Tubular Truss Additive Manufacturing Lunar Utility Tower. Jack Sorensen[1] and Thomas Murphey[1], [1]Opterus Research and Development, Inc. (815 14th St SW Suite C200 Loveland, CO 80537, jsorensen@opterusrd.com, tmurphey@opterusrd.com)

Introduction: As commercial and government entities advance lunar infrastructure in the late 2020s and early 2030s, establishing reliable, scalable, and versatile power and utility structures will be essential. Various masts and trusses have been proposed to support the development of lunar utility infrastructure, such as those developed under the NASA Game Changing Development Lunar VSAT program [1]. Because of the strict mass and volume constraints for launch, a lightweight, highly compactable and deployable solution is necessary to achieve the required tower heights and array sizes for operational functionality.

Tubular Truss Additive Manufacturing (TTAM) offers a robotically assemblable solution for deploying large structures on the lunar surface and on orbit. TTAM utilizes a robotic riveting mechanism alongside Opterus's Trussed Collapsible Tubular Masts (TCTMs) and Recirculating Belt Deployers (RBDs) to autonomously deploy and assemble a truss. An example of the TTAM system is shown in Figure 1. The TCTM booms are constructed with High-Strain Composite (HSC) materials made from fiber-reinforced polymers, which have a greater strength-to-weight ratio and a lower coefficient of thermal expansion than metal-based alternatives. HSC materials enable TCTM to be rolled and stowed with exceptional packaging efficiency, and enough material to assemble a 100m truss can be packaged into a volume less than 1m^3.

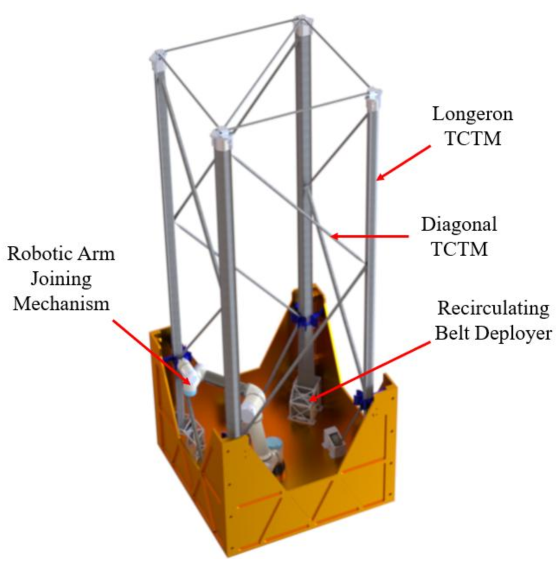

Fig. 1. TTAM Assembly Concept

Assembly Process: TTAM uses an RBD to unfurl longeron and diagonal TCTMs and a robotic mechanical fastening method to join the trusses with rivets. During the TCTM manufacturing process, holes are placed incrementally along the length of the booms. The edges of the holes are reinforced with composite stiffeners on the diagonal booms and metal grommets on the longeron booms to prevent the composite fibers from fraying and provide a rigid backing for the rivet clamping force. As booms deploy, the robotic mechanism identifies hole locations with visual tags, limit switches, or conductive strips and inserts rivets using its end effector. Because of the compliant nature of the TCTMs, the robotic arm can correct alignment errors between the diagonal and longeron booms by adjusting the diagonal boom position. In collaboration with the NASA Jet Propulsion Laboratory robotics team, the riveting process was successfully demonstrated in a laboratory environment. This demonstration, shown in Figure 2, utilized visual identification methods and a robotic end effector to align the riveting holes on the diagonal and longeron booms and apply a rivet.

