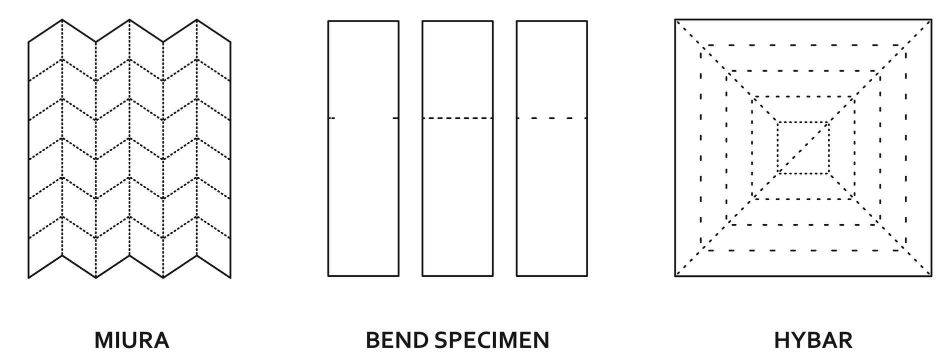
STRENGTHENING ORIGAMI STRUCTURES
WITH THE LAYER JAMMING EFFECT

INTRODUCTION

When sheets of paper are vacuum-packed together, the air pressure gradient causes the sheets to be pushed together, creating large frictional forces. Approximately, the resulting tensile force required to pull the stack apart is $F = (n - 1)\mu \Delta P S$.

Where μ is the coefficient of friction, n is the number of sheets, ΔP is the pressure difference between the inside of the envelope and the outside, and S is the surface area of the sheet [1]. By varying ΔP, the shear strength between the layers can be greatly altered, allowing for light flexible structures to be turned into strong rigid ones without the need for mechanical stiffeners. This effect has been explored for applications in furniture, digital displays, shoes [1], variable stiffness robotics [2], and haptics [3] and may have future applications, where light and/or readily configurable structures are needed such as in aerospace or emergency structures.

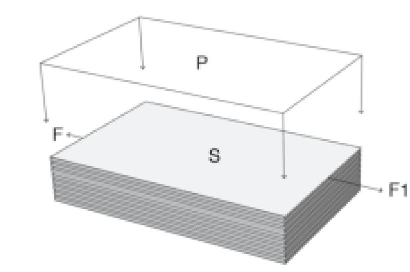
This project seeks to elaborate on the work done by the MIT Media Lab by looking at how perforation ratio (i.e. the proportion of the crease that is cutout) and layer jamming affects the bending stiffness of a stack of paper and how layer jamming affects the tensile strength of the Miura-Ori (Miura). This project also attempted to see how jamming affects the pop-through behavior of the Hypar. Due to time constraints, this project was unable to obtain simulation results.



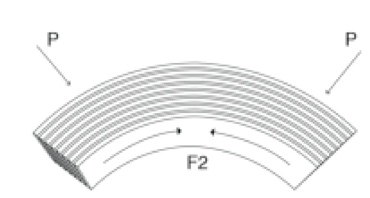
SPECIMEN DESIGN

The Miura, Hypar, and bend test specimens were all created from laser-cut 70lb charcoal sketching paper.

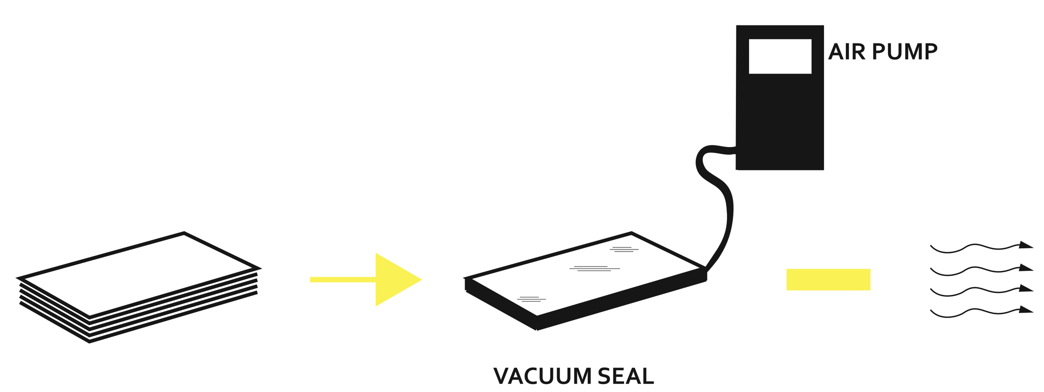
FOLD & REPEAT



F_1 : Maximum resisting tensile force



F_2 : Compressive bending force



= LAYER JAM

PROCESS

Each pattern is then stacked and encased in an adhesive backed plastic sheet (Glad Press'n Seal) to form the jam envelope. Air is then removed. The air pressure gradient causes the sheets to be pushed together, creating large frictional forces.

