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Working Toward a Solution to the UMass Problem: We began with the Hadley Max 500-day Design Reference Mission (DRM) conceptual background [1], and proceeded to call on Apollo 15 (A15) mission scientific goals and objectives, combined with expanded scientific goals and objectives derived from A15 mission results and recent regional geologic mapping [2]. We then identified the Regions of Scientific Interest (ROSI) for the Hadley Max DRM [3], and the used these scientific requirements to define the Mission Architecture [4], and more detailed Hadley Max mission design and traverse planning activities [5]. Here we address one of the most significant problems for long-duration and sustained human presence on the Moon and concurrent scientific exploration success: the Key Enabling Technology to alleviate the huge and continuous upmass requirements necessary to support the base and exploration infrastructure [4]. In order to help alleviate this “UMass roadblock”, we have pursued two promising technologies: 1) Myco-Architecture [6-9], where building materials can be “grown in situ” in order to significantly minimize upmass penalties, and 2) Inflatable Structural Elements [10], in which low-volume, low-mass inflatables can be combined with Myco-Architecture to produce a wide range of enclosures in situ. Here we outline the evolution of our progress on “Myco-Architecture” and future goals and objectives.

Definition of Required Habitats, Enclosures and Related Architectural Elements: As a baseline for required architectural elements, we called on the Hadley Max DRM Architecture [4] and Traverse Planning [5] studies that produced these baseline elements. 1. Landing Pads (LP): For both Human and Robotic missions; like helo pads, flat, devoid of soil backwash contaminant. 2. Initial Base Structure (IBS): Living and working habitat; follows the initial stages where there is a landing module (LM). 3. Evolutionary Base Structure (EBS): Larger scale, separation of work/living activities; increased in situ science activities; IBS evolves to dust mitigation structure. 4. Outposts: Remote Science Bases (RSB): Modeled after IBS, but located >10 km radius from Landing Site. Require up to ~5 RSBs for in depth, in situ science activities. Increase number in order of science priority. 5. ‘Pony Express’ Stations (PEX): These are the lunar ‘pup tents’ that will be precursors to the Remote Science Bases (RSB), and then Earth-day sleepstations on the way to the final Remote Science Bases (RSB). Sample storage stations, geophysical stations; can be resupplied/samples collected by CLPS missions. 6. Robotic Rover Requirements: a) LRV garage at base for surviving lunar night, re-outfitting; b) Robotic LRV ‘pup tents’ for surviving lunar night, caching samples. 7. Application to the Artemis Circumpolar Environment (ACE): How do we optimize these basic requirements and DRM concepts for the harsh conditions of the South Circumpolar Region. 8. Assessing Feed-Forward to Mars Exploration: How does the Mars environment modulate and modify these DRM strategies and architectural elements? Here we investigate elements 1-6, and explore how producing construction materials in situ on the Moon can help alleviate the upmass problem. We plan to treat 7 and 8 in future analyses.

Background and Approach: Transporting materials beyond Earth, such as spacecraft, Astronauts, and construction materials, is limited by mass constraints. Yet long-term residence, operation and scientific exploration on the lunar surface requires an extensive infrastructure, a significant upmass, and a major large-mass component of this is in habitats, designed to protect crew and equipment from radiation, extreme temperatures and micrometeorite bombardment. There is a significant mismatch between habitat requirements at destination and what can realistically transported there. Infrastructure for human survival is not automatically “user ready” on the Moon. Habitats could be built with locally sourced regolith or ice materials by in In Situ Resource Utilization (ISRU), but in the end, even this requires significant upmass. To alleviate this problem, we have been exploring technologies [6-9] that are self-replicating and self-repairing, to assess their utility in circumventing the upmass problem. Life meets these technological criteria for space utilization and in addition can be reprogrammed through synthetic biology. In this quest, we look to exploit the genetic hardware store inherent in our vast biodiversity, moving capabilities from familiar forms such as trees for wood, to a more tractable space-faring chassis such as yeast or bacteria.

Strategy and Concepts: A critical aspect of human space exploration and eventual settlement is the ability to construct habitats while minimizing payload mass launched from Earth. To respond to this challenge, and as a continuation of our research program initiated under the auspices of the “Myco-architecture Off Planet” NASA NIAE Team, we have explored the use of fungal biocomposites, for example Bio-Bricks, (Fig. 1) for growing extra-terrestrial structures and building materials, directly at the destination, significantly lowering the mass of structural materials transported from Earth and
minimizing the need for high mass robotic operations and infrastructure preparations. Currently, the idea of working with living biological organisms, and the phenomenon of growth itself, is of increasing interest in architecture and space applications. Here, we describe the use of mycelium-based composites as an alternative, biological approach for constructing regenerative and adaptive buildings for extraterrestrial habitats. These composites, are fire-resistant and insulating, and do not consist of volatile organic compounds from petrochemical products. These can be used independently or in conjunction with regolith, and could employ the living biological growth in a controlled environment for the process of material fabrication, assembly, maintenance, and repair, providing structures resilient to extra-terrestrial hazards. We explored avenues to make this biological approach feasible, providing new, growing materials for designing and building sustainable habitats for long-duration space missions.

Our research has explored the potential and challenges of using mycelium-based biocomposites for space applications. The approach of using biological growth for the off-Earth construction, similarly to other researched ISRU-based approaches, is designed to lower the mass of materials needed to be transported from Earth. In addition, it focuses on lowering the energetic costs of the construction of in situ habitats, such as the work required to assemble the habitat. In the long-term, using biological materials and growth as a construction method, opens up the potential of ELMs (Engineered materials composed of Living cells that form or assemble the Material itself or modulate the functional performance of the material in some manner) [11] to potentially provide supplementary capabilities, such as sensing and responding to environmental stimuli, self-healing, etc. Such developments could make the habitats even more flexible and reliable. The further development of research on ELMs and mycelium-biocomposites will allow for advancements in the field of biotechnology and habitat construction. These concepts employ living biological growth in a controlled environment for the process of material fabrication, assembly, and maintenance. Positive attributes of these approaches and techniques include the modest upmass requirements of a few spores, nutrition for mycelial growth, and a growth framework, along with the potential to reproduce using in situ resources, the ability to grow to accommodate on-site terrain, and the potential additional control provided by the tunability of the materials. We see myriad possibilities for mycotecture utilization off planet. Because the research is still in an early stage, one of our major goals once the enabling technologies are identified, is to use the Hadley Max 500-day DRM Architecture to develop a technology roadmap and recommendations for further development.


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Fig. 1. Left: Bio-Brick made of Myco-Architecture Materials (Courtesy Chris Maurer): This brick is a composite of wood and fungal mycelium. Fungi break down biochemicals like cellulose converting them into their own chitin-rich biomass. By growing mycelium on plant fodder they fuse at a cellular level allowing us to utilize the best characteristics of their respective Kingdoms - Plantae and Fungi. We are currently developing methods to grow these multi-kingdom composites off-planet to save transport cost, reduce energy demands, and utilize bio-performative aspects such as radiosynthesis, that may one day convert space travel's biggest liability, ionizing radiation, into a resource for material production. Bio-Brick dimension is 17 x 12.5 x 5.5 cm. Right: J. Head and NASA Administrator Bill Nelson examine one of our Bio-Bricks at Brown University. Photo by RI Senator Jack Reed.