

RESEARCH QUESTION

How can the strength-to-weight (STW) ratio of Miura-Ori origami be optimized to create **stronger and more efficient** deployable structures?

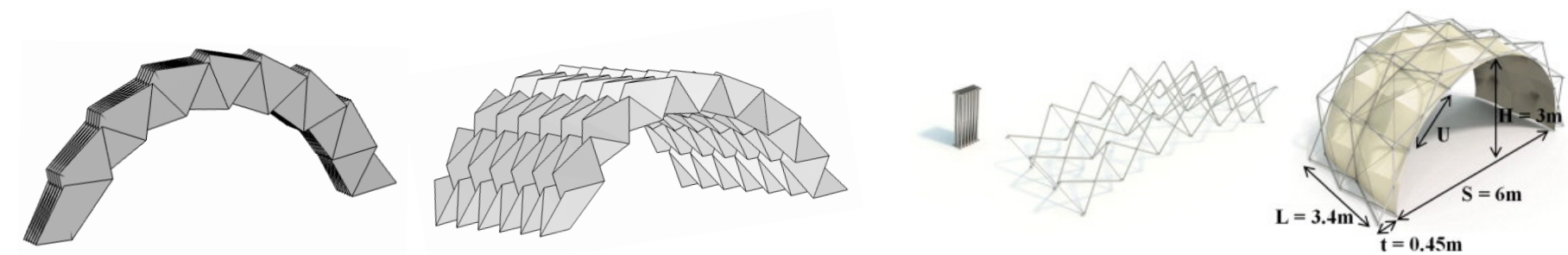
HYPOTHESIS

That smaller, less acutely angled panels made of heavier material will yield a greater strength-to-weight ratio. These patterns would be more compact and dense compared to patterns with larger panels and lighter paper, possibly resulting in greater strength.

BACKGROUND

Deployable structures

- Can easily transform from a compact to a deployed state, e.g. scissor structure (collapsible wire frame connected by hinged joints)
- Many uses: temporary post-disaster housing, deployable spacecraft structures, robotic mechanics



Conceptual arch made of Miura-Ori that is compact while still being strong and easy to deploy. Simulation created by Miles Wu using Origami Simulator (origamisimulator.org), 2025.

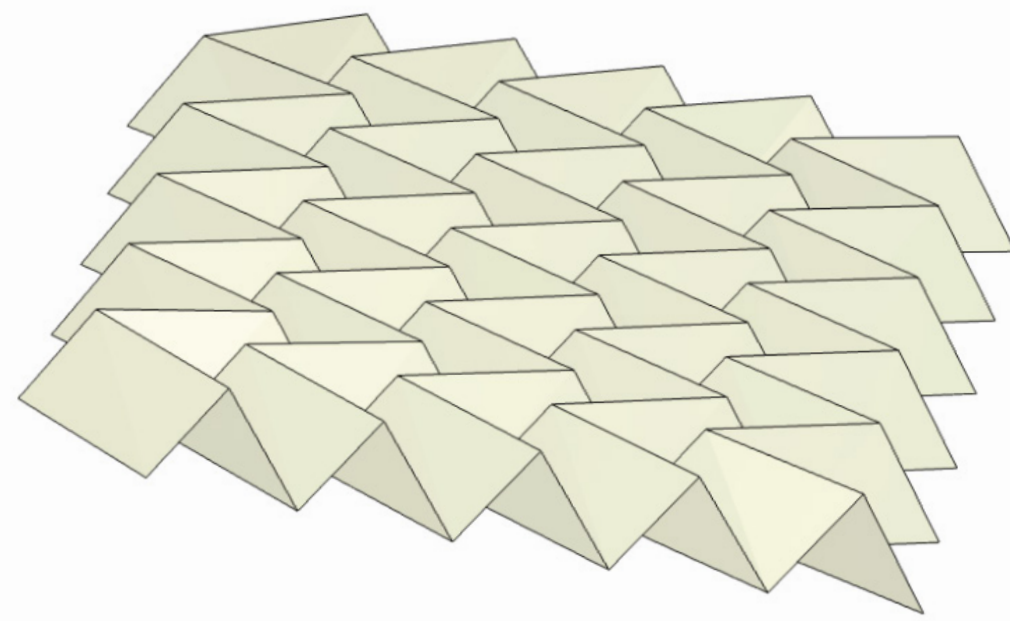
Scissor structure arch. Note: From ScienceDirect [graphic], by Alegria Mira, L., Threlk, A. P., & De Torenemarian, N. (2014). <https://doi.org/10.1016/j.autcon.2014.03.014>.

