METALS: Metallic Expandable Technology for Artemis Lunar Structures

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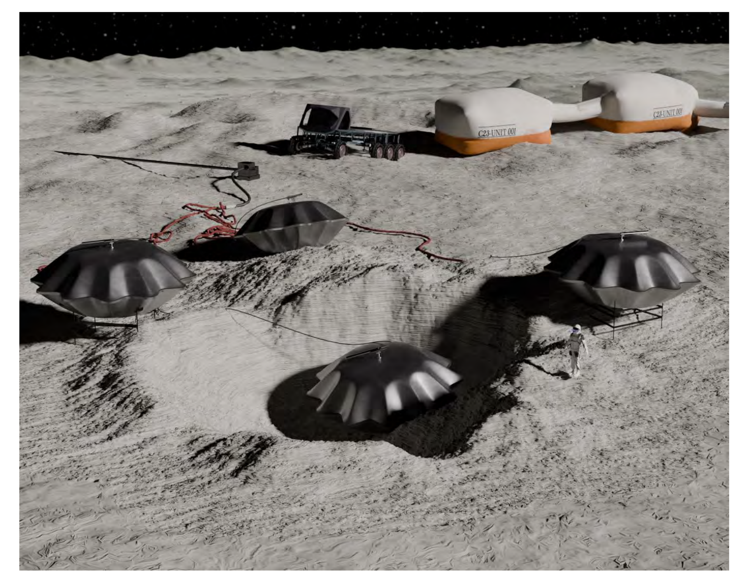
Abstract: METALS is an inflatable system which utilizes edge-welding of sheet metal to create objects which expand and plastically deform, giving them superior puncture, temperature, and radiation resistance over traditional inflatables. Modules are optimized for use in cryogenic storage.

Overview

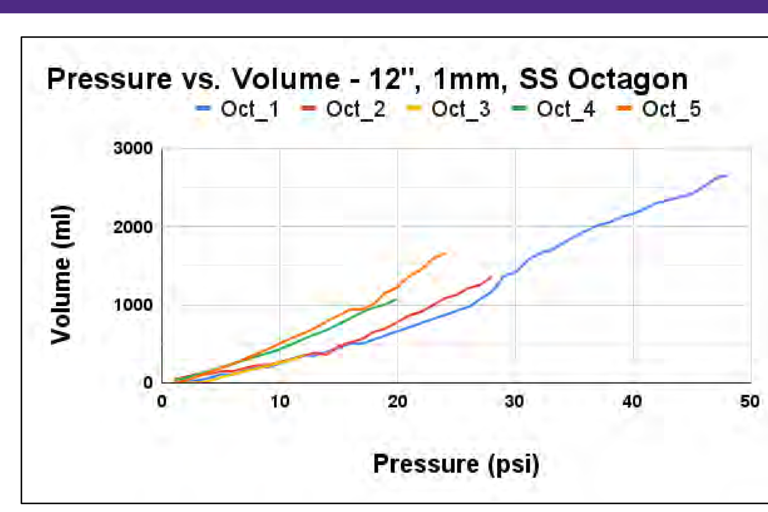
Inflatable technologies will be critical to a scaled, sustainable lunar human presence, but existing polymer-based inflatables are susceptible to lunar environmental conditions (including drastic temperature fluctuations, space irradiation, and abrasive lunar dust), making them largely unsuitable for long-term infrastructure development. Metal-based inflatables can provide extraordinary improvements against each of these environmental hazards, thus enabling the packing and deployability advantages of inflatable technologies with survivability characteristics suitable for the rapid and sustainable development of a permanent human lunar presence.

