iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 **Issue:** IX **Month of publication:** September 2024

DOI: https://doi.org/10.22214/ijraset.2024.64419

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue IX Sep 2024- Available at www.ijraset.com

Engineering Origami: A Systematic Literature Review in the context of Space Technology, Design, and Applications

Aryan Amit Kashikar
Grade XII student, Pune, Maharashtra, India

Abstract: Origami is the ancient art of Japanese paper folding. For years it has been used to create stunning works of art. But origami has also been used in more surprising ways, like car airbags, stents, and even space exploration. Origami is a bit more than just a paper crane. Engineers use it for use, solve the interesting problems. Origami teaches how to fold very large thin sheets into very small spaces. And that's exactly what space engineers need. The reason for incorporating origami for space applications is to launch structures in space that are just amazingly big using flashers, starshade folding, tessellations, etc. So being able to fold these structures such that they fit neatly within our rocket and then unfold when they get to space. The researcher has attempted to do a literature review and to demonstrate how origami can be used in aerospace engineering and related fields. Innovative aerospace solutions such as morphing aircraft wings and deployable space constructions are made possible by the principles of origami. Using sophisticated modelling and simulation tools is essential for creating intricate origami structures for aerospace applications.
Keywords: Origami modelling, space exploration, aerospace engineering, space applications, tessellations.

I. INTRODUCTION

The term "origami-based designs" describes the utilization of the age-old craft of origami to address various engineering challenges. Origami-based designs are always characterized by the laws governing their geometrical qualities at any scale, even when they are applied at dimensions ranging from the nano to the meter scale. It follows that the growing interest across disciplines in studying their applications is not surprising. [1] Origami-based applications in engineering are reviewed primarily in the following fields: biomedical engineering, architecture, robotics, space structures, biomimetic engineering, fold-cores, and metamaterials. This article aims to review recent origami-based applications in engineering, design methods, and tools. The second section discusses design techniques, design instruments, and associated manufacturing limitations. [18]

The paper folding art form is being used for high-tech and sci-fi-like technology developments. What we want in space are large structures, not necessarily massive, but large, which means you can make them out of thin materials. And wherever you can make them out of thin materials, you can use origami to fit them in these rockets. Many space projects have used the folding principles of origami [4]. The solar array wings on the ISS use a Z folding pattern, and the Mars Phoenix Lander used a fan folding solar array called the Ultraflex. Because the biggest rockets we have right now are only about 5 meters in diameter, we must come up with a way of folding up this very large structure into spaces that we can launch inside a rocket.

And once it gets to space, it can unfold itself. And origami is one mechanism by which we can do that, because it gives us the underlying mathematics of how large thin sheets fold up.

II. INNOVATIVE AEROSPACE SOLUTIONS USING ORIGAMI

Origami-inspired aeronautical engineering is opening new possibilities thanks to smart materials and microfabrication processes. Space exploration could undergo a revolution thanks to origami, which offers small, movable structures for equipment and shelters. The age-old craft of origami paper folding is dramatically changing aeronautical technologies. Its ideas are facilitating creative fixes for drones, spaceships, airplanes, and upcoming aerospace designs. [2]

Of all the instructions scientists may give robots, origami is one of the most elegant and basic. While humans are unable to accomplish certain tasks, robots are not able to be programmed with human inclinations. Robots can interpret directions much more precisely and accurately because of the mechanical nature of material folding. In space, robots can readily understand the common language of origami.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue IX Sep 2024- Available at www.ijraset.com

One of the earliest applications of this language is the self-folding robots created by Samuel Felton, an assistant professor at Northeastern University, and his colleagues. After bending its bodily parts, the robot moves away as electricity flows through the circuit board like blood via veins. In the far future, according to Dr. Felton, these robots might be used on space missions. [3][4]