Cons of scissor structures:

expensive → possibly cheaper
flimsy → strong
difficult to deploy → compact, easily deployable
lacks insulation → insulating
needs separate cover → single component

Pros of Miura-Ori:

possibly cheaper
strong
compact, easily deployable
insulating
single component



An example of a Miura-Ori. Simulation created by Miles Wu using Origami Simulator (origamisimulator.org), 2025.

The Miura-Ori fold

- Invented in 1984 by Koryo Miura, Japanese inventor and astrophysicist
- Origami tessellation of repeating parallelogram panels
- Initially used in deployable satellite solar panels
- Now has applications in engineering, materials science, architecture

Properties of Miura-Ori

- Miura-Ori's mechanical properties give it **countless applications** as aerospace deployments, temporary infrastructure, retractable roofs and more
- Flat-foldable** (folds flat)
- Rigid-foldable** (can be folded from rigid materials using hinges)
- Material-independent** (applicable to almost all materials)
- Developable** (unfolds without deforming)
- Single degree of freedom** (opens/closes in one mechanism)
- Scalable** for large-size application
- Load distribution** (distributes weight efficiently along entire pattern)
- Anisotropic stiffness** (varying stiffness depending on the direction of force)
- Highly compact** when folded
- Impact absorption capabilities**

METHODS

Independent Variables:

- Panel height (1, 2 in.)
- Panel width (0.5, 1, 2 in.)
- Angle of panels (45°, 60°, 75°)
- Paper weight (40, 65, 110 lb) (i.e. 59.2, 96.2, 162.8 gsm)

Constants:

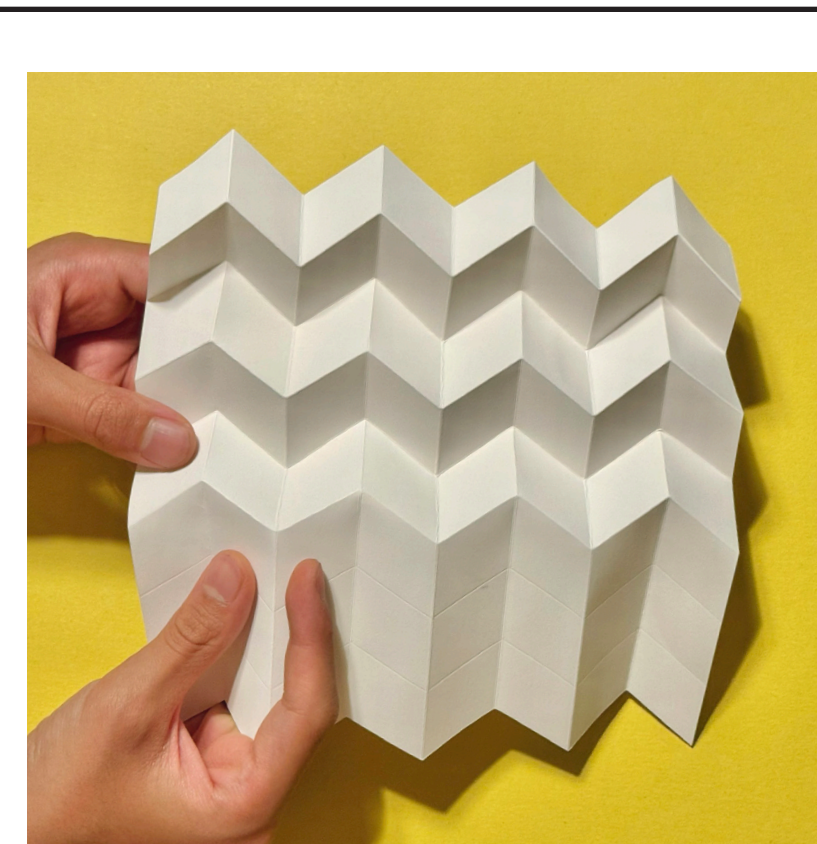
- A pre-folded paper size of 64 square inches
- 54 total variants, 2 trials each, 108 total trials**

Optimizing the Strength-to-Weight Ratio of Miura-Ori Patterns

PROCEDURE

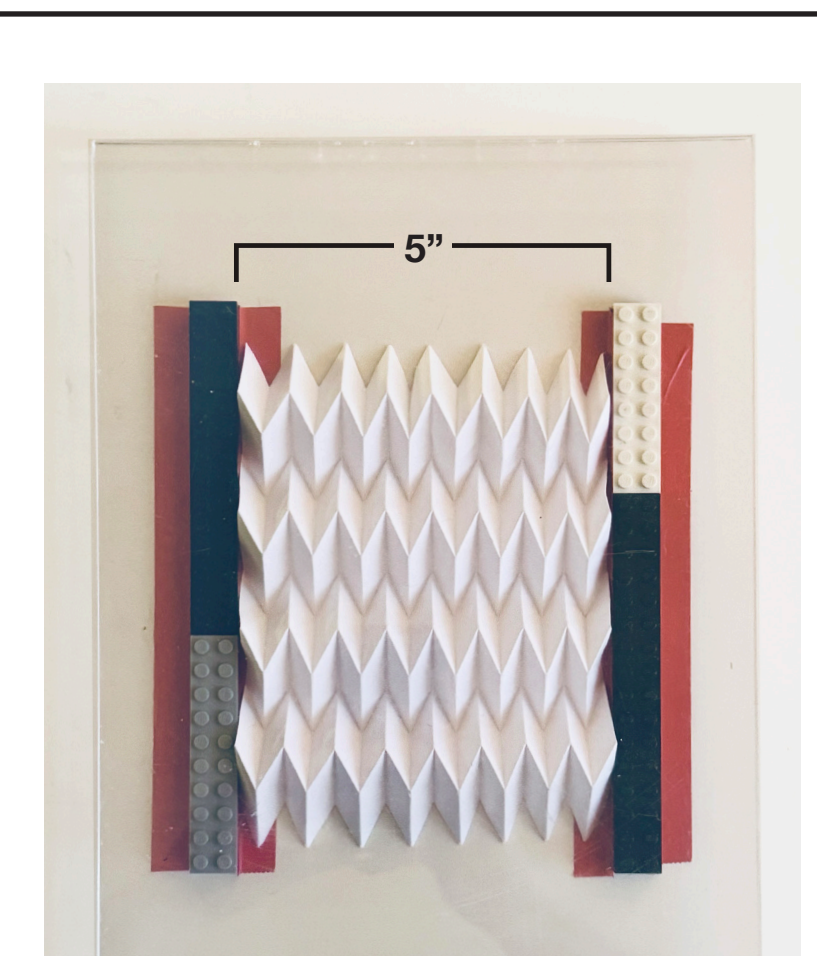


Designed digital files for all 54 variants; cut and scored paper using digital cutting machine according to pattern

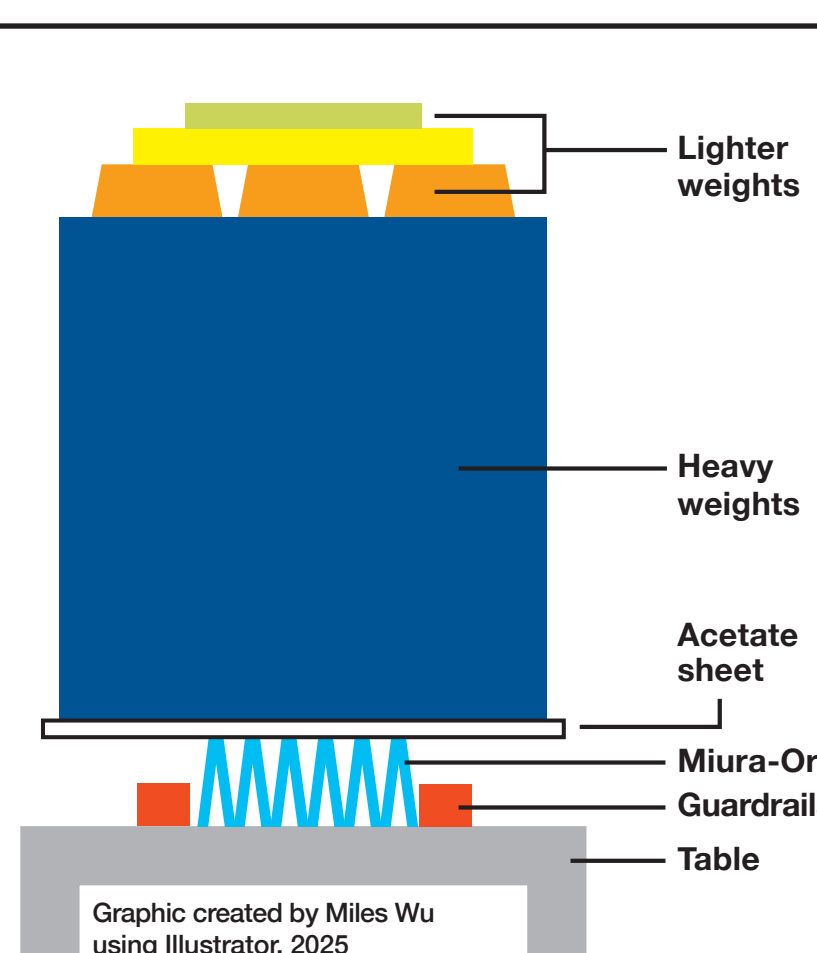


Hand-folded template along scored lines

Weighed Miura-Ori to the 100th of a gram



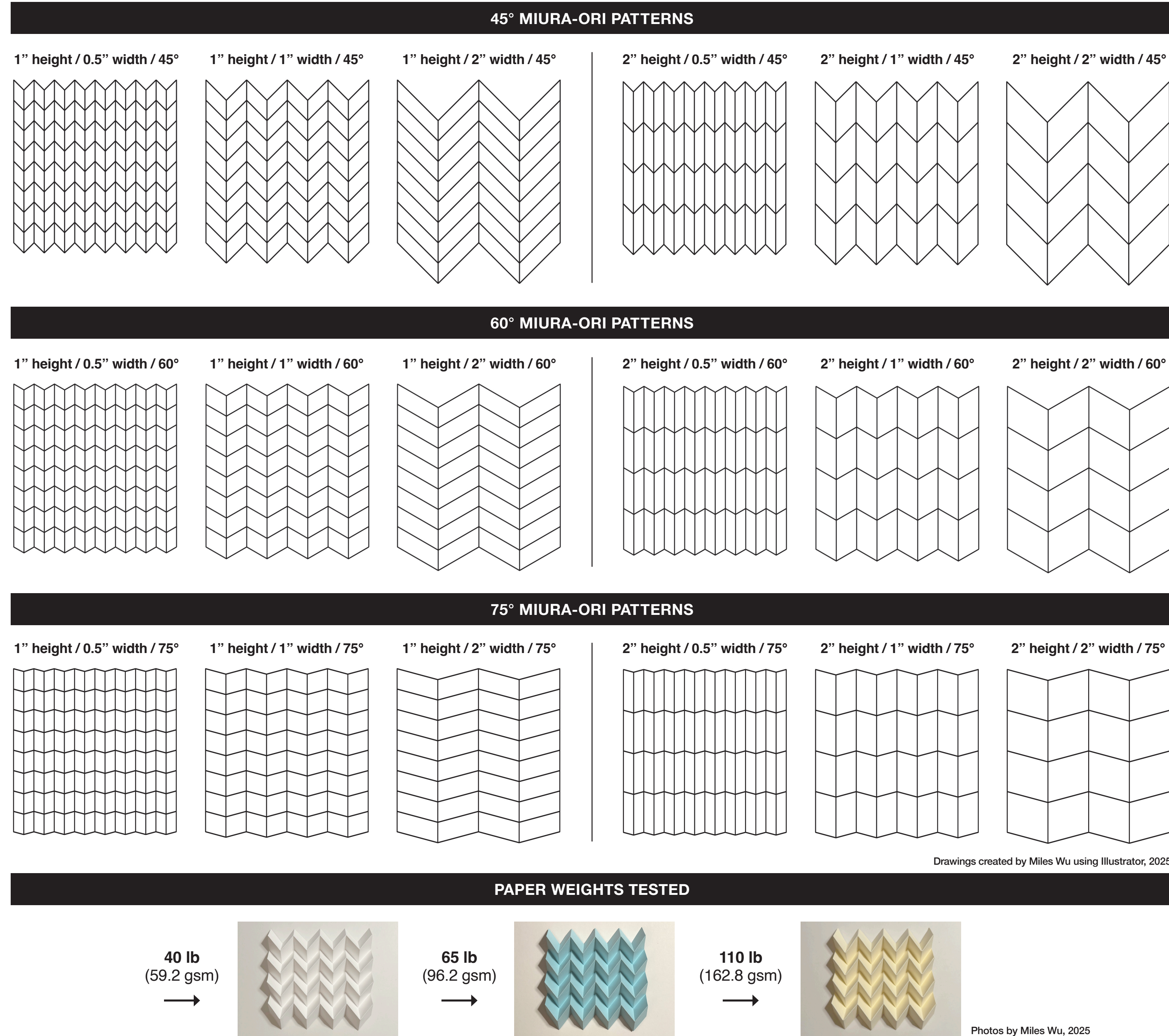
Constrained folded Miura-Ori between guardrails 5 inches apart; placed clear acetate sheet on top to distribute weight



Loaded heavy weights at regular intervals until total weight approached expected weight threshold (around 20-30 pounds less); added lighter weights at regular intervals until Miura-Ori collapsed or deformed (defined as loss of height of folded Miura-Ori)

Two trials per variant for accurate results

MIURA-ORI VARIANTS (FOLDING PATTERN AND PAPER WEIGHT)



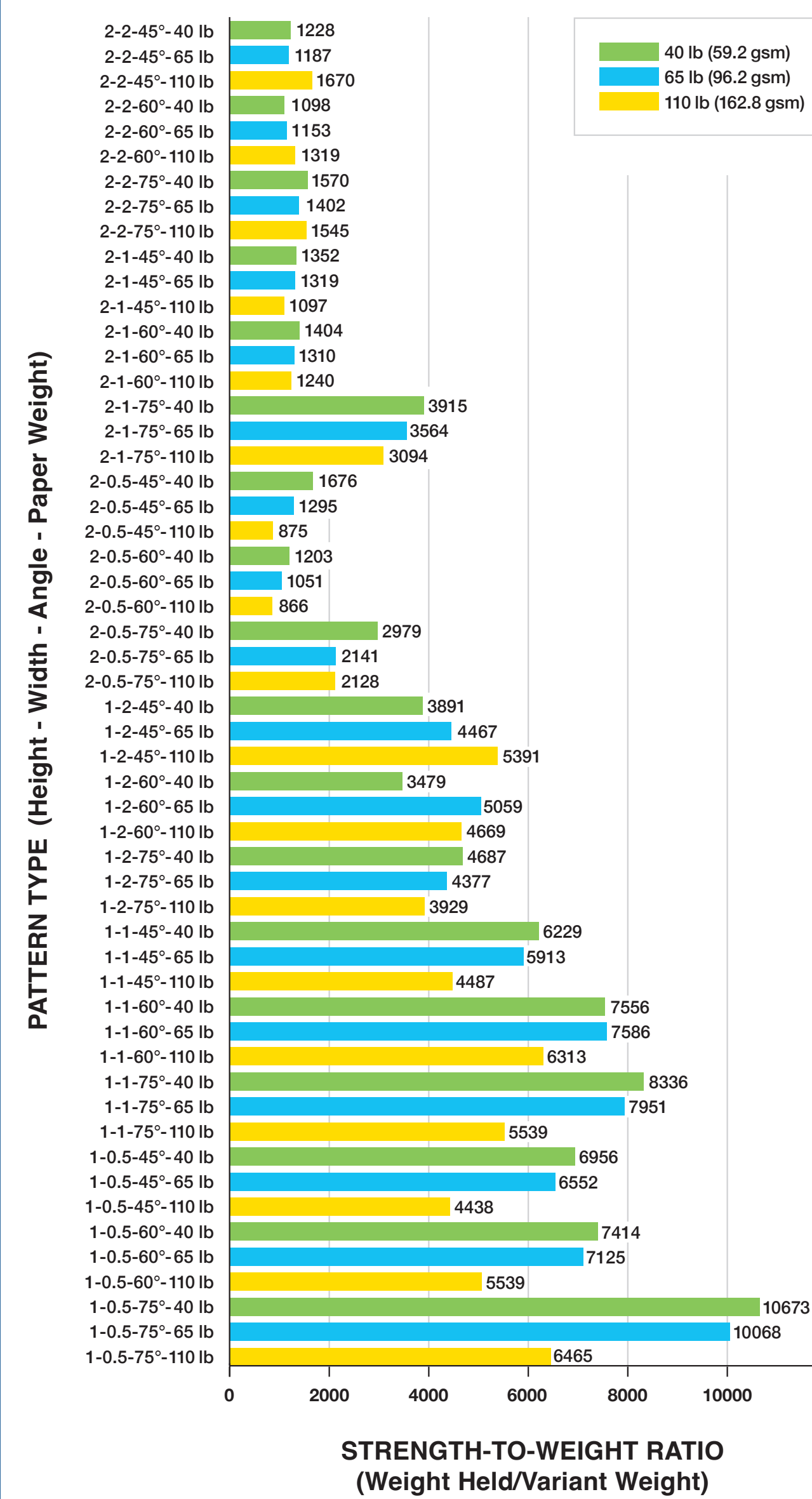
RESULTS

RAW EXPERIMENTAL DATA

			45°			60°			75°		
			Strength	Mass	Ratio	Strength	Mass	Ratio	Strength	Mass	Ratio
40 lb	2 height 2 width	1	7,166.76	6.14	1,167.22	6,985.32	6.24	1,119.44	6,679.63	6.11	1,420.56
		2	7,957.87	6.17	1,289.77	6,622.45	6.15	1,076.82	10,568.70	6.15	1,718.49
		Avg	7,562.31	6.155	1,228.50	6,803.89	6.195	1,098.13	8,624.17	6.13	1,569.53
	1 height 2 width	1	21,593.09	6.18	3,494.03	19,776.63	6.08	3,252.73	27,894.61	6.18	4,513.69
		2	26,501.17	6.18	4,282.22	22,981.06	6.17	3,705.20	29,846.08	6.14	4,800.76
		Avg	24,047.13	6.18	3,891.12	21,318.84	6.125	3,478.97	28,869.84	6.16	4,667.22
	2 height 1 width	1	7,438.91	6.12	1,215.51	9,477.54	6.1	1,553.69	24,786.80	6.12	4,050.13
		2	9,183.23	6.17	1,488.37	7,711.07	6.15	1,253.83	23,017.79	6.09	3,779.60
		Avg	8,311.07	6.145	1,351.94	8,594.30	6.125	1,403.76	23,902.30	6.105	3,914.87
	1 height 1 width	1	38,373.91	6.19	6,196.34	43,803.71	6.17	7,065.43	48,946.48	6.13	8,131.60
		2	38,555.35	6.16	6,258.99	40,401.87	6.14	6,045.91	63,114.30	6.22	8,539.28
		Avg	38,464.63	6.175	6,229.16	46,497.79	6.155	7,555.67	51,481.41	6.175	8,335.59
65 lb	2 height 2 width	1	10,135.77	6.12	1,656.17	7,076.04	6.12	1,156.22	15,805.67	6.19	2,553.42
		2	10,341.91	6.1	1,696.39	7,620.35	6.1	1,249.24	20,976.63	6.16	3,405.30
		Avg	10,239.84	6.11	1,676.28	7,348.20	6.11	1,202.73	18,391.16	6.175	2,979.36
	1 height 2 width	1	43,078.14	6.2	6,947.76	43,316.75	6.18	7,009.18	56,380.21	6.09	9,273.05
		2	42,686.67	6.13	6,963.57	48,396.99	6.19	7,818.58	74,614.63	6.18	12,073.56
		Avg	42,881.40	6.165	6,955.67	45,856.87	6.185	7,413.88	65,497.42	6.13	10,673.31
	2 height 1 width	1	8,890.41	7.32	1,214.54	7,983.23	7.27	1,098.11	9,253.28	7.13	1,297.80
		2	8,420.35	7.26	1,159.83	8,799.69	7.28	1,209.75	10,886.22	7.23	1,505.70
		Avg	8,655.38	7.29	1,187.18	8,391.46	7.275	1,153.43	10,069.75	7.18	1,401.75
	1 height 1 width	1	32,342.18	7.24	4,467.15	35,535.61	7	5,219.37	31,523.35	7.31	4,312.36
		2	32,477.21	7.27	4,467.29	35,809.86	7.31	4,898.75	32,158.38	7.24	4,441.77
		Avg	32,409.70	7.255	4,467.22	36,172.73	7.155	5,059.06	31,840.67	7.275	4,377.06
110 lb	2 height 2 width	1	9,616.16	7.32	1,313.68	9,434.72	7.28	1,295.98	24,403.27	7.29	3,347.50
		2	9,528.44	7.19	1,346.42	9,616.16	7.38	1,324.44	27,748.49	7.35	3,779.46
		Avg	9,570.80	7.255	1,318.25	9,525.44	7.27	1,310.26	26,091.89	7.32	3,563.58
	1 height 2 width	1	44,361.33	7.28	6,093.59	56,289.22	7.31	7,700.30	55,104.76	7.23	7,621.68
		2	42,184.09	7.36	5,731.53	53,567.67	7.17	7,471.08	59,782.16	7.22	8,280.08
		Avg	43,272.71	7.32	5,912.56	54,928.45	7.24	7,585.69	57,443.40	7.225	7,950.88
	2 height 1 width	1	9,162.57	7.16	1,278.69	7,257.48	7.16	1,096.12	14,253.46	7.24	1,970.09
		2	9,571.85	7.3	1,311.21	7,846.20	7.21	1,006.59	16,870.64	7.3	2,311.46
		Avg	9,367.21	7.23	1,295.45	7,842.20	7.185	1,051.35	15,566.55	7.27	2,140.77
	1 height 0.5 width	1	47,053.28	7.33	6,419.27	51,299.98	7.18	7,144.84	68,899.36	7.22	9,542.85
		2	48,401.95	7.24	6,685.35	51,299.98	7.22	7,105.26	77,336.18	7.3	10,594.00
		Avg	47,727.61	7.285	6,552.31	51,299.98	7.2	7,125.05	73,117.77	7.25	10,068.42
162.8 lb	2 height 2 width	1	21,591.00	12.53	1,723.14	17,508.07	12.5	1,400.89	20,713.35	12.52	1,654.42
		2	19,207.62	12.67	1,515.99	15,696.39	12.68	1,237.89	18,460.17	12.66	1,435.47
		Avg	20,399.31	12.6	1,619.57	16,602.53	12.59	1,319.29	19,586.76	12.69	1,544.95
	1 height 2 width	1	58,493.33	12.37	4,728.64	59,878.10	12.2	4,883.45	44,042.50	12.5	3,523.40
		2	75,975.26	12.55	6,003.81	56,475.73	12.68	4,453.92	63,749.38	12.4	4,334.63
		Avg	67,234.30	12.46	5,366.28	58,026.91	12.44	4,668.69	54,395.94	12.45	3,929.01
	2 height 1 width	1	14,968.55	12.54	1,193.66	14,696.39	12.55	1,171.03	38,190.38	12.65	3,098.05
		2	17,348.97	12.69	1,364.00	16,440.70	12.56	1,308.97	39,173.91	12.68	3,089.43
		Avg	16,348.57	12.615	1,097.25	15,568.55	12.555	1,240.00	38,682.15	12.665	3,093.74
	1 height 1 width	1	54,840.37	12.55	4,369.75	64,544.61	12.23	5,277.56	65,633.50	12.54	5,233.93
		2	57,938.97	12.58	4,493.26	90,671.53	12.34	7,347.77	72,346.66	12.38	5,843.83
		Avg	56,374.67	12.565	4,436.50	77,608.07	12.285	6,312.67	68,990.08	12.46	5,538.88
162.8 lb	2 height 0.5 width	1	10,704.78	12.71	842.23	11,203.73	12.56	892.02	28,002.68	12.74	2,198.01
		2	11,430.53	12.6	907.18	10,523.34	12.52	840.52	26,126.92	12.69	2,058.86
		Avg	11,067.65	12.655	874.71	10,863.54	12.54	866.27	27,064.80	12.715	2,128.44
	1 height 0.5 width	1	54,975.40	12.49	4,401.55	61,709.22	12.5	4,936.74	70,781.07	12.32	5,745.22
		2	56,014.04	12.52	4,473.16	66,330.10	12.7	5,222.84	69,673.99	12.48	7,185.41
		Avg	55,494.72	12.505	4,437.76	64,019.66	12.6	5,079.79	70,227.48	12.4	6,465.31

Data table created by Miles Wu using Google Sheets, 2025

STRENGTH-TO-WEIGHT RATIO OF MIURA-ORI VARIANTS



Data table created by Miles Wu using Illustrator, 2025

COMPARISON OF INDEPENDENT VARIABLES

	Highest STW ratio	Lowest STW ratio	% change between highest and lowest
Height	1 in.	2 in.	268.50%
Width	0.5 in.	2 in.	51.50%
Angle	75°	45°	51.80%
Weight	40 lb	110 lb	25.80%

- Percentage change in strength-to-weight (STW) ratio between highest and lowest levels of variables

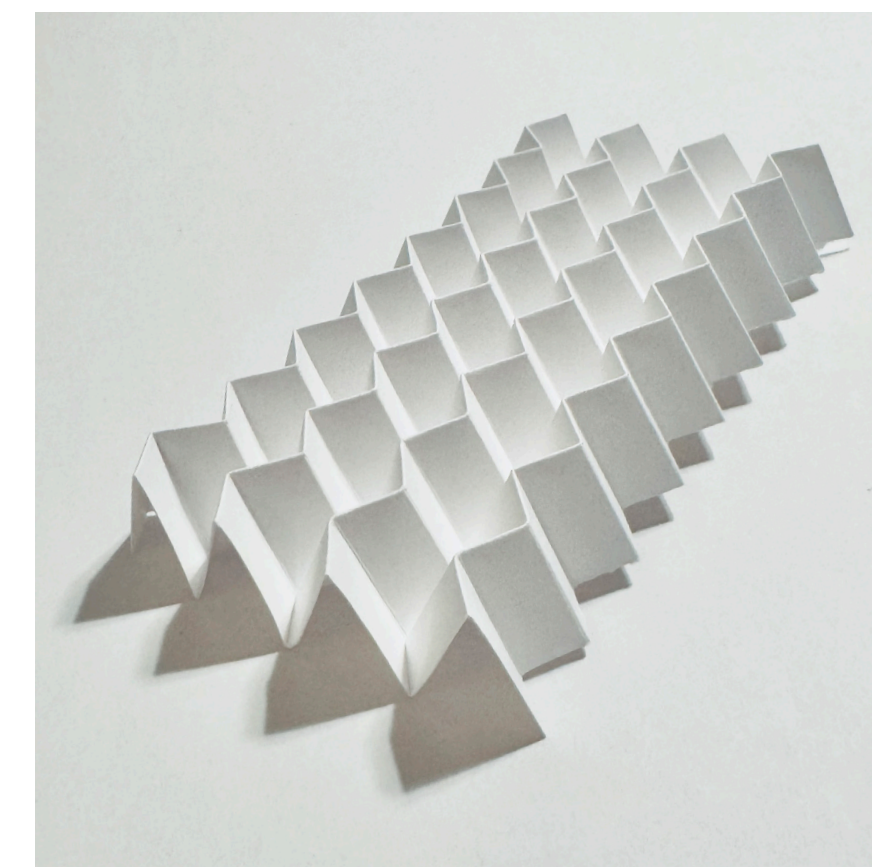
Data table created by Miles Wu using Google Sheets, 2025

DISCUSSION

- Hypothesis was mostly supported by data** — Miura-Ori with smaller and less acutely angled panels yielded higher strength-to-weight ratio; however the heavier paper did not in comparison to lighter paper.
- Miura-Ori can hold **thousands of times their own weight** — up to 10,673 times!
- The height of panels had a **major effect on the STW ratio of the pattern**: 1-inch height patterns had a 268.45% greater ratio than 2-inch height patterns.
- The Miura-Ori was very strong throughout all paper weights, and smaller and less acutely angled panels increased the STW ratio regardless of paper weight.

Potential sources of error:

- Human error in cutting, folding and testing was mitigated as much as possible through the use of digital cutting machines and the acetate sheet base (see procedure).
- Some Miura-Ori may have been misaligned through the cutting process, weakened during the folding process, or damaged while being stored.



The strongest Miura-Ori variant, with 1 in. height, 0.5 in. width and 75° panels made from the 40 lb paper

Next steps:

- Using professional lab equipment (this experiment was fully carried out within my living room) such as a hydraulic press, molds and a more accurate milling machine, in order to further mitigate human error
- Applying Miura-Ori to thick, rigid materials such as cardboard, wood or steel using hinges
- Testing the strength of Miura-Ori against not only lateral compression but multidirectional forces
- Prototyping a deployable structure like ones mentioned below

REAL-WORLD APPLICATIONS

Post-disaster temporary structures

- Easily transportable to disaster site via helicopter
- Quick and easy to deploy, no construction needed
- Strong enough to resist elements
- Could be developed from Miura-Ori curved into arches, or multiple Miura-Ori sheets combined to create rectangular or tent-shaped structures.



Post-disaster relief tents being constructed

Other applications in aerospace, robotics and materials science where origami is being used but could be optimized for increased strength

CONCLUSION