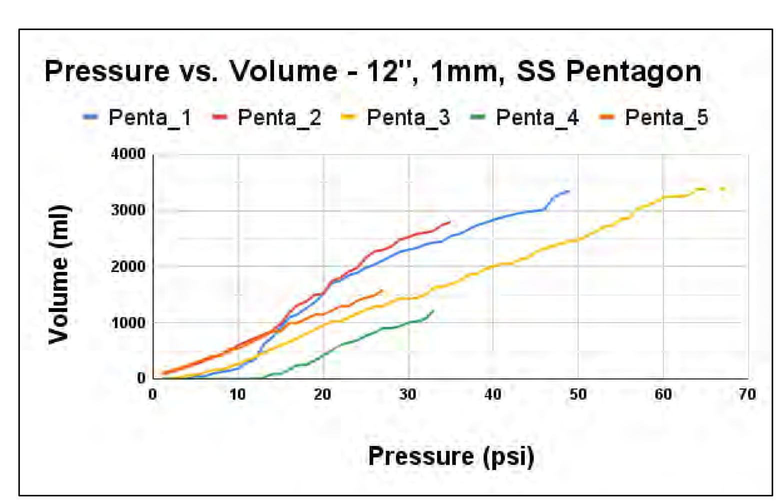


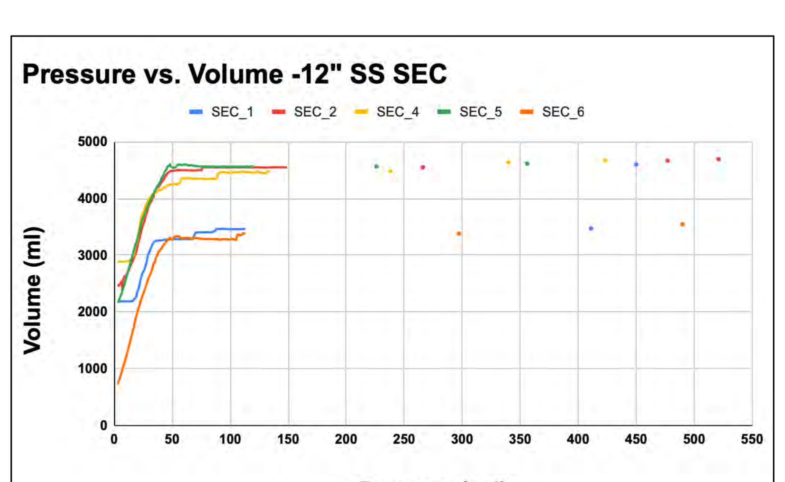
This project has demonstrated a rapid, affordable, and accessible method for manufacturing metal inflatables, in which two identical pieces of sheet metal are cut and welded at their aligned edges to create a small enclosed volume. After packing flat within a lunar lander, the inflatable can be pressurized and deployed to create large internal volumes. Critically, the metal deforms plastically during inflation, allowing it to maintain its deployed configuration even when internal pressurization is lost.

Experimental Validation

The simple and affordable METALS manufacturing process allowed the team to manufacturing and test over 300 designs, including pentagon, octagon, circular, and various sinusoidal-based configurations. While most designs inflated continuously under their burst pressure was reached, the SEC design was distinctive for quickly reaching its maximum deployed volume and maintaining that volume for pressures far exceeding other designs.







Other experiments were performed to assess performance under relevant lunar conditions and mission scenarios, including vacuum leak testing, inflation at cryogenic temperatures, heat transfer modeling, repairability testing, and compression/reinflation testing.

Design and Optimization

The entire design space of METALS is defined, by the 2D shape cut from stock sheet metal, along with alloy selection (stainless steel), sheet metal thickness, and inflation pressure. The 2D shape must be optimized to reduce stress concentrations and encourage controlled buckling when inflating from 2D to 3D, thus maximizing both deployed volume and working pressure.

SEC Pre-Inflation

By matching the sinusoidal stress and buckling patterns observed computationally and experimentally in spherical inflatables, and optimized design called the Sinusoidal Edged Circle (SEC) was found, with boundary defined by $r = R + A\cos(F\theta)$, where R is a base radius, A is the sinusoidal amplitude, F is the sinusoidal frequency, and (r, θ) define polar coordinates.

SEC Post-Inflation (Side View)

SEC Post-Inflation (Top View)

Key Accomplishments

- Demonstrated a simple and reliable manufacturing process for metal inflatables, enabling accelerated production times, reduced fabrication costs, and accessible entrance my future commercial suppliers, enabling rapid optimization, scalability, and flight qualification for METALS modules within the decade.
- Optimized Sinusoidal Edge Curve (SEC) design maximizes deployed volume and working pressure.
- Successfully demonstrated scalability of SEC design up to 48” diameter, creating pathway to scale for Artemis-relevant storage capacities.
- Inflation within a vacuum environment demonstrated no irregularities with atmospheric testing.
- Punctures can be easily repaired using a metal patch or filler material
- Ideal performance is achieved when modules are inflated at high temperatures (for maximum ductility, toughness, and deployed volume). Cryogenic testing demonstrated that these modules can then be pressurized with cryogenic fluid without failure.

METALS is a high-value, low-risk, low-cost inflatable solution for scalable, sustainable lunar infrastructure and cryogenic fluid storage within the decade.