# The Luna-F.O.L.D. Mechanism

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# Specific Issue Being Addressed

- Protect mission critical assets from effects of **Plume Surface Interaction (PSI)** on the Moon.

- Directly approaching the prevention of exhaust reaching the ground.

# Plume Surface Interaction

- The interaction between the rocket exhaust and the lunar regolith.

- Can damage lander, block sensors, rip space suits and cause health risks for astronauts.

# Assumptions

- Data from Apollo missions were used as this data is most applicable to the Artemis missions.
- The lunar weight of the Starship HLS is assumed to be **485,000 lbs** and the landing feet are 6 ft diameter circles.

$$Starship\ Weight\ x\ \frac{g_{moon}}{g_{earth}}$$

- The landing zone would be free from large rocks and boulders, and would be relatively flat.

# Solution Method

- Create a physical barrier between the rocket and the lunar environment.
- Support the weight of the lander to prevent any sinking into the soil.
- Acts as a staging area for astronauts.

# The Luna F.O.L.D. Mechanism

1. **Landing Pad**

2. **Pneumatic Unfurling System**

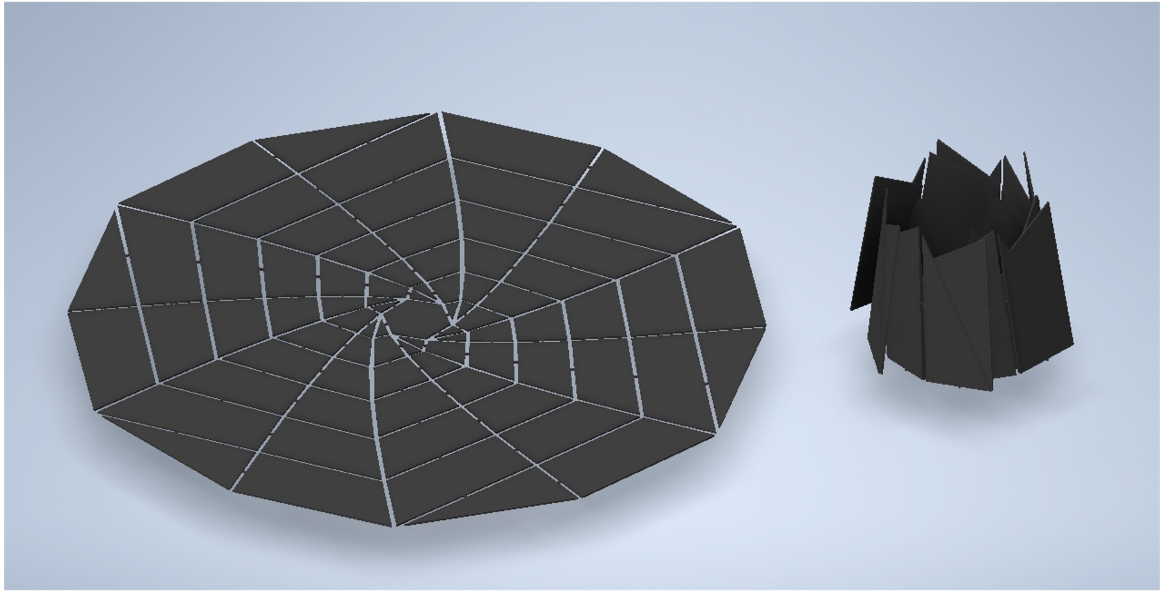


***Figure 1***: Folding Geometry

# Landing Pad System

- Reduces diameter by 5 times for transport.
- All segments are connected, meaning the pad moves all at once.
- Meant to completely prevent PSI.

