1) quantify the effects of real space environments on the thermomechanical properties and shape recovery performance of SMPs and (2) evaluate SMPs as actuators for extraterrestrial applications.