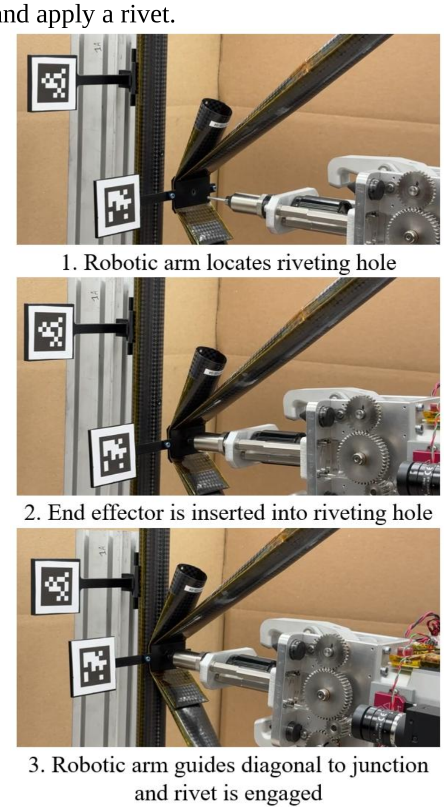

Fig. 2. Demonstration of Robotic Joining of TTAM Truss Junction

The assembly method utilizes low-power deployers and mechanical fastening at truss junctions, which greatly decreases power requirements compared to competing joining methods such as thermal forming, welding, curing, or 3D printing.

Applications and Outfitting: Once assembled, a TTAM tower can support and integrate various equipment, such as photovoltaic arrays for power generation, communication and power beaming systems, light-reflecting mirrors for heat directing and spotlighting, and research equipment such as imaging and sampling instruments. Figure 3 shows an assembled system concept.

Concepts for a fully outfitted tower have been generated. Electrical wiring can be cocured into the TCTM laminate or threaded through the hollow cross-section. The composite materials used have a near-zero coefficient of thermal expansion and provide thermal protection to the wiring, preventing excess expansion and contraction along the tower's height. Additionally, the junction locations along the truss can be used as mechanical and electrical connection points for equipment, which can attach to these locations and access the power network. A platform affixed to the tip of the tower serves as a hub for equipment requiring a wide range of sight over local terrain or nearby infrastructure.

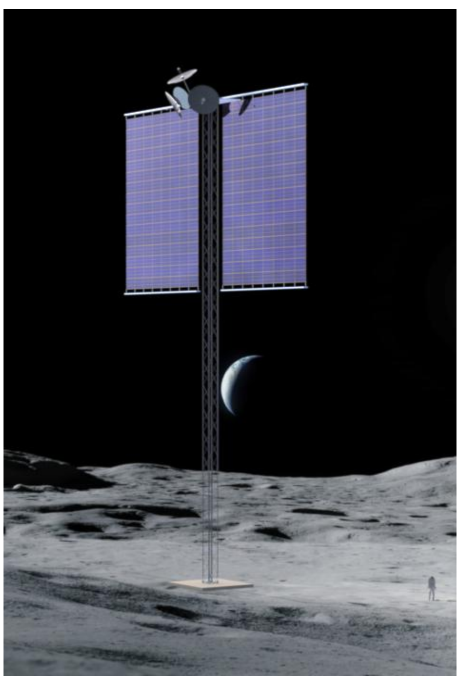

Fig. 3. TTAM Lunar Tower Concept Rendering

The assembled length of the truss is only constrained by the length of the stowed booms. TTAM's current architecture could support heights over 300m. Taller structures overcome terrain blocking access to direct sunlight, enhancing capabilities such as power generation, surveillance, and operating hours in areas such as the lunar south pole. Furthermore, TTAM's assembly rate is several meters per hour, making large towers operational in a matter of days.

A baseline architecture and assembly Concept of Operations have been developed, but the design is adjustable based on particular applications and desired capabilities. The TCTM cross-sections and truss dimensions are scalable to support various loads and lengths. Additionally, removable fasteners or magnets can be used at truss junctions to enable the truss to retract for servicing and relocation.

Performance: Opterus TCTMs are thin-walled collapsible tubes that provide truss-like strength and stiffness while maintaining extremely high packaging efficiency and low manufacturing costs. By joining TCTMs into a truss, the structural efficiency is increased further, greatly outcompeting similar architectures when considering stiffness, strength, and mass efficiency. The structural performance of a TTAM truss has been experimentally and analytically validated to provide sufficient load-bearing capacity for the use case described [2].

References: [1] Taylor, Chuck and Pappa, Richard "Space Technology Mission Directorate Game Changing Development Program – Vertical Solar Array Technology Project." [2] Aulicino, Alexa et al. (2024) "Structural Testing of and ISAM Truss Architecture for Large Space Structures."