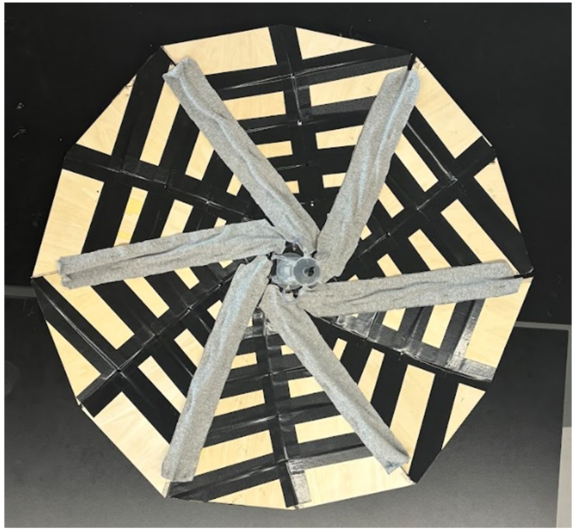


***Figure 2***: Scaled Prototype

# NASA Starshade

- Used to block light from stars.
- Uses origami to pack down efficiently.
- Inspiration for Luna-F.O.L.D.

***Figure 3***: Starshade [1]

# Linear Actuator System

- Impact force compresses working fluid.
- Pneumatic system unfurls landing pad.
- One time use.
- Center of Gravity located in foot of plunger to minimize likelihood of flipping after deployed.

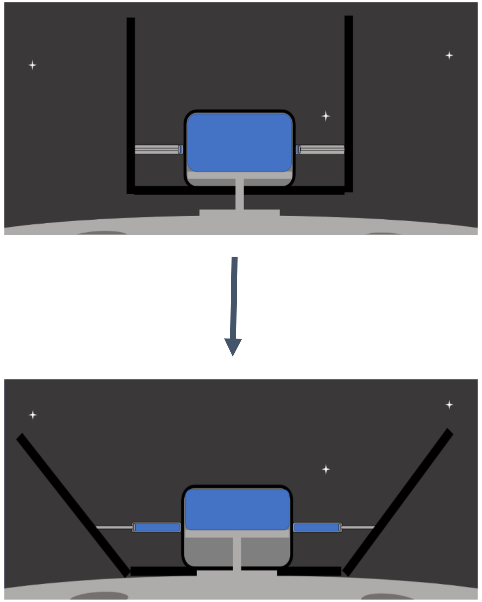


***Figure 4:*** Actuation Method

# Deployment Method

- Deployed from a secondary rocket before the Starship HLS arrives to the moon.
  - Height of **100-150 meters** above lunar surface.
  - Impact force drives pneumatic actuator system.

# Deployment Demonstration

# Prototype Testing

- Two tests to simulate a landing were performed, one with the pad and one without.
- A leaf blower was used to simulate rocket exhaust and flour was used to represent the lunar regolith.

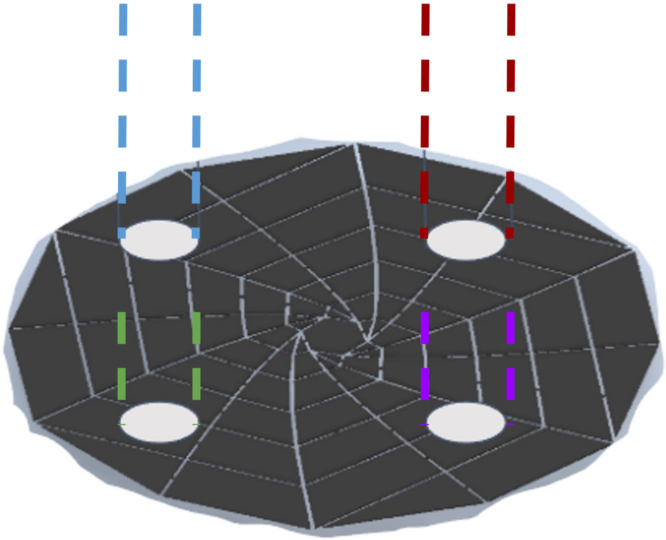
# Prototype Testing Video

# Full Scale Analysis

- Segments made from carbon fiber.
- Segments attach by being bridged with kevlar fabric.
- Parts coated in ceramic heat shielding.
- Scaled up to 60 ft in unfurled diameter.