BENDING TESTS

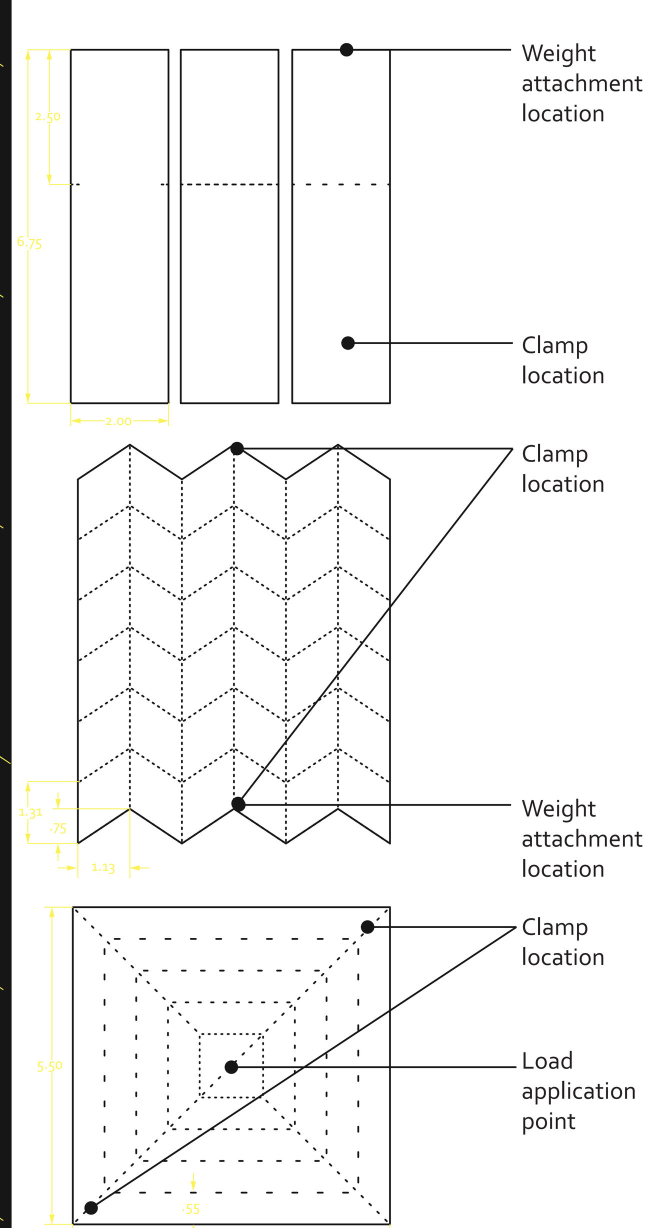


Figure 10 shows the falling weight deflection test for the bend specimens. The 0-perforation ratio exhibits higher than expected deflection. This can be explained by the way the creases were formed. The creases were bent until a permanent crease could be seen on the paper. For the perforated samples, only a partial bend was needed, but for the unperforated sample the bend need to be fully completed. It is hypothesized that fully bending breaks more paper fibers than a partial bend.

The near constant deflection for the -7psig test could be explained by torque. As the z-deflection becomes greater, the effective lever arm of the system becomes lower, which makes any further beam bending or hinge movement more difficult. For the tests in vacuums of -10 and -15psig, deflection increases as perforation increases,but it appears to increase only after the knee at .40 perforation. This is probably due to friction.

Figure 11, 12, and 13 shows that increasing the vacuum increases the tensile strength of the Miura. Clearly, the tensile strength of the jammed Miura varies considerably. Specimen 2 and 3 were folded and assembled by the same person, and specimen 1 by another. The variations could be due to panel distortions, which alters the contact area between the panels.