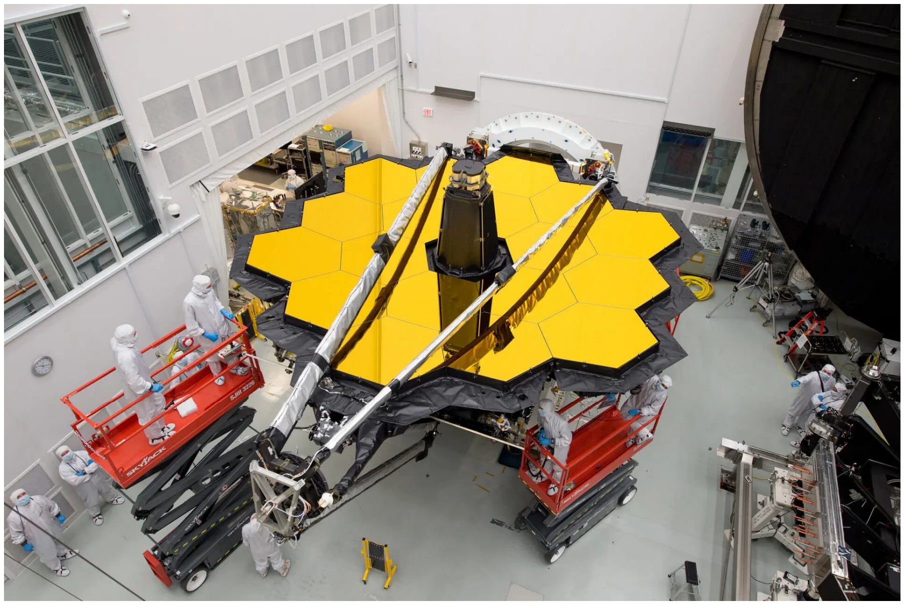


Fig. 1 Featured image: Webb at NASA Johnson, NASA/Desiree Stover, CC BY 2.0 DEED, via Flickr

One of the first uses of Origami in space was the Space Flyer Unit launched by Japan in 1995. It was a satellite with a folded array of solar panels using the Miura or a folding technique. Moving forward to 2010, the Japan Aerospace Exploration Agency launched the Icarus. This spacecraft used a solar sail that propelled it from Earth to about 80,000 kilometers away from Venus. A solar sail works like a boat sail, but instead of wind, light particles are bouncing off of the sail in space, moving it forward. The spacecraft is then able to move through space at close to the speed of light, allowing it to travel to other solar systems possibly within 100 years, which would take tens of thousands of years with today's chemical rockets [3][6]. The Planetary Society, run by Bill Nye, has already launched, and tested two generations of solar sails. It is sail too uses materials that are thinner than a human hair. The thin material, along with Origami folding methods, allows for a larger solar sail to be packed and launched into space. To really see space origami in action, then we need to have a look at star shade. When a space telescope wants to observe an image in exoplanet, bright stars can wash out the images. The same thing happens when you are trying to look far away on a sunny day, the sun's brightness can make it hard to see. This is solved by holding your hand up to block the sun [5].

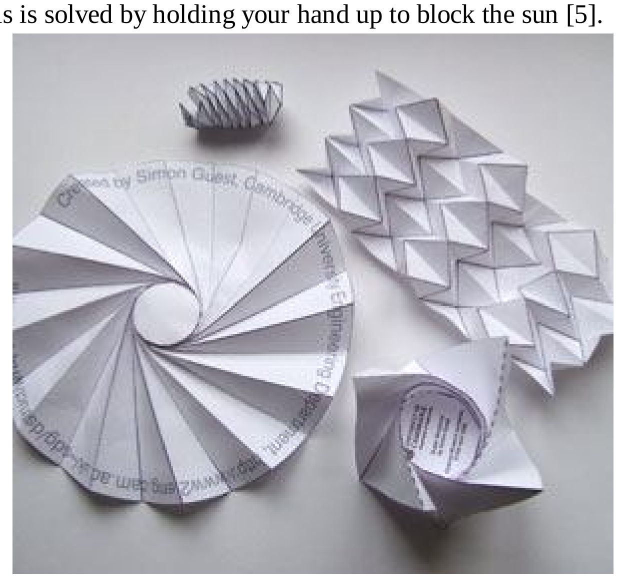


Fig. 2 Origami paper starshade and patterns(adopted from Exoplanet Program: Starshade Technology Development (nasa.gov))

As depicted in the above figure 2, a star shade acts like your hand. It will move in between the stars and the telescope, allowing faint planets to be imaged. This lets space telescopes study other planets and see if there are other Earth-like habitable planets, where life might be possible. These star shades would have to be large. In space, the star shade would unfold to a diameter of about 85 feet. [12] So, NASA is working on origami techniques to fold and allow them to fit into a rocket. Originally, space stations were made of solid, non-foldable modules. This meant that the International Space Station took 30 launches to build. Bigelow aerospace and other companies such as Sierra Nevada are working on inflatable space station modules. [6] These modules would fold up tightly inside of a rocket, then inflate in space, creating large structures with fewer launches.