# Boundary Conditions

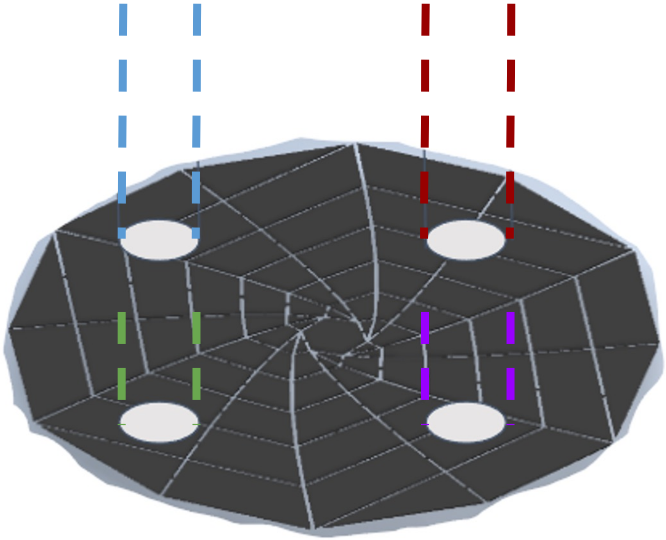
- 4 circular pressure loads placed symmetrically about center.
- P = 4,300 psf
- 6' diameter



- Regolith ground simulated using characteristics of quartz-silica beach sand[2].
- $\boldsymbol{\nu} \cong 0.270$[2]
- $\mathbf{E} \cong 475{,}000$ psf[3]

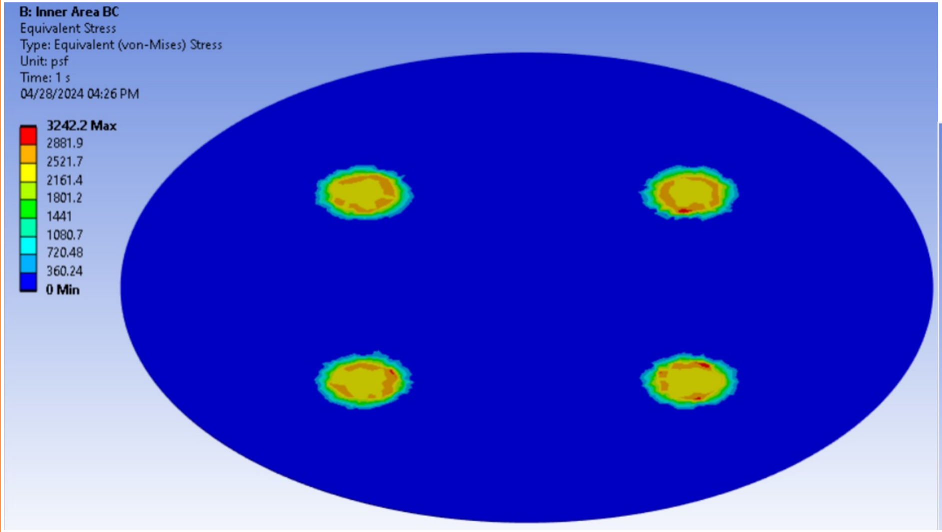
# Boundary Conditions

- Carbon Fiber used for pad segments[4].
- $\boldsymbol{\nu} \cong 0.2$
- $\mathbf{E} \cong 6.06 \times 10^9$ psf



- Kevlar used was DuPont Kevlar 49 Aramid Fiber[5].
- $\boldsymbol{\nu} \cong 0.36$
- $\mathbf{E} \cong 2.34 \times 10^9$ psf

# Full Scale Analysis



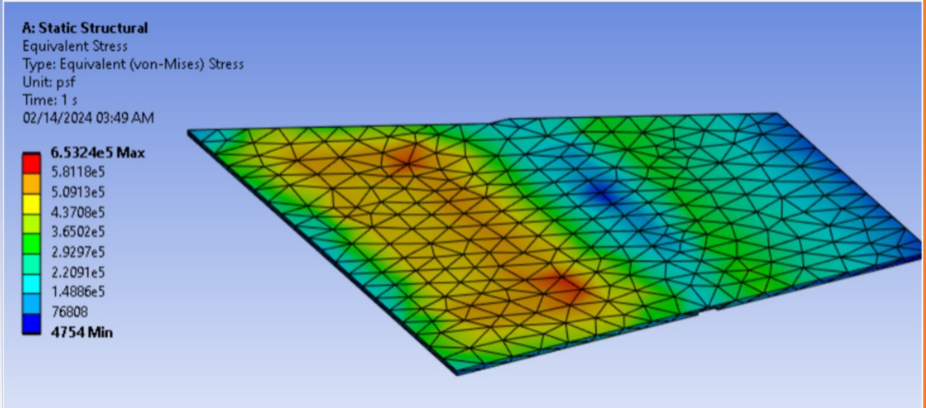




***Figure 5***: Stress induced by landing

***Figure 6***: Hinge Tension Analysis

# Hinge Material?

- Grey fabric and black tape regions.
- <u>Full Scale</u>: Materials to maintain integrity under extreme conditions

