2023 NASA Entrepreneurs Challenge

Technical Submission Round 2

Applicant Name: Moon Matter Makers
Applicant Affiliation:Collaboration between Crimson Ag, and Jinxbot 3D Printing LLC
Technology Focus Area Chosen: Lunar Payloads

Team Members:

- Dr. Alexander Litvin (Team Captain)
- Mr. Jason Reynolds

SECTION ONE:

1. **Relevance to Challenge Technology Focus Area**

Our approach utilizes In-Place 3D printing with moon dust to support human lunar presence and a robust lunar economy, focusing on the LI-4 objective. By utilizing in-situ resources, we reduce costs and logistical challenges associated with transporting materials from Earth. The autonomous 3D printer enables faster establishment and expansion of human presence on the moon, aligning with the Challenge's focus on industrial scale ISRU capabilities.

By printing manufacturing components from regolith, our solution aligns with NASA's scientific objectives for Lunar Payloads by reducing cost and logistical challenges by utilizing in-situ resources, while providing fast and local manufacturing components for future habitat designs. Printing is done by a minimally constructed rover, the Robo Regolith Sinterer, which collects and filters lunar regolith powder which is then fed to a Selective Light Sintering (SLS) printing apparatus, utilizing traditional additive manufacturing principles. While the minimal architectural design of the rover greatly reduces its mass, its design is fully scalable; allowing for adaptation of resizing to meet any payload and power requirements for logistics.

2. **Impact & Significance of Objective**

Moon Matter Makers' additive manufacturing solution using regolith offers logistical and economical advantages for NASA's Lunar Payloads. By utilizing lunar resources, costs and challenges are reduced, eliminating the need to transport raw material to the moon for construction. Custom structures can be created on-site, enhancing and customizing habitat design and enabling long-duration human presence while reducing dependency on resupply missions. This makes feasible new and larger scientific endeavors on the moon and elsewhere by implementing the practical application of Additive Manufacturing with rovers and furthering interest in the expanded possibilities of NASA research

If successful, our approach would greatly expand and accelerate humanity's foothold on the moon. By using lunar material to safely and inexpensively, build large infrastructure, NASA would be able to build habitats not only for large scientific instruments, but also an expanding population

SECTION TWO: ***Innovation of Approach (10%)***

3. **Solution Novelty, Competition and Technology Superiority**

The system is an integration of two established technologies, giving them a novel application. Firstly, it employs foundational principles from rover robotics. To this, we've integrated an SLS 3D printer tailored to harness moon dust as its primary resource. What sets our design apart is its utilization of concentrated sunlight for the sintering process, eliminating the need for the battery system to power a laser. This sun-driven approach considerably reduces the need for additional components, making the system both lightweight and efficient, especially in extraterrestrial conditions. Its design is energy-conservative; the rover can recharge its battery, accumulate lunar regolith, and commence its printing operations. The sintering process relies on a Fresnel lens to focus solar energy while the onboard power is chiefly dedicated to the system's mechanical components, like servos for the lead screws and the galvos directing the sunlight. Once the printing phase concludes, the machine expels the completed part. As the rover progresses, it sequentially deposits a trail of lunar-crafted building materials.

High costs and logistical challenges due to the need for transporting raw and finished materials from Earth create a barrier for future expansion under current practices. Additionally, current print technology can be slow or have components requiring frequent servicing. Resolving these challenges involves minimizing or eliminating material transport and reducing the need for repairs or on-site maintenance.

With SLS printing using regolith, our initial concept was to make simple bricks or tiles that could be applied to lunar habitations to aid in construction, buildings, and protection from radiation. With the versatility of the additive manufacturing system (the SLS system on our rover), we can also use it to make piping, conduit, and other useful construction items as well. Our dedicated SLS construction rover technology surpasses other approaches by reducing size, complexity, and energy requirements. It eliminates the need for material transportation from Earth by utilizing lunar regolith as the raw material, reducing costs and logistical challenges. By employing concentrated sunlight with a Fresnel lens, our method enables diverse structures and eliminates potential clogging issues seen with FDM printing, offering a sustainable, cost-effective, and dependable solution for lunar additive manufacturing. By cleverly adapting existing technologies like rover robotics and 3D printing, and refining only essential methods/components, we've designed an innovative integrated system. This system not only expedites lunar base construction but also bolsters human presence on the moon. Moreover, it presents an automated solution that could potentially save billions of U.S. dollars. (Jones, 2018).