The International Space Station already has one inflatable module called BEAM, which was installed in 2016. It is made up of two metal bulkheads, an aluminium structure, and multiple layers of fabric. Future designs such as the Olympus Module look to be much larger. It would require a much larger rocket, such as SpaceX's Starship, but when in space it will expand to be over twice the size of the International Space Station. This kind of large space habitat, launched on an inexpensive reusable rocket such as Starship, would make space hotels affordable.[2][5] This technique can also be used to build large habitats on the moon and Mars. We can start to see that there are several benefits when it comes to using origami to develop new tech. First, manufacturing in 2D is cheaper and easier in a lot of cases. Secondly, large structures can be made to fold into more compact and smaller forms. This is being combined with the development of advanced materials that are as thin as the human hair. Another benefit of origami and high-tech development is that it can allow a structure to change shape when needed.

When it comes to using origami to develop new tech, one person to keep an eye out for is a man named Robert Lang. He is a well-known origami expert and physicist. Computational origami is a branch of computer science that began with work done by Robert Lang on origami design. It models how different materials can be folded into structures. Lang worked at NASA's JPL and has over 50 patents on semiconductor lasers, optics, and has worked on space solar arrays. He has authored over 20 books on origami, which have often combined the ideas of science and engineering. [16]

The robo-gami robots could fold into a large robotic arm perfect for picking up certain objects, then fold into a transportation robot based on the task. This is ideal for space development, as it saves on the amount of equipment needed to be launched into space. In the future, we will be able to launch a few sheets of origami robots and they will transform and perform any task.[5] Harvard University have also created foldable robots that can fold themselves and walk away. These robots are made from thin layers of laser-cut wood and laminate materials. The motors are controlled by a small microcontroller. A robotic arm developed its sole national university in Korea can fold and extend into a rigid structure. The origami design makes it lightweight at 30 grams and can withstand a compressive load of 12 kilograms. The team attached the lightweight robot arm to a drone to pick up objects. [2][3][6]

III. ORIGAMI BASED SPACE STRUCTURES

Structures for space missions must be able to operate at a size ranging from 10 to 1000 m when fully deployed, and they must be able to be stored within the restricted space of launch vehicles. When designing space structures, three key requirements must be met: the structures must be huge when deployed in orbit, lightweight when transported from the ground to space, and tiny when assembled. Following the initial proposal by Miura and Natori [7], scientists have developed several origami-based designs that can meet the functional requirements of space systems and the transportation constraints. Reduced friction, minimal need for lubricants, improved precision, and simplicity of downsizing are just a few benefits of using origami-based technologies in the construction of lightweight, deployable structures.[8][12]

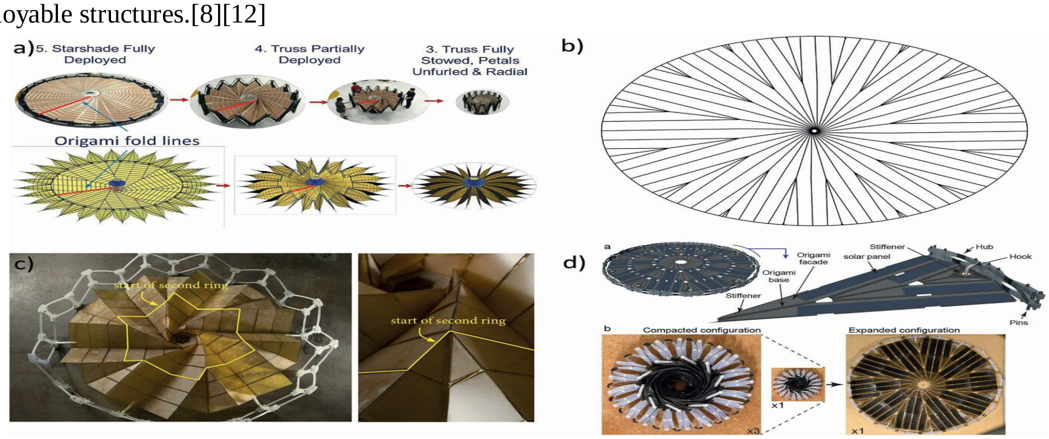


Fig. 3 Origami-based space structures.

