BUILDING THE FIRST MICRO SPACE FOUNDRY PROTOTYPE AND THE PATH TO TRANSFORMING SPACE DEBRIS INTO A SPACE RESOURCE

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Introduction: In 2021, with NASA and private funding, the CisLunar Industries team advanced their vision for an in-space metal processing system from concept to a working benchtop prototype. Fully realized, this Micro Space Foundry (MSF) system will enable the recycling of spent upper stages, satellites, and space debris, transforming otherwise dangerous materials into space resources. The MSF will reprocess metal from space debris into metal propellant rods and basic metal materials in the form of wire filament, rods, and other geometries useful for In-space Servicing, Assembly, and Manufacturing (ISAM).

In this paper we present the results from research conducted in collaboration with Nanoracks and the Colorado School of Mines under a NASA Phase I SBIR. We also discuss progresss made since the conclusion of the Phase I SBIR, plans for the upcoming NASA Phase II SBIR, and the potential impact of space debris recycling on active debris removal and the industrial in-space economy.

Results of the NASA Phase I SBIR: Building on the legacy of the EML (Electromagnetic Levitator) operating on the ISS [1], CisLunar Industries demonstrated the initial feasibility of using an electromagnetic induction furnace to produce useful materials from simulated cut space debris. Nanoracks provided data for debris location, composition, and methods for harvesting metal feedstock from captured space debris. The results of multiple tests, both in and out of vacuum, showed that ribbon and strip geometries offer numerous processing advantages over chips. Finally, using the prototype MSF, metal propellant rods were produced in vacuum conditions, tested in the Neumann Space vacuum arc thruster testbed, and shown to produce thrust [2].

To highlight the envisioned ecosystem, on October 19, 2021, the Colorado School of Mines hosted CisLunar Industries for a live demonstration its benchtop prototype MSF. Astroscale, Nanoracks, and Neumann Space joined the event to demonstrate the complete value-chain and show how space debris can be captured, cut, recycled, and used as a spacecraft propellant.

Demonstration of Automatic Rod Making

Aluminum 6061 ribbon feedstock was fed directly into a mold via the ribbon feeder to produce a propellant rod meeting requirements of 25mm diameter, and ≥ 25mm length. To simplify the experiment, the 3mm center hole feature was added with a post machining process prior to testing in the Neumann Thruster testbed.

Figures below show the basic rod forming process:

1. Ribbon is fed into the mold forming a melt ball which fills the mold
2. Feedstock ribbon is retracted from the melt
3. The induction coil is turned off, allowing the melt to cool
4. Solid rod is easily removed from the mold due to shrinkage during cooling

Figure 1. Steps of the rod forming process.

To create the automated rod maker, the original sample collector was modified by adding a Z-axis for vertical movement and replacing the alumina crucibles with two-piece boron nitride molds. Rods were cast while the mold moved down in relation to the induction coil to provide uniform heating and push the melt into the mold. After the rod cooled the molds were automatically lowered and the carousel indexed to a position that extracted the finished rods.

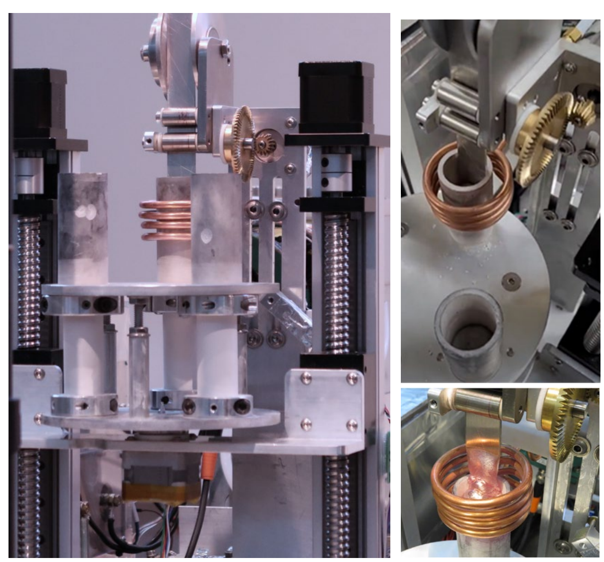

Figure 2. Automatic rod former.

Demonstration of thrust from a metal propellant rod made by CisLunar Industries

CisLunar Industries supplied cast Al 6061 rods made in vacuum with the benchtop prototype from recycled material for testing in the vacuum arc thruster being developed by Neumann Space. The metal propellant samples were shaped to fit early generation test hardware, and thus were 25mm diameter, ~30mm long cylinders with a 3mm center-bore hole drilled to accept the arc triggering electrode.

Figure 3. Aluminum propellant rod in a vacuum arc thruster test bed.

During testing Neumann Space confirmed that the prototype propellant generated impulse in line with expectations. Initially Isp was observed to be lower as the outside layer of aluminum oxide was ablated, but quickly ramped up as the aluminum alloy was exposed. These results indicate that recycled structural aluminum material can be used to generate thrust in space-like conditions, without the need for additional material refinement. As such, recycled space debris represents a promising in situ source of metal propellant which should be investigated further. Successfully refueling debris removal spacecraft with the debris they are capturing could lead to a significantly more cost-effective, scalable, and economically sustainable solution to the orbital debris challenge.

Progress after NASA SBIR Phase I: Building on the promising results of the NASA Phase I SBIR, CisLunar Industries significantly advanced the size and efficiency of its Micro Space Foundry technology. The power input to heat the same amount of metal was reduced by a factor of three. The size of the system was reduced from that of a toaster oven to less than 1U. Improvements in efficiency further resulted in dramatic reductions in active heat extraction requirements.

Outlook: CisLunar Industries' NASA Phase II SBIR proposal was recently awarded and will proceed over the next 2 years. In this next phase, we will continue development of key components and subsystems resulting in a functional prototype capable of demonstrating the manufacture of rods and wire on the International Space Station (ISS) under persistent microgravity.

Two processing approaches for the Micro Space Foundry will be evaluated:

1. An investment casting approach that produces rods of discrete length through a molding process;
2. A continuous casting approach, capable of casting rods and other forms of unlimited length.

Based on the results of this trade study and risk assessment, one of the foundry testbed concepts will be down selected for use in the working prototype for demonstration on the ISS.

Lessons learned from the ISS and follow-on in-space demonstrations are expected to lead to deployment of the first commercially available Micro Space Foundry in the mid-2020's

Conclusion: In the near term, the existing need for space debris clean-up coupled with the ongoing and increasing deployment of mega-constellations demands a more scalable, economically sustainable solution. Successful development of CisLunar Industries' Micro Space Foundry technology combined with key partner capabilities will enable the utilization of space debris as a space resource for propulsion and in-space manufacturing.

Converting space debris into a resource could accelerate the development of key technologies along the entire ISAM value chain, and drive the emergence of a robust, commercially-driven in-space economy, while simultaneously creating and maintaining a sustainable space environment.

References:

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[2] Neumann P. R. C. , Bilek M., McKenzie D. R., A centre-triggered magnesium fuelled cathodic arc thruster uses sublimation to deliver a record high specific impulse, Appl. Phys. Lett. 109, 094101 (2016)