The wheels of the rover are based on the mars rover system, building off established and proven technology by NASA. By attaching system components together in a novel way, we reduce risk from unproven new technology. Through merging proven robotic designs with our methodologies, we aim to establish IP protections for the automation process and system design. Our diverse expertise in systems design research and additive manufacturing gives us confidence in developing a competitive regolith SLS Additive Manufacturing solution with robust IP protections. Furthermore, we seek to make our solution generalized so that it can address different problems as they arise. Initial system designs would be applicable for lunar construction through unabated solar energy driving the light/heating source for sintering, and additional versions of the system for terrestrial applications on Earth, Mars, and beyond.

Because travel to space is currently dangerous for humans, the solution as it pertains to NASA would be composed 100% of parts that could be salvaged and reused for astronaut needs. This includes the paneling type, screws, structure, and even electronic components. By doing so, we leverage an additional value-add aspect to support the safety and well being of astronauts in the event of a crisis. This design and intended uses presents substantial value and benefits to NASA missions and aligns well with the aim of establishing a sustainable human presence on the moon.

SECTION THREE: ***Technical Credibility of Approach (20%)***

4. **Technical Feasibility**

Our proposed technology utilizes concentrated sunlight to melt lunar dust, shaping it into patterns using an autonomous rover mounted 3D printer. Combining the SLS printer onto a lunar rover enables on-site construction, while sensors and navigation systems ensure precise control and obstacle avoidance during the printing process (Fig. 1).

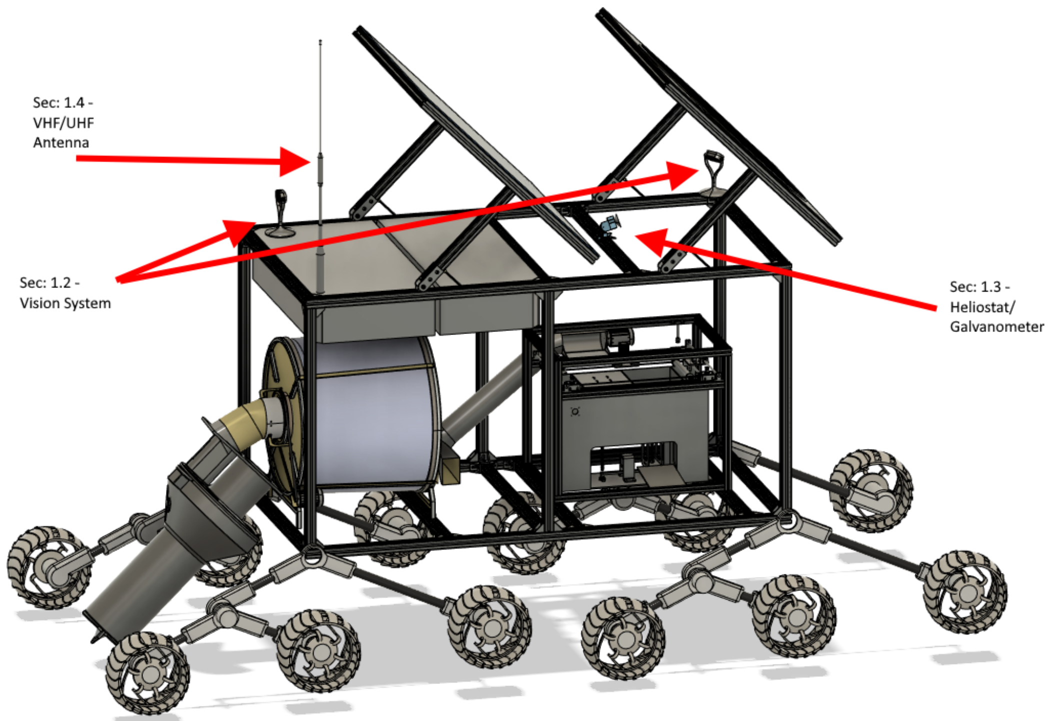

Fig. 1: Rover design locations of primary navigation and tracking system and communication antenna.