a) Starshade deployment motion. Reproduced with permission.[9] Copyright 2016, SPIE. b) Crease pattern for a dual elliptic solar reflector. Adapted with permission.[14] Copyright 2017, IEEE. c) Hanaflex solar array. Reproduced with permission.[15] Copyright 2015, SPIE. d) Self-folding solar array. Reproduced under the term of Creative Commons Attribution 4.0 International License.[16] Copyright 2019, The Authors, published by American Physical Society.

NASA is currently working on a project that includes designing a creative starshade made of origami (Figure 3a). The goal of Starshade, which is connected to a separate space telescope, is to block off starlight so that exoplanets can be imagined circling those stars. With a 20 m core disk and 28 external, flower-like petals that are each 7 m long, the structure has a deployed diameter of 34 m. A shield material made of several layers of black Kapton soaked with carbon covers an optimized version of the Flasher origami pattern on the inner disk. The petals consist of a thin composite structure constructed of carbon fiber that is coated in the inner disk's shield material. [9][10]

It has been stated that the structure folds smoothly and reliably, fitting within the 5 m launch vehicle limit with a high deployed to stowed ratio. One novel feature of the design is the utilization of an inverse design process to ascertain the optimal crease pattern geometry. The number of gores the system produces, the deployed diameter, the stowed height, the stowed diameter, and the thickness of the material are inputs to the algorithm. Information on material compression, gore strain, stowed volume, and packing efficiency are outputs, coupled with an appropriate crease pattern.

An enormous dual elliptic solar reflector has been designed using the same method that was used to create the Starshade crease pattern.[14] The chosen shape, which is also derived from a Flasher crease pattern (Figure 3b), enables the achievement of a deployed dimension that is 40 times larger than the stowed one. Composed of composite fabric and aluminum Mylar, the two reflectors are intended to be deployed via an inflatable torus after being separated by a deployable boom. The suggested design could deploy flat in accordance with the requirements for deflection constraints, according to FEM calculations. [11]

Zirbel et al. have presented Hanaflex, an origami-based deployable device for solar arrays, as another variation of the flasher pattern (Figure 3c).[15] The suggested Flasher pattern modification can be deployed to a dimension ten times larger than its initial stowed state. The system's ability to add more rings to the base unit without changing the stowed geometry's height and only slightly increasing its diameter is one of its most important features.

Even with all of the research done on the deploy ability, shape optimization, and material composition of origami-based space structures, actuation systems still rely on complex networks of motor-driven actuators. An origami-based self-deployable solar array that is designed to activate in response to variations in the surrounding temperature was developed by Chen and colleagues with the goal of streamlining actuation systems and lowering the actuators stowed mass during the shipping phase (Figure 3d).[16] The construction is made up of an optimized origami Flasher sheet embedded in a ring scissor mechanism, and it is 3D printed using shape memory polymers.

In addition to lowering the system's overall bulk and increasing its stowability for transportation, the origami-based design offered a controlled deployment and a simplified actuation. Origami-based designs have a limited relevance to real-life tasks, despite being especially well suited for space structure design. Their use in space missions is frequently constrained by the evaluation of intricate factors like the nonlinear deployment dynamic.[17] Simplified design procedures, enhanced simulation tools, and experimental testing are necessary due to the intricacy of mechanical systems and the difficulties of testing them in orbit. These methods should be able to yield dependable data for the optimization and evaluation of finished products [18].

IV. CONCLUSIONS

Although there has been tremendous advancement in origami engineering, there is still a great deal of unrealized potential in the aerospace industry. Through overcoming scale issues, origami has the potential to revolutionize everything from medical equipment to deployable designs in space. It has been shown that origami-based designs are a versatile tool for implementing creative engineering solutions. Recent study findings promise to optimize and widen their applicability. This thorough analysis of origami-based tools, techniques, and applications is intended to encourage transdisciplinary innovation.