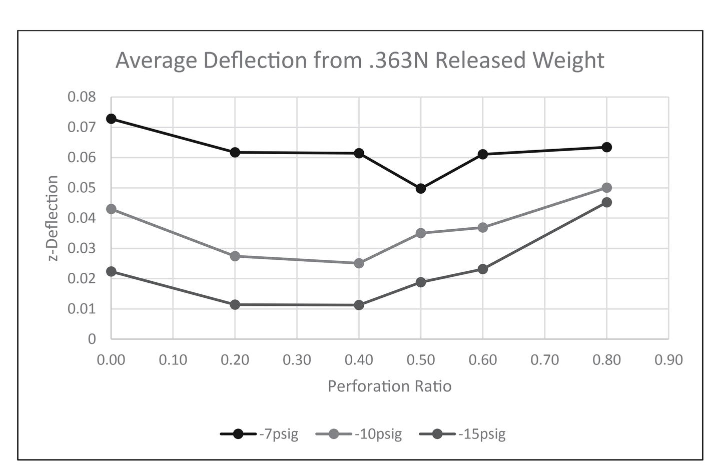


Figure 10

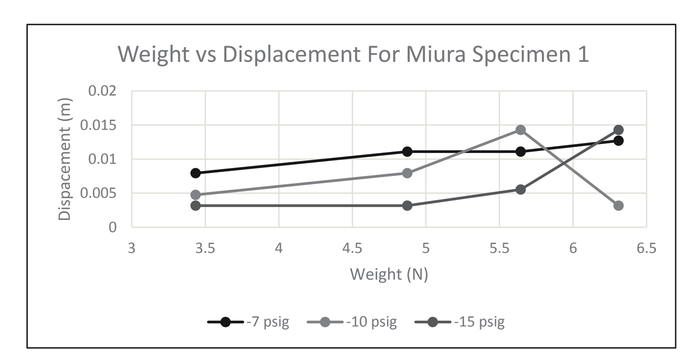


Figure 11

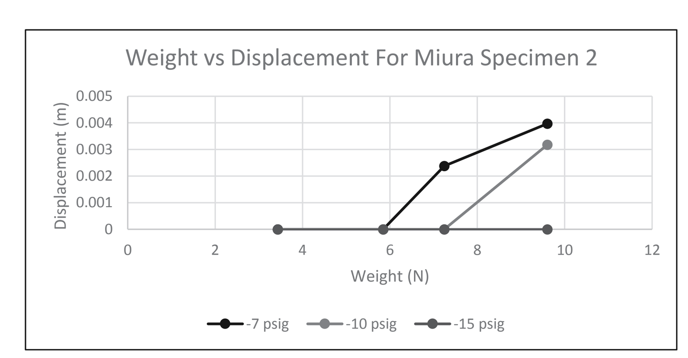


Figure 12

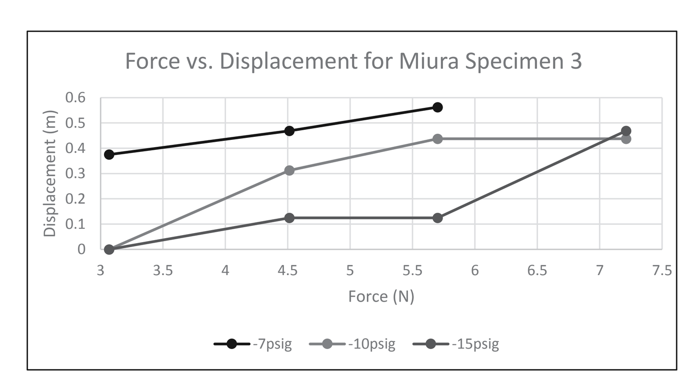


Figure 13

CONCLUSIONS

Layer jamming can increase the strength of folded structures, but its effectiveness depends on the quality of the jamming envelope and the folding. The bend tests show that increased perforations result in decreased folding resistance and the Miura tensile tests show that the tensile strength of a Miura array increases with increasing vacuum. The pop-through tests with the Hypar qualitatively show that layer jamming preserves the bi-stable behavior, but it depends on the load rate.

Overall, these results are preliminary, but interesting. More trials are needed to control for statistical variations, and more explicit folding and assembly directions need to be laid out to control for procedural errors. Finally, better equipment is needed to capture any transient behaviors like the Hypar pop-through.