The primary principles of this technology are as follows:

Navigation section: Navigation via GPS is not an option on the moon. Camera vision and LiDAR sensors will provide the basic mode of navigation for the rover. This will allow the rover to perceive its immediate surroundings for identifying nearby obstacles and hazards, as well as the initial roll out of the lander and preparation for normal working parameters. A higher degree of accuracy will not be needed in the rover's movements as the collection and sintering of the regolith are done separately. Solar alignment for the Fresnel lens and the solar panel do not need to be adjusted frequently adding to the simplicity of the system. To further increase rover positioning tracking, the rover will deploy 2 beacons upon landing, with a third beacon remaining on the lander to establish a navigation triangulation of the area. These beacons will operate a tracking network through Bluetooth BLE Angle of Arrival technology (You and Wu, 2019). The computer vision enhanced camera system will be the primary component for hazard avoidance. In conjunction with general mapped data downloaded prior to launch, and BLE beacon navigation, the camera system is the final determinate for avoiding large rocks, craters, and initial evaluation of surrounding area for appropriate regolith printing supply.

Beacon section: Bluetooth beacons can provide a low energy use tracking method that can accurately track to less than 0.1m within a large indoor setting such as supermarkets and hospitals. Accuracy of tracking can be further increased by controlling the distance of the target from a given beacon, the frequency of pings for tracking, speed of the target being tracked, power usage, and sophistication of the components used for both the beacons and tracked target. To further improve precision, our approach seeks to use high quality electronics available commercially using a higher transmission signal. While this would drain a power source more quickly, a 3V battery with 1,000 mAh capacity may be sufficient to last a year with broadcasts every 350 ms (Locatify, 2016), connecting a small solar panel should allow for higher frequency pings without concern to power consumption. With the rover pausing movements and requesting additional pings for positioning, and the lack of interfering signals and structures on the moon, we expect an accuracy within cm, which is more than sufficient for the rover's needs.

Fresnel Lens section: Solar light is unobstructed by an atmosphere on the moon, resulting in high radiative potential. The rover will use a large Fresnel lens to harness this radiation and concentrate it into a beam for heating/sintering and aggregating lunar regolith. On Earth, a Fresnel Lens deployed under sunny conditions providing 7.5 KWh/m^2 with a lens of 1 m^2 can produce between 1,400 to 1,600 °C; sufficient to melt and sinter silica sand (Al-Dabbas, 2013; Tang et al, 2003; Wang et al., 2013). Lunar regolith requires approximately 1,200 °C for sintering (Warren et al., 2022). As solar radiation in space is more intense in the absence of an ozone layer as shown in cases of reduced ozone layer areas (Bais et al., 2018) and breadth of radiation type in space (Restier-Verlet et al., 2021), the lens needed for the rover is expected to be substantially smaller than its equivalent on Earth. This allows for additional backup lenses to be brought for redundancy. The Fresnel lens and solar panel are situated above the rover framed by respective extruded aluminum frames, and pivoting on an arm that is perpendicular to the frames. This pivoting will be computer controlled via a lead screw.

Solar Panel section: The solar panel composition will be gallium arsenide based on prior success on the International Space Station (ISS). Currently a single solar array wing on the ISS is approximately 35 m long by 12 m wide, producing 30kW of power, and equates to approximately 4.65 mW/cm^2 (Gietl et al., 2000; Saenz-Otero and Miller, 2005). The Robo Regolith Sinterer will dedicate 1 m^2 to solar panels, providing 46.5W when in direct sunlight. With a lunar synodic period of approximately 29.5 Earth days, 14.75 of which with sunlight (Schaefer, 1992), this should provide ample power to run electronics while maintaining sufficient charge to keep the system online through a lunar night.

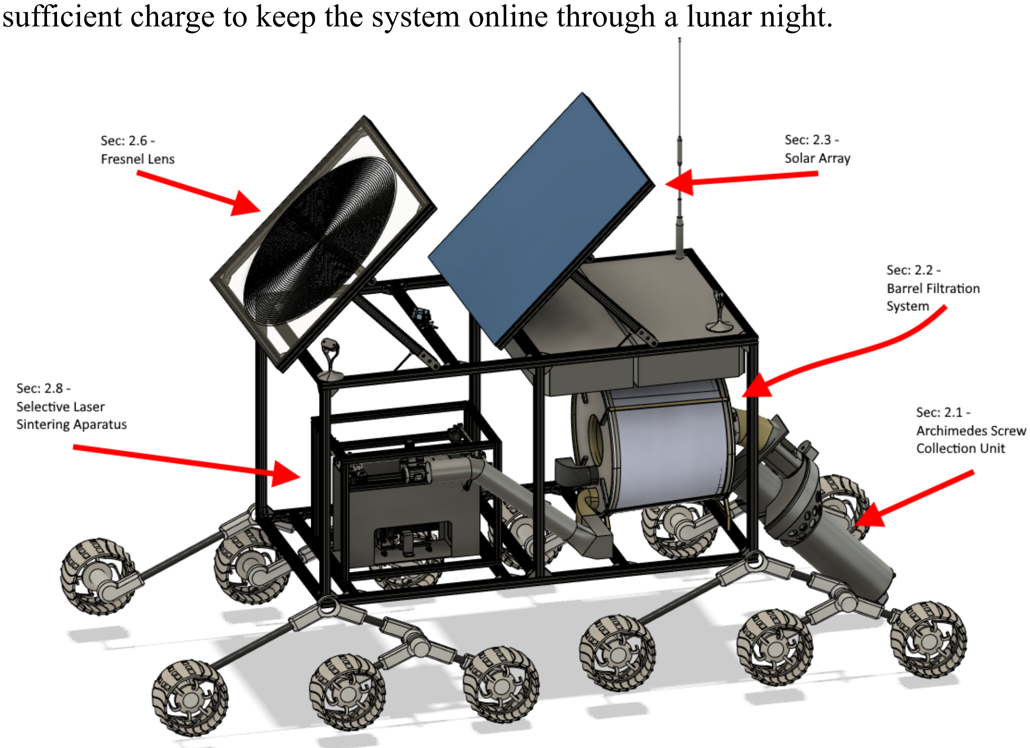

Fig. 2: Rover locations for regolith processing (Sec. 2.1, 2.2, and 2.8), and solar (Sec. 2.6 and Sec. 2.3).

Rover build: The rover itself will be minimally constructed to conserve weight (Fig 2). It is composed primarily of readily available aluminum alloy extrusions or a more wear resistant stainless steel option. The 1 x 2 meter structure sits on an established rover wheel design, which gives the system its mobility. The structure houses the connection for the Archimedes screw style regolith collection unit (Fig 2 Sec 2.1), which feeds into the barrel type double rotating filtration system (Fig 2 Sec 2.2). Once the regolith is filtered it is transported and deposited into the adjacent SLS system (Fig 2 Sec 2.8). Above the barrel filtration system, two sealed containment units will house the electronics and battery system, respectively. On top of the body structure, connections for the communications antenna, and visual feedback system (Fig 1 Sec 1.2 & 1.4) ensure there is no interference from the structure itself. Two pivoting arms at the top of the structure connect the solar array (Fig 2 Sec 2.3) and the Fresnel lens (Fig 2 Sec 2.6), providing power and light to the system. The rover's main purpose is to autonomously create building materials without human interaction, programmable to print anything needed, including different shape bricks, blocks, piping, or conduit to fit unique or unexpected scenarios.