Transitioning from paper models to full-sized operational systems presents challenges for practical applications of origami. Comprehending the fundamental concepts of fold kinematics and mechanics is essential. Dynamics, weight, and forces are all very different from paper origami art. Additionally, space and flight require robustness and dependability to be incorporated in.

But advancements in manufacturing, simulation, and materials science will make it possible to overcome these obstacles. Paper folds can be more accurately modeled with multi-material composites that have unique characteristics.

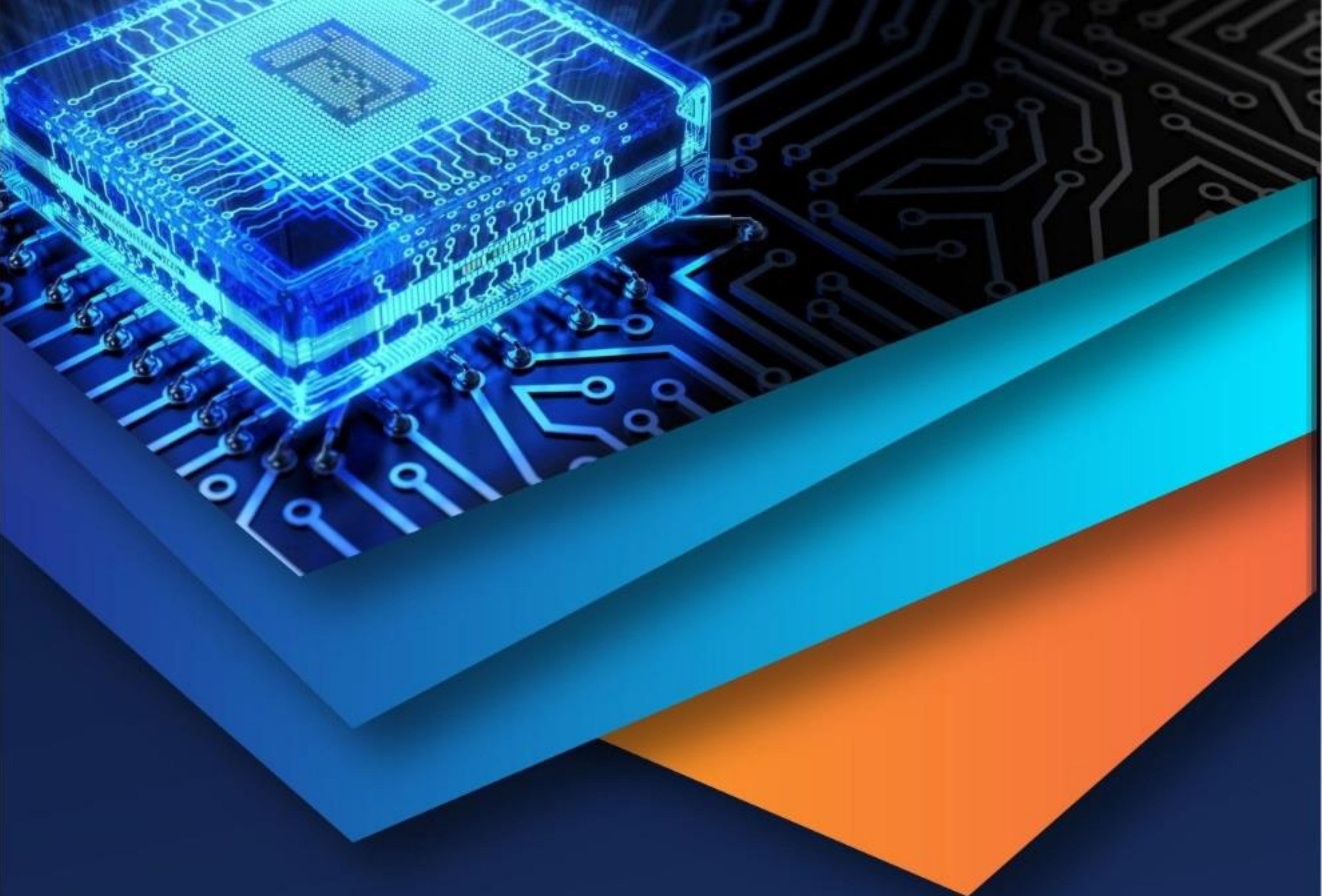
Before expensive physical testing, performance is predicted by high-precision simulation. The creation of fully functional origami systems is made easier by 3D printing and intelligent materials.