ACKNOWLEDGEMENTS

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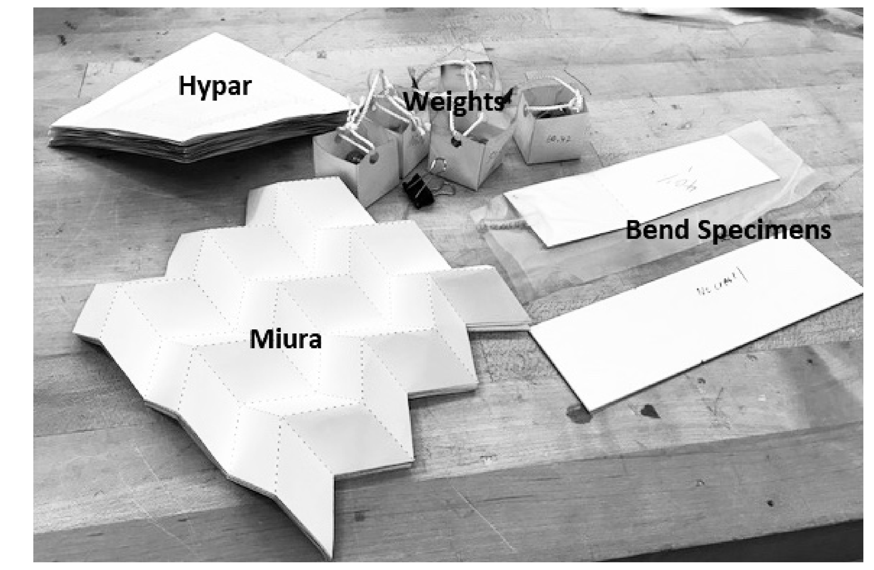
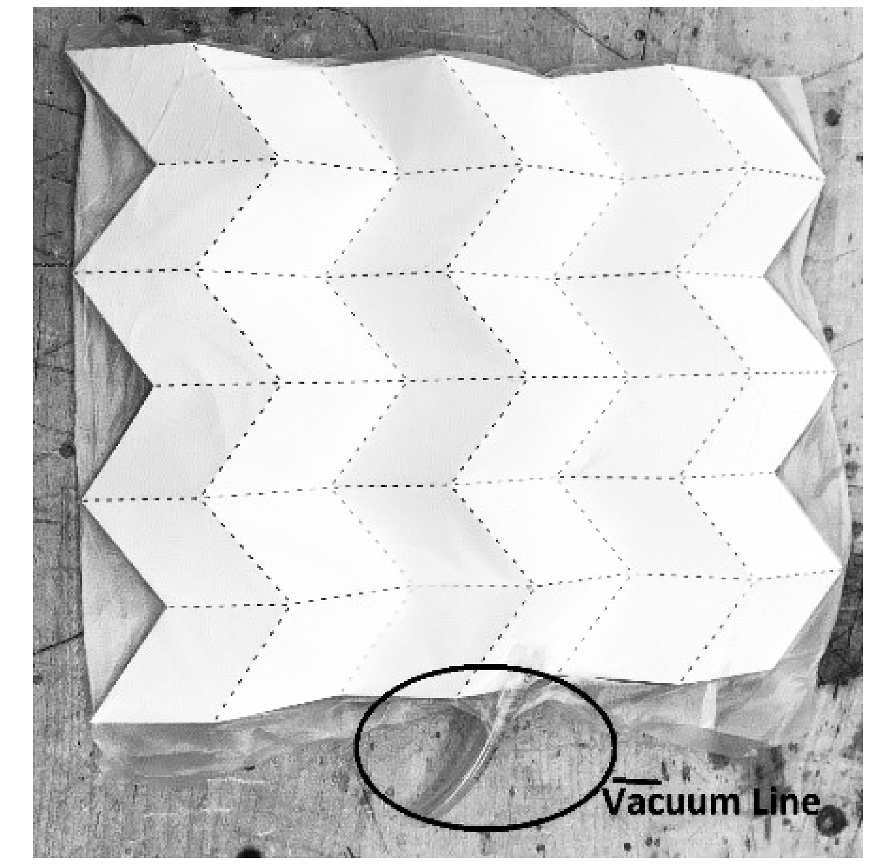
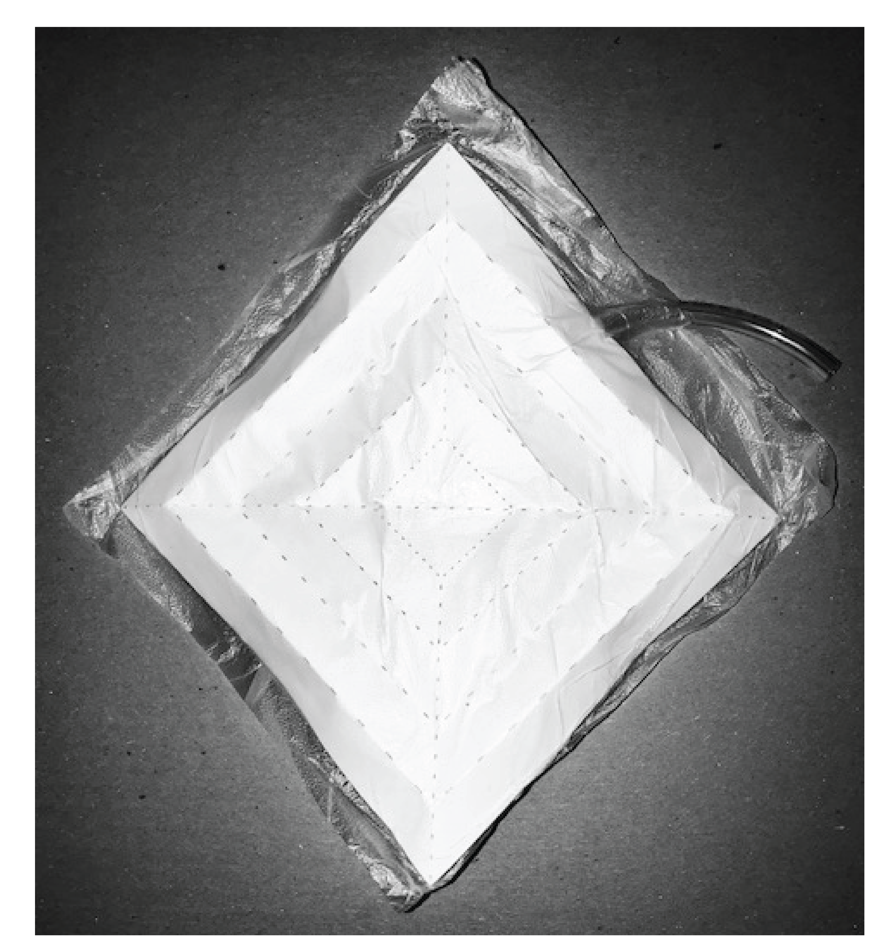
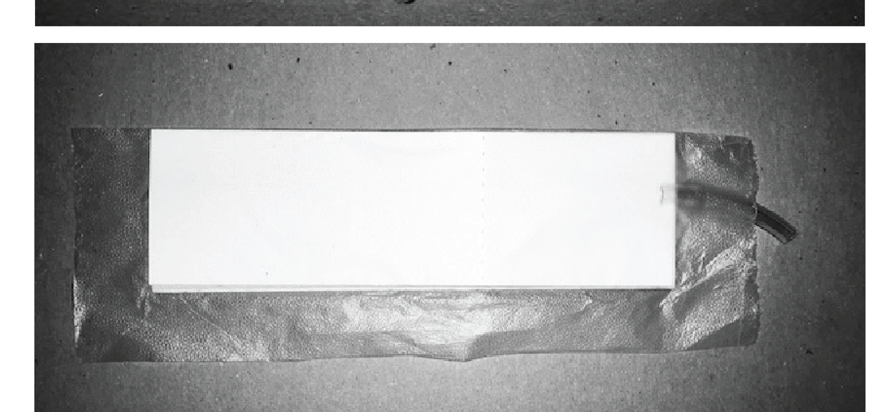


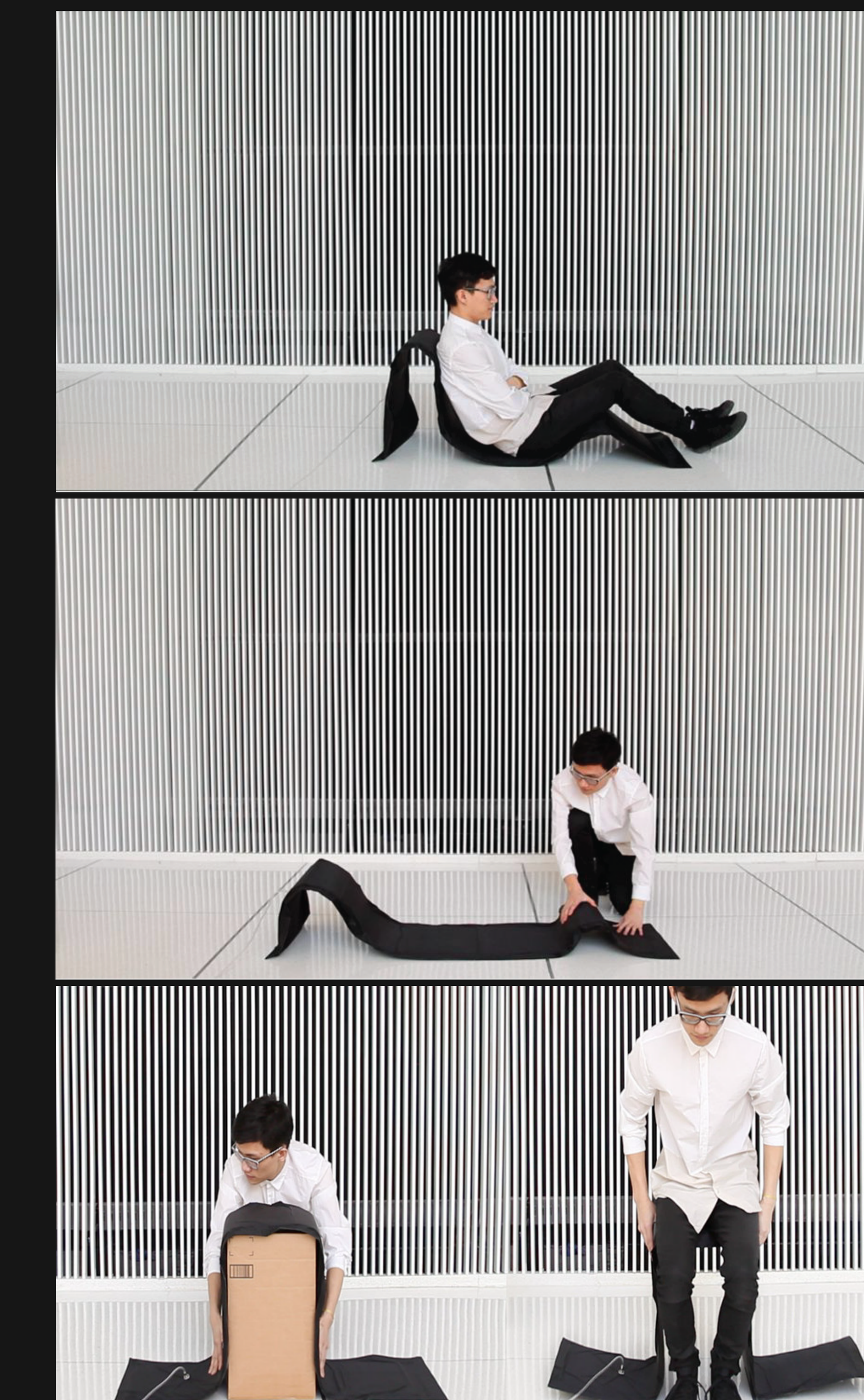






APPLICATIONS

DEVELOP-ABLE FURNITURE



FLEXIBLE DISPLAY WITH CONTROLLABLE STIFFNESS

JAMMING SHOE

LESSONS LEARNED

1. Project development takes a long time: the jam envelopes took several weeks of iterations of on and off work to get right.

2. Experimentation is Resource Intensive: Even though only a couple of trials were conducted for each test, the group still needed to make and assemble many things.

3. Quality control: Because of the mechanical variability of origami and folds, more explicit folding techniques should have been laid out to eliminate procedural errors.

4. Over ambition: A satisfactory project could have been done on just studying the Miura with layer jamming effect. Resources were spread too thin on the project.

5. Human resource utilization: Layer jamming is an interesting concept, but the project was too scientific in scope. If it was more application oriented, then the talents of the group could be more fully utilized.

CITATIONS

[1]: Ou, J., L. Yao, D. Tauber, J. Steimle, R. Niiyama. H. Ishii, jamSheets: Thin Interfaces with Tunable Stiffness Enabled by Layer Jamming, TEI, 2014

[2]: Kim, Y., S. Cheng, S. Kim, K. Iagnemma, A Novel Layer Jamming Mechanism with Tunable Stiffness Capability for Minimally Invasive Surgery, IEEE Transactions on Robotics, 2013

[3]: Choi, I., N. Corson, L. Peiros, E Hawkes, S. Keller, S. Follmer, A Soft, Controllable, High Force Density Linear Brake Utilizing Layer Jamming, IEEE Robotics and Automation Letters, 2017