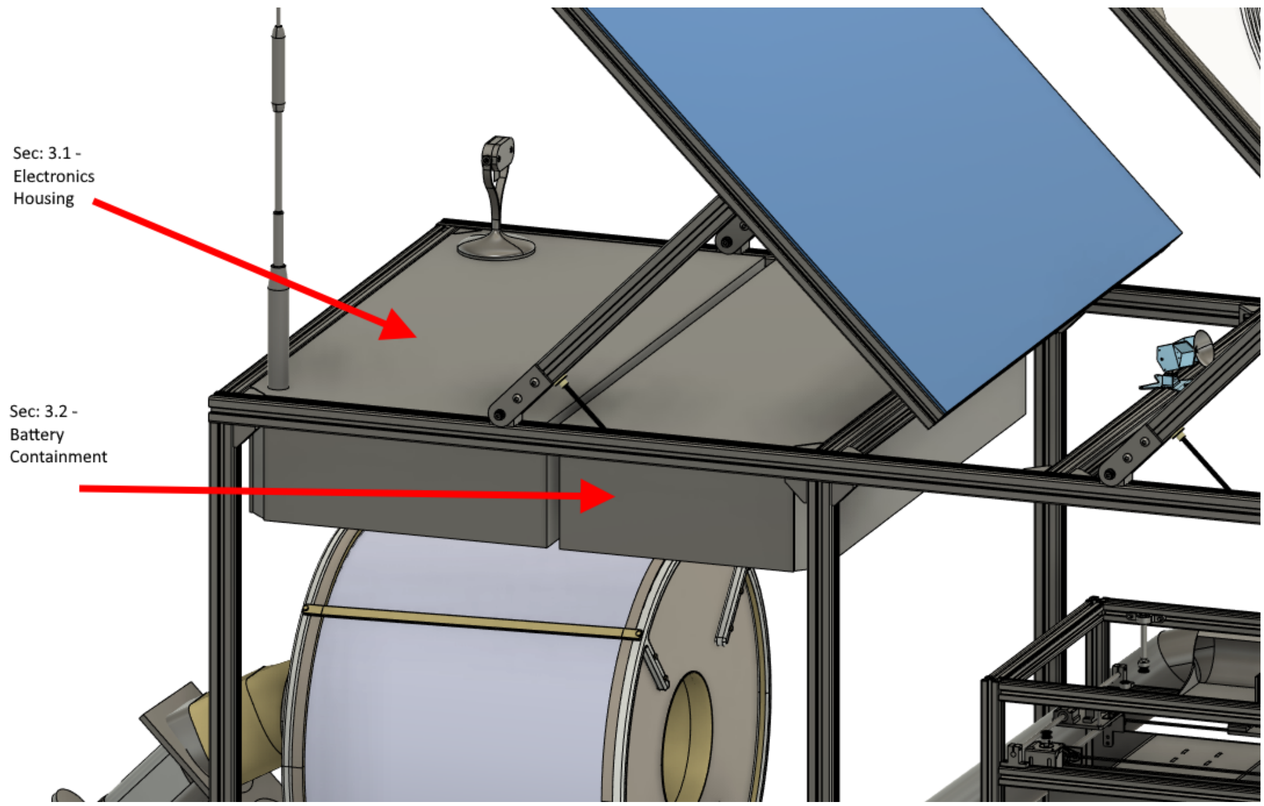

Fig. 3: Rover locations of the computer and power supply systems.

Main power for the rover is needed only to run periodic communication protocols, navigational systems, its movement of both the solar array and Fresnel lens, traversing the area, and other general computer applications. As such, the battery will be a 40Ah solid state power source (Fig 3 Sec 3.2), located at the top front of the rover. While this will provide less power than 160Ah total as found on a Mars rover (Ratnakumar et al., 2006), rover usage does not need to be constant. Primary power needs occur under full light conditions when the solar panel would be in operation, and night-time operations would be limited to minimal traversing landscape and maintaining component integrity. The battery pack would currently be designed with 18650s or 21700s as they are established, consistent, and readily available. The design provides an updated power source to the previous lithium-ion generation of batteries used for Martian rovers while still providing the 28 volt power in line with general NASA applications such as rovers and space shuttles (Ratnakumar et al., 2006; Saenz-Otero and Miller, 2005). This even allows for the power source to be compatible for emergency repurposing as needed by astronauts once onsite. During the lunar day, the rover will position itself in an area for easy regolith collection and begin intake via an archimedes screw. Once it has collected enough to fill the SLS hopper, it aligns itself with the sun's path traversing overhead. To maximize rover reliability and performance, the single axis pivot tracking of the lens requires rover positioning along the axis of solar tracking. The solar panel and Fresnel lens are then able to pivot along this axis and concentrate the sunlight to hit a Heliostat/Galvanometer which will direct the light onto the SLS apparatus. Given the length of the lunar day (29.5 earth days), and the industry average SLS speed, a single rover could potentially produce 60-120 items per Lunar day.

Regolith Sintering System:

Collection, Filtrations, Transport: To gather lunar regolith for sintering, an Archimedes screw-based intake system collects regolith from the lunar surface, similar to auger systems used in agriculture and sand/silica collection/processing plants. To protect the intake system, the Archimedes screw will be rubber-tipped to reduce wear on the metallic auger, and ensure continued performance under varying mineral types. The intake system will take in regolith from the surface and bring it up to the filtration system. The filtration system is the second part of this subsystem. It is a barrel type double rotating enclosed mesh with two levels of filtration for the regolith to fall through, the first will eliminate any larger rocks/ pebbles that would create inconsistencies and other issues for the SLS system. The second layer ensures that we are using a more uniform regolith, giving us cleaner sintered parts . The filtered regolith then falls to the outer layer and is transferred to the bottom channel where it is met with the third subsection, the transport section to the SLS system. Continuing to use an archimedes screw type mechanism, it transfers the filtered regolith to the SLS system. During this last stage prior to the SLS system, regolith is analyzed by x-ray fluorescence to determine mineral composition of the substrate. This information is later used by the SLS system to adjust printing parameters for timing and temperature.

The SLS System: Utilizing a standard SLS system will ensure reliability and dependability. By adapting it for use with a Fresnel lens and regolith, the SLS apparatus will use concentrated light to sinter the collected and filtered regolith into building materials and other useful objects. Once the SLS process has completed creating an object, it ejects the object onto the lunar surface for later collection. There are two main sections of the SLS system. In the first section, powder is lifted by a lead screw underneath the bottom platform which feeds the printing/sintering section. A roller on top will distribute a thin layer of regolith from the intake powder side, to the printing side. The concentrated light from the Fresnel lens sinters a layer in the given pattern, the build plate then drops down, where the roller can apply another layer of fresh powder regolith. The camera system in the regolith processing portion of the rover will additionally evaluate the SLS process and make adjustments from those readings, such as light intensity, sinter quality, and regolith quality passing through the filtration system. When the part is finished, it is ejected out of the side of the SLS printer, onto the ground where it can cool appropriately and be collected later.

SQuID overview section: For error reporting, self diagnostics and correction SQuID is an androgynous low-cost electromechanical interface that will provides strong mechanical connection of components for power transfer and data fidelity, and is integrated to the rover to improve autonomous reliability. The system, designed and provided by Orbital Outpost X in support of this project, is built on a Zero Trust Architecture (ZTA) and is designed to enable robotic systems to perform functions such as refueling, control Solar Array Drives (SAD), robotic arm control and more. It is filled with sensors to not only know the state and environment of the system and its surroundings via video cameras, LIDAR, 6-DOF

Mechanical force, 9-DOF Orientation IMU and more providing additional capabilities when used in groups to monitor and control a network of systems.

In order to meet NASA mission needs, our executable approach to advance this technology to would involve several key steps:

Development: Our focus remains on advancing and fine-tuning our technology here on Earth. This includes precision calibration and autonomous recalibration. We're also emphasizing the printer's adaptability to different lighting conditions for accurate print scheduling. Strengthening the structural elements of our mobile printer is essential, guaranteeing its performance and durability across diverse conditions.

Collaboration with NASA: Our goal is to work closely with NASA, ensuring our tech development aligns with their lunar payload needs. This includes adding component redundancies to bolster mission preparedness and having backup parts on standby. With many mission-critical tech designs, like rovers and power systems, now public, we'll consistently cross-check our designs to meet both current and upcoming NASA standards. We'll also adjust components as needed to emphasize redundancy. Moreover, we aim to partner with NASA to seek funding opportunities and foster a mutually beneficial relationship.

Field Testing and improvement: After the development stage, we would perform field testing on Earth using moon dust analogs to refine and validate our technology, including the creation of structures and building blocks. This testing would simulate lunar conditions and involve chemically similar regolith found at the landing site, assessing metrics such as tensile strength and optimal light intensity for melting and binding the material. As opportunities present themselves, we would continue to refine and improve our approach to optimize its capabilities and efficiency. Additionally, we would also seek to identify new applications and opportunities for our technology to enhance NASA's efforts in lunar exploration and research.

Overall project is expected to take up to 30 months to complete all phases of development and testing. Milestones are as follows:

Concept report: In the first month, our team will compile a detailed concept report. This report will cover the necessary elements such as technical specifications, feasibility studies, components, required resources, design guidelines, anticipated challenges, and budget estimates. The report is an essential tool for our team, offering a clear outline of what the project will entail and the goals we aim to achieve. It sets the foundation for the subsequent stages of the project, ensuring clarity and direction.

Prototype development: Over the following 6-9 months, we'll focus on the development of the Robo Regolith Sinterer prototype. In Stage 1, our priority will be to design a rover capable of autonomous navigation in unpredictable terrains. Stage 2 will be about refining the printer to efficiently utilize sunlight, converting it into building blocks as the rover navigates. The prototype development phase is crucial because it translates our plans into a tangible product, allowing us to evaluate its performance and make necessary modifications based on real-world feedback.

Testing and validation: Once the prototype is ready, the subsequent 6-8 months will be allocated for its rigorous testing. Using simulated lunar conditions, our team will assess the rover's capabilities, including its mapping accuracy, movement strategies, printing precision, regolith management, and autonomous navigation. This phase is dedicated to understanding how our prototype functions, identifying its strengths, and pinpointing areas that need improvement. The insights gained during testing will shape the next steps of our project.

Brassboard design: After validating the prototype, the next 3-6 months will be utilized to develop the advanced brassboard design. This phase is about taking the prototype to the next level, integrating feedback from the testing phase, and ensuring every component is in line with NASA's standards. Additionally, this design phase will incorporate backup systems and redundancies to ensure the reliability of the end product.

Final testing and evaluation for deliverables: The final 3-4 months of the project will be devoted to testing and evaluating the brassboard design. This will include more extensive testing in simulated lunar environments and evaluating the printer's ability to create structures that meet NASA's requirements. At the end of the project, we will provide a final report summarizing the key findings and results of our project will be completed within 2 months of final testing. We will also deliver a working prototype of the mobile 3D printer capable of creating blocks from lunar dust using concentrated sunlight. This prototype can serve as a starting point for future development and refinement of the technology.

When developing lunar technology, testing for printing performance with simulated regolith chemistry under solar radiation conditions is a key operational consideration. Additionally, the size and speed of the printing process are constrained by the limitations of the vehicle, including weight and size restrictions. To address these challenges, we will test our technology using simulated lunar regolith composition and intensified lighting conditions. The multi-purpose rover design, made from redundant NASA materials, reduces the need for spare components and optimizes size and mass. Printing performance constraints will be addressed through autonomous printing capability and the design of smaller and more precise parts for faster production.

We plan to follow a rigorous testing and validation plan that includes the following steps:

Simulation: Operation of our 3D printing system in a virtual environment using material compositions mimicking the lunar regolith. This will be heated to levels in lab settings as expected to experience through the Fresnel lens under full solar radiation on the moon. This will allow us to identify any potential operational issues and refine the design of our system before physical testing.

Testing: After simulating the operation of our 3D printing system, we will conduct a series of ground tests to validate its performance in a constructed terrain setting outside on a hot clear day. This will include testing the driving performance, accuracy of our solar concentrator and servos, as well as the printing and solidification tolerances. Final tests will also include flight readiness as we will evaluate the weight distribution and structural integrity readiness in preparation for flight. Testing includes measuring mass distribution across all corners of the system when folded into shipping state, turbulence impact on structural integrity, and deployment capability after simulated travel for operational readiness.

Continuous Improvement: At every test, a review stage will evaluate performance and opportunities for improvement before passing to next stage development. Thus, the system is continually refined for design and performance optimization; ensuring long-term reliability in the harsh lunar environment.

5. Risks and Barriers

There are several roadblocks and limitations to our proposed solution:

Technical Challenges: One of the biggest challenges we will face is the development of a fully autonomous mobile 3D printing system capable of navigating and printing on the lunar surface. The system will need to be robust enough to withstand the harsh lunar environment. Additionally, stationery printers on Earth are easily uncalibrated from excessive movement. The rover printer will need to be designed to maintain high precision calibration while withstanding frequent movements and shaking of the instrumentation.

We seek to overcome these challenges through a combination of component selection, external partnerships, and guidance from past and current NASA mission reports. By integrating components that have proven function and reliability, we seek to streamline several aspects of the development portion and thus reduce costs through time saved by using established finished products. For specialized portions, we seek collaboration with academic labs for compartmentalized components needed to be tailored for the project, and would reference past and current NASA missions for guiding direction on designs and constraints. Finally, we have secured, as an option for development, use of proprietary components and robotics lab use from Orbital Outpost X to further accelerate development for space-ready systems.

Competition: There may be other companies or research groups working on similar solutions, which could limit our ability to establish ourselves as the market leader in this area. We will need to stay up to date with advancements in the field and continue to innovate to stay ahead of the competition.

To address the risks and barriers associated with our solution, our team has developed strategies for mitigating the challenges. For the technical aspects, our team plans to work closely with experts in the field of robotics, materials science, and additive manufacturing to address the technical challenges that may arise during the development of our solution. We hope to collaborate closely with NASA counterparts to build off of already proven technology and ensure compatibility with expectations. Initial collaborative agreements are being discussed with external partners such as Orbital Outpost X which has offered use of their robotics division. Extensive testing and simulations in controlled environments will ensure the feasibility of our approach before deploying it on the lunar surface, as well as model life expectancy of components for addressing long service life of the system. This will mitigate some operational constraints in testing, such as the real world testing not easily done on Earth. To address these constraints, we plan to collaborate with American universities with access to extreme testing facilities; leaning on both the advanced laboratories and subject matter experts to ensure system readiness. Finally, there are multiple logistics solutions for transport, including NASA SLS, SpaceX Starship, and potential new American space rocket corporations that would allow for competitive cost-saving options in coordinating a future NASA mission. With this approach in mind, any pressure from competitive bids will be reduced to the extent of allowing our team to focus on the primary objective of the value proposed from our solutions.

Ultimately, close collaboration with private space companies such as Orbital Outpost X and with NASA scientists and engineers is crucial in overcoming challenges related to environmental conditions unique to space, ensuring print precision, structural integrity, system reliability, and absence of human supervision. Through these collaborations, we aim to develop a rover capable of withstanding extreme temperatures, solar radiation, and the lunar surface for effective construction using concentrated solar radiation. By leveraging past mission deliverables and optimizing communication and autonomy, we strive to minimize operational risks and increase the probability of successful lunar infrastructure development.

CITATIONS

Al-Dabbas, M.A., 2013, May. Solar sintering of Jordanian silica sand. In *2013 1st International Conference & Exhibition on the Applications of Information Technology to Renewable Energy Processes and Systems* pp. 49-54

Gietl, E.B., Gholdston, E.W., Manners, B.A. and Delventhal, R.A., 2000, March. The electric power system of the International Space Station-a platform for power technology development. In *2000 IEEE Aerospace Conference. Proceedings (Cat. No. 00TH8484)*, 4, pp. 47-54

Jones, H., 2018, July. The recent large reduction in space launch cost. *48th International Conference on Environmental Systems*. pp. 1-10

Locatify.com. 2016. BLE Beacons for Indoor positioning – Beacon limitations. [online] Available at: https://locatify.com/blog/ble-beacons-no-bull-beacon-review/ [10/05/2023]

Ratnakumar, B.V., Smart, M., Whitcanack, L., Chin, K., Herman, J., Ewell, R., Surampudi, S., Puglia, F. and Gitzendanner, R., 2005, August. An update on the performance of Li-ion rechargeable batteries on Mars Rovers. In *5th International Energy Conversion Engineering Conference and Exhibit* pp. 4741

Restier-Verlet, J., El-Nachef, L., Ferlazzo, M.L., Al-Choboq, J., Granzotto, A., Bouchet, A. and Foray, N., 2021. Radiation on earth or in space: what does it change?. *International Journal of Molecular Sciences*, 22, p.3739.

Saenz-Otero, A. and Miller, D.W., 2005. Design principles for the development of space technology maturation laboratories aboard the international space station. *Massachusetts Institute of Technology, Department of Aeronautics and Astronatucis, Ph. D. Thesis, Cambridge, MA*.

Schaefer, B.E., 1992. The length of the lunar month. *Journal for the History of Astronomy*, 23, pp.S32-S42.

Tang, Y., Fuh, J.Y.H., Loh, H.T., Wong, Y.S. and Lu, L., 2003. Direct laser sintering of a silica sand. *Materials & design*, 24, pp.623-629

Wang, X.H., Fuh, J.Y.H., Wong, Y.S. and Tang, Y.X., 2003. Laser sintering of silica sand–mechanism and application to sand casting mould. *The International Journal of Advanced Manufacturing Technology*, 21, pp.1015-1020

Warren, P., Raju, N., Ebrahimi, H., Krsmanovic, M., Raghavan, S., Kapat, J. and Ghosh, R., 2022. Effect of sintering temperature on microstructure and mechanical properties of molded Martian and Lunar regolith. *Ceramics International*, 48, pp.35825-35833

You, Y. and Wu, C., 2019. Indoor positioning system with cellular network assistance based on received signal strength indication of beacon. *IEEE Access*, 8, pp.6691-6703.