**WORLDS FIRST DEMONSTRATION OF CONTINUOUS METAL CASTING IN MIRCOGRAVTIY FOR ISAM AND SM&L**

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**Introduction:** CisLunar Industries is developing a modular Space Foundry solution to enable the processing of metals for In Space Assembly and Manufacturing (ISAM) and propulsion for Space Mobility and Logistics (SM&L). In a Phase I NASA SBIR project we successfully demonstrated the feasibility of on-orbit recycling using an electromagnetic induction furnace [1] in vacuum. The reach goal of producing metal propellant rods and testing the thrust on a Neumann Space pulsed plasma thruster [2] was also accomplished.

NASA Phase II work is intended to mature the stated technology to TRL 5 through demonstration in relevant environments, including microgravity by means of a parabolic flight. Results to date are presented in this work.

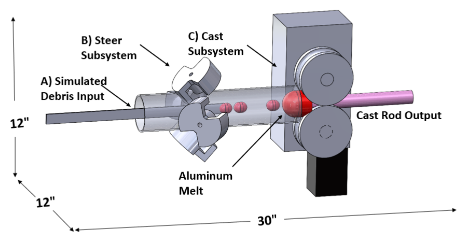


*Figure 1. Conceptual design for Continuous Casting MSF*

**Materials and Methods:** CisLunar Industries tested Steer and Cast subsystems of the modular space foundry (MSF) in a parabolic flight. In the final configuration metal is transported from the Steer subsystem to the Cast subsystem. For alpha parabolic flight testing the Steer and Cast subsystems were separated. The Alpha Parabolic flight payloads flew 30 zero g parabolas with Zero-G.

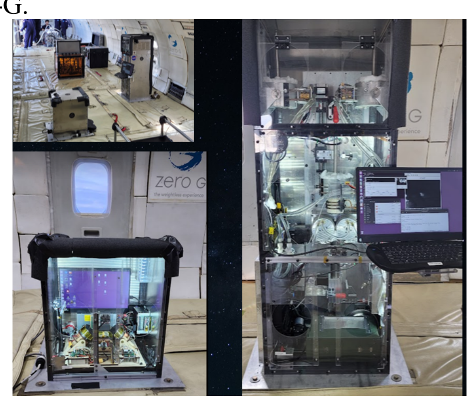

*Figure 2. CisLunar Industries Alpha Parabolic "Steer and Cast" Payloads*

*Cast Subsystem Setup.* The continuous Cast payload utilizes moving molds to "continuously" cast metal into a 25mm diameter rod. For the purpose of the alpha test metal is fed from induction heated sample cartridges preloaded with 300g samples of aluminum material continuous cast.

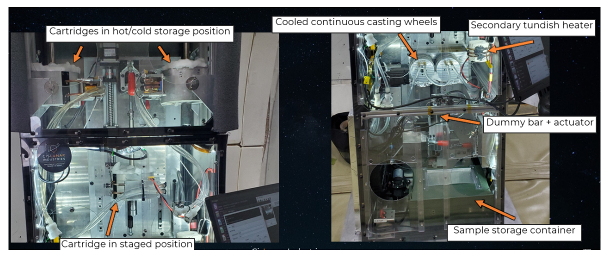


*Figure 3. CisLunar Industries Space Foundry alpha parabolic Cast Subsystem.*

*Steer subsystem setup.* The Steer payload is designed to group and feed metal strips and chips into the Cast process. For the alpha configuration Steer consists of 4 independently controlable induction coils which shape their combined fields to move metal samples within a control region. The Steer experiment focused on the positional stabilization of aluminum objects within the EM fields in zero- g.

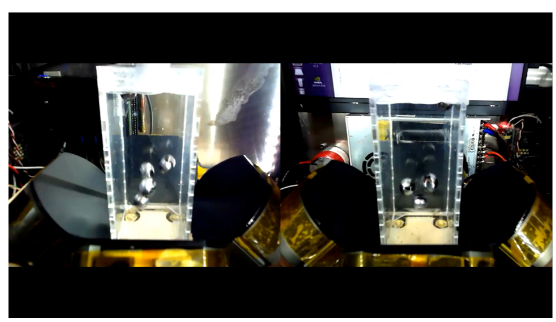

*Figure 4. CisLunar Industries Space Foundry alpha parabolic Steer Subsystem.*

**Results:** *Cast subsystem.* The continuous casting system produced a partial rod in microgravity. The microgravity portion of the rod was evidently fractured and displaced by the increased pressure that occurred during hyper-gravity. This breakout required extra intervention to reset for the next test. The system reliably produces rods in 1G and several unknows related to operation in the zero-g environment were realized. Results from the test provided critical verification of ability to cast in zero-g and how to design for the zero-g environment.

*Figure 5. Left- partial rod cast during zero-g, right- rods cast in 1G,*

*Steer subsystem*

Test object positioning and grouping was successfully demonstrated in Zero-g.

*Figure 6. Grouping of simulated aluminum debris in paraboilic flight with CisLunar Industries EM Steer.*

**Discussion:** *Cast subsystem improvements*

Parabolic flight and subsequent testing have shown that we need improved regulation of the melt temperature and the tundish tip temperature to improve the quality of the casted material. Furthermore, concept development is ongoing for a tundish "tip" which has integrated induction heating that allows for thermal control during the casting event.

*Steer subsystem improvements.* The stability of microgravity in Zero-G flights is less than "stable". Greater control over induction coils provides improved holding power to overcome pertubances. For future parabolic flight testing, using water or another fluid to fill the container may prove advantageous in terms of cancelling out the shaking motion of the aircraft.

**Conclusions:** Continuous casting in microgravity has been demonstrated for the first time. Results were promising, and also helped to improve the system for future parabolic flights. The following improvements to the MSF system have been identified:

1. Temperature regulation of the aluminum melt and tundish nozzle to improve consistency and repeatability of the casting process.
2. Reduction or elimination of steel components for the furnace system due to the degradation of this material at molten aluminum temperature.
3. Develop tooling and processes for machining and joining ceramics to facilitate new tundish designs without steel.
4. Improve Steer system control as operation in the limited time window and shaky environment of parabolic flight makes existing Steer system impractical in terms of delivering molten metal to the casting system.
5. Continue Steer system research on ground – more detailed modeling and ground testing and verification to learn what this technology may be suited for.

**Outlook:** CisLunar Industries' NASA Phase II SBIR continues through spring 2024. In this next phase, we will continue the development of key components and subsystems and prepare for a second parabolic flight in Q3 of 2023. Based on the results of this parabolic flight the system will be improved to produce a working prototype for demonstration on the ISS.We will demonstrate the manufacture of rods on the International Space Station (ISS) under persistent microgravity in Q4 2024 with ISS- National Labs. Lessons learned from the ISS and follow-on in-space demonstrations are expected to lead to deployment of the first commercially available Modular Space Foundry in the second half of the 2020's.

**References:**

[1] Diefenbach, A., Schneider, S., & Volkmann, T. (2020). Experiment Preparation and Performance for the Electromagnetic Levitator (EML) Onboard the International Space Station. In Preparation of Space Experiments. IntechOpen.

[2] Neumann P., 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)