V. ACKNOWLEDGMENT

I would like to acknowledge my favourite Origami folders Robert Lang, Jo Nakashima, Satoshi Kamiya, John Montroll, Manan Aaya, and Jeremy Shafer. Watching their folders on YouTube and folding objects by following the instructions from their published books I pursued a lot of interest in how origami can be used in space technology. The reading about the contributors for developing and maintaining the space objects developed by NASA also helped me to understand the field and its applications.

REFERENCES

[1] Marco Meloni, Jianguo Cai, Qian Zhang, Daniel Sang-Hoon Lee, Meng Li, Ruijun Ma, Teo Emilov Parashkevov, Jian Feng, Engineering Origami: A Comprehensive Review of Recent Applications, Design Methods, and Tools, 13 May 2021, https://doi.org/10.1002/advs.202000636
[2] Callahan, Molly. “New Professor Creates Self-Folding, Origami Robots.” News@Northeastern, 24 Oct. 2016.
[3] Chang, Kenneth. “Origami Inspires Rise of Self-Folding Robot.” The New York Times, 7 Aug. 2014.
[4] Good, Andrew. “What Looks Good on Paper May Look Good in Space.” Jet Propulsion Laboratory, 22 Sept. 2017.
[5] Lee, Elizabeth. “Ancient Origami Art Becomes Engineers’ Dream in Space.” Voice of America, 26 Oct. 2017.
[6] Rodriguez, Joshua. “Flower Power: NASA Reveals Spring Starshade Animation.” Exoplanet Exploration, 24 Sept. 2020.
[7] K. Miura, M. Natori, Space Sol. Power Rev. 1985, 5, 345.
[8] R. M. Fowler, L. L. Howell, S. P. Magleby, Mech. Sci. 2011, 2, 205. Web of Science®
[9] D. Webb, B. Hirsch, C. Bradford, J. Steeves, D. Lisman, S. Shaklan, V. Bach, M. Thomson, in Proc. SPIE 2016, 9912, 991201.
[10] D. Sigel, B. P. Trease, M. W. Thomson, D. R. Webb, P. Willis, P. D. Lisman, in Proc. of ASME 2014 Int. Design Engineering Technical Conf. and Computers and Information in Engineering, Vol. 5B, ASME, Buffalo, New York 2014, V05BT08A033. https://doi.org/10.1115/DETC2014-34315
[11] B. P. Crill, N. Siegler, in Proc. SPIE 2017, 10398, 103980H.
[12] D. Webb, B. Hirsch, V. Bach, J. Sauder, S. Bradford, M. Thomson, presented at 3rd AIAA Spacecraft Structures Conference, San Diego, California, USA, January 2016.
[13] L. Bowen, B. Trease, M. Frecker, T. Simpson, in Proc. of ASME 2016 Conf. on Smart Materials, Adaptive Structures and Intelligent Systems, Vol. 1, ASME, New York 2016, V001T01A012. https://doi.org/10.1115/SMASIS2016-9172
[14] R. Salazar, S. Murthy, C. Pellazar, A. Stoica, in Proc. of 2017 IEEE Aerospace Conf., (Ed: A. Okamura) IEEE, Piscataway, NJ 2017, pp. 1–7.
[15] S. A. Zirbel, B. P. Trease, M. W. Thomson, R. J. Lang, S. P. Magleby, L. H. Howell, in Proc. SPIE 2015, 94671C.
[16] T. Chen, O. R. Bilal, R. Lang, C. Daraio, K. Shea, Phys. Rev. Appl. 2019, 11, 064069. CAS Web of Science®
[17] B. N. McPherson, J. L. Kauffman, in AIAA Scitech 2019 Forum, Reston, VA 2019, pp. 1–18. https://doi.org/10.2514/6.2019-0480.
[18] Jorge C. Lucero, Origami in Aerospace Engineering: Ancient Art Meets Modern Technologies, 29 June 2024



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY