# ***Additive Manufacturing On The Moon – 3D Printing With Aluminum***

## Project Overview

With Artemis missions, NASA will land the first woman and first person of color on the Moon, using innovative technologies to explore more of the lunar surface than ever before. We will collaborate with commercial and international partners and establish the first long-term presence on the Moon. Then, we will use what we learn on and around the Moon to take the next giant leap: sending the first astronauts to Mars[(1)].

One of the many challenges involved is to reduce the cost of building, and maintaining, a human habitat on the Moon's surface. Current estimates place the cost of shipping material to the Moon at $15,000 per kilogram[(2)].

NASA is studying the feasibility of mining aluminum on the moon. Once the process of isolating aluminum is determined, the next phase will involve using this resource as a building material. Creating products using in situ materials will dramatically reduce the cost of shipping finished products from Earth.

Some universities and companies are being tasked with extracting aluminum from lunar regolith and turning the aluminum into products, including the use of 3D printing.

Stakes for tarps, or guide wires, are a test product for printing on the moon. Stakes are a simple, one piece part, and by implementing additive manufacturing techniques it is possible to reduce mass by designing an internal matrix that maintains structural integrity.

Despite the apparent simplicity of a stake, identifying the optimal design for use in abrasive lunar regolith is challenging. Your objective is to design and test a stake that can be printed in aluminum that satisfies multiple building requirements.

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**Project Objective**

## The purpose of this project is to design, 3-D print, and test a stake, that is anchored in lunar regolith by astronauts wearing a pressurized space suit.

We don't want to waste the aluminum produced on the moon, so the structure needs to be strong and hold in the dirt well, while using as little material as possible. 3D printing allows for a semi-hollow internal matrix that reduces the total amount of material needed. However, we want a design that compromise ductility, tensile, or compressive strength.

Minimize support material—we don't want the astronauts to have to spend time deburring the tarp stakes, nor do we want to use the aluminum in unnecessary locations



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## Project Requirements

Design, print, and test a stake that will hold securely in a lunar regolith simulant with the least amount of material and the most strength.

- Maximum length 6”
- Must not be a trip hazard
- Must include an attachment to a drill
- Can be driven into the regolith using a drill while in a space suit which allows crouching, but does not allow kneeling.
- Once inserted the stake must be attachable to both guide wires, and tarp material. Keep in mind that most tarps have grommets with a fixed diameter hole, but don’t limit your design ideas to grommets exclusively.
- Many stakes are inserted at an angle. You need to do testing to determine the best angle for insertion, and a method to assist astronauts wearing pressurized space suits. You may want to design an wedge, or guide, if your testing indicates their value.
- CAD must be reproducible for printing in aluminum
- Grommet Hole size 1/2” with 1.05” flange, space 1” from the edge of the tarp
- https://www.mcmaster.com/products/grommets/grommets~/fabric-grommets-6/
- Student teams decide how the tarp stake attaches to the grommet
- The stake could be printed in more than one piece if it saves from having support material and it is easy to assemble without falling apart.
- Two tests in approved lunar regolith simulant
    - 1. vertical pull
    - 2. guy wire pull—stake is driven into the ground at 30 degrees. Wire attached and pulled at 45 degrees
    - What is the right angle to test?

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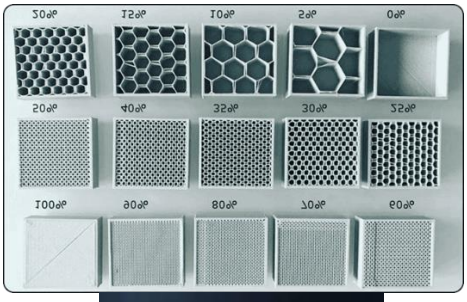
## Factors To Consider

**The top 5 teams selected during the Critical Design Reviews will have their design printed in aluminum by Elementum 3D in Colorado for the Final Design Review.**


- What Internal structure will minimize mass, and maximize strength?
- Is it better to have solid threads or could there be value to small holes in the threads to capture particles?
- One of the biggest problems with being on the moon is the dust. Instead of walking through it all the time, there may be value in having tarps to act as sidewalks to minimize the amount of dust the astronauts get into—an early temporary fix to dust. We will need to hold down the tarps with some kind of tarp stake so people aren't tripping on them. We may also need to keep equipment like radio towers and other equipment from being blown around by the rocket exhaust from landers by staking them down with guy wires.
- Minimize trip potential once stake is in place
- What is the optimal angle for stake and guide wires?
- You may need to design a device (wedge?) that will assist in drilling stake at desired angle.
- What is the effect of abrasive lunar regolith on edges of spirals?•
- Is a regular drill, or impact drill more efficient at insertion and removal?
- Is the core of the stake important or needed?
- We have provided several articles related to printing in aluminum, please read and make sure you are understand the process.
- If you have questions, ASK!!!

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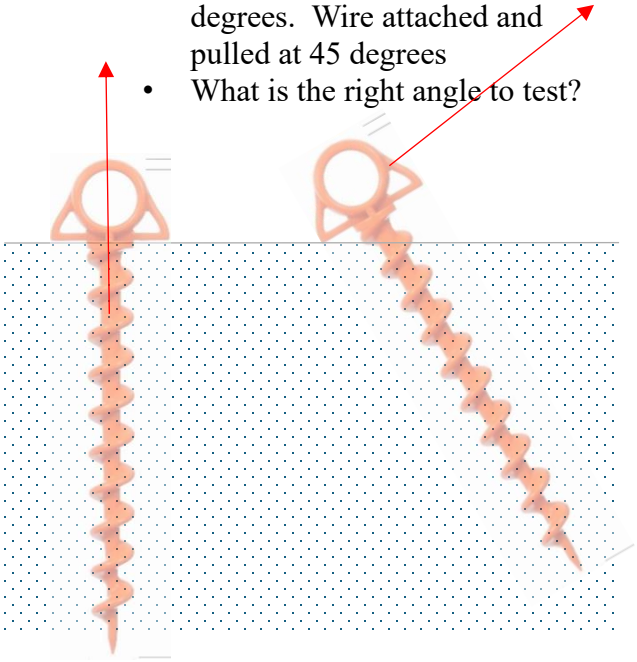
## Testing

- Testing must be done using a lunar regolith simulant
- Video tests
- Record force applied to stake in pounds.
- How much force is needed to pull stake out of ground? Conduct multiple tests
- How much force is needed to deform the stake? Conduct multiple tests.
- Conduct multiple pull tests to determine optimal angle for stake and guide wire ($30^0$ ?, 450 ?, etc.)
- Demonstrate ability for astronaut in space suit to (pressurized gloves, minimal bending) to insert and remove stake
- Using some kind of force sensor or fish scale test to see how much force is required to remove the stakes.
- 1. vertical pull
- 2. guy wire pull—stake is driven into the ground at 30 degrees. Wire attached and pulled at 45 degrees
- What is the right angle to test?



## References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