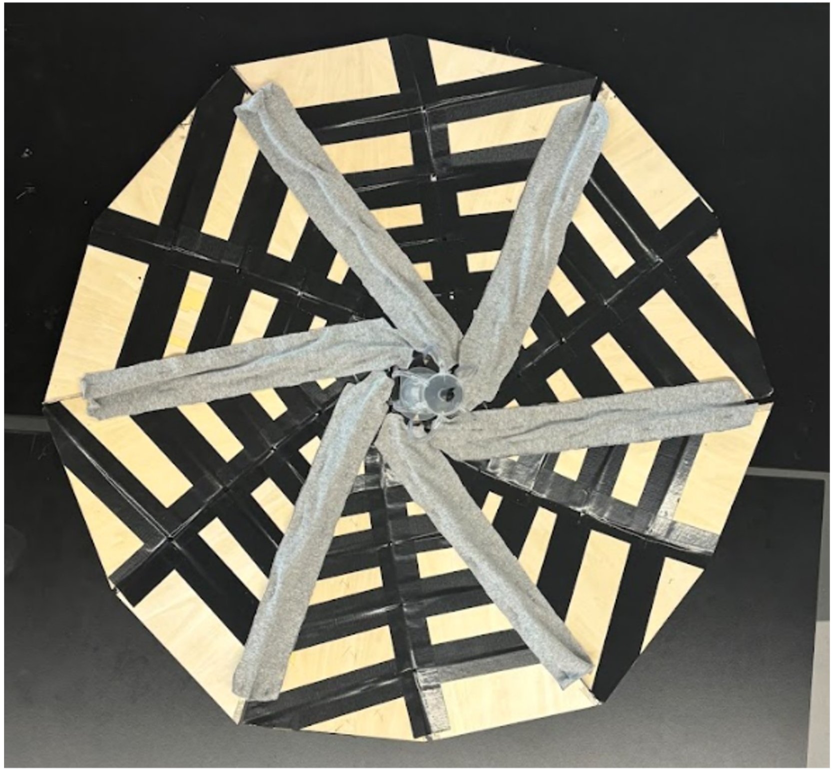


***Figure 7***: Hinge Material Location

# Full Scale Material Testing

- Potential materials were submerged in **liquid nitrogen**.
    - Simulate extreme temperature conditions present on the lunar surface.
- Samples were then tensile tested in an Instron machine.

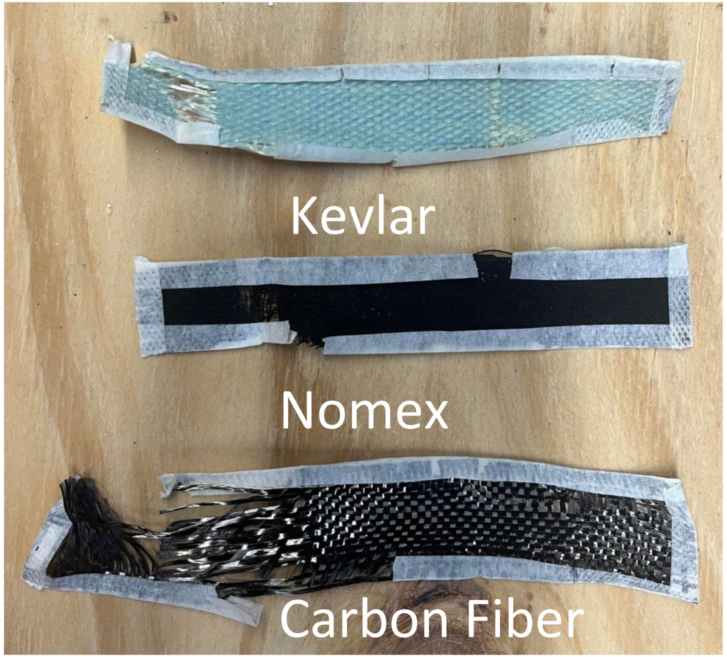



***Figure 8***: Tested Samples

# Full Scale Material Testing

- Kevlar was the strongest material tested.
- Under cryogenic conditions, it maintained a high tensile strength.
- Withstands projected stresses.

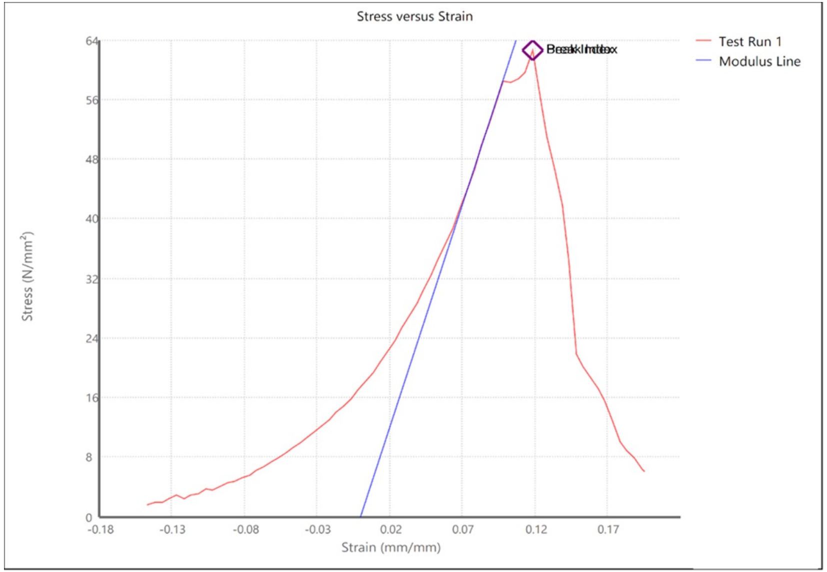



***Figure 9***: Ultimate stress curve for Kevlar, reaching **62.6 MPa**

# Full Scale Material Testing: Results

***Table 1:*** Peak Stress in Each Material

| **Material** | **Ultimate Tensile Stress (MPa)** |
|---|---|
| *Kevlar* | **62.6** |
| *Nomex* | **19.5** |
| *Carbon Fiber Cloth (Twill Weave)* | **42.2** |

# Full Scale Material Testing: Costs

***Table 2:*** Material Cost Comparison

| **Material**[6] | **Length** (in) | **Width** (in) | **Thickness** (in) | **Cost** ($/in$^2$) |
|---|---|---|---|---|
| *Kevlar* | **12** | **60** | **.024** | **0.0492** |
| *Nomex* | **12** | **12** | **.010** | **0.3328** |
| *Carbon Fiber Cloth (Twill Weave)* | **36** | **50** | **.025** | **0.0867** |

# Closing Remarks

We believe this is a cost-effective and innovative method of nullifying plume-surface interaction.

Questions?

# Citations

[1] “Capturing the art and science of NASA’s origami starshade,” *Photography*, Jun. 15, 2024. https://www.nationalgeographic.com/photography/article/art-science-nasa-starshade-origami-behind-the-cover-february

[2] S. K. Thota, T. D. Cao, and F. Vahedifard, ASCE, tech. https://par.nsf.gov/servlets/purl/10202899

[3] M. G. Kalyanshetti, S. A. Halkude, D. A. Magdum, and K. S. Patil, AJER, tech. https://www.ajer.org/papers/v4(08)/ZG04802440249.pdf

[4] ANSYS Workbench Database

[5] “DuPontTM Kevlar® 49 Aramid Fiber,” MatWeb, https://www.matweb.com/search/datasheet.aspx?MatGUID=77b5205f0dcc43bb8cbe6fee7d36cbb5&ckck=1 (accessed Jun. 4, 2024).

[6] McMaster-Carr, https://www.mcmaster.com/ (accessed Jun. 4, 2024).