Mission Architecture Defined by Science Requirements: Regions of scientific interest (ROSI) for the Hadley Max mission [1] are derived from Apollo 15 mission results [2] and recent regional geologic mapping [3]. From this, we synthesize more detailed traverse goals and objectives [1,5]. Here, we utilize the distribution of ROSI to assess implications for the broad architecture of the Hadley Max 500-day Mission (exploration range, mobility requirements, crew size, number of bases, number of EVAs, upmass and downmass requirements, human-robotic partnership requirements, habitat requirements, etc.).

1. Operational Access Requirements: Landing Sites:
On the basis of attaining a broader exploration and sampling region [1,5] consistent with current NASA science goals and objectives [6], we select the original Apollo 15 landing site as the primary landing site. The 10-20 km radius of operations necessitated by the distance from the A15 site to the farthest ROSI [1], and uncertainties in the ability to cross Hadley Rille, dictate that two separate landing sites/bases of operations are required. To optimize the scientific return, we place the second landing site/base of operations to the W of Hadley Rille in mare unit Im3 (Fig. 1).

2. Crew Size, Space Suit and Mobility Requirements: Crew Size: We assume 4 crew per base in order to accommodate contingencies (i.e. EVA rescue), allow for the possibility of simultaneous EVAs, and to properly allow for the division of labor among scientific goals (e.g., one crew rille, one crew highlands). For the full Hadley Max mission with both landing sites, this equals 8 crew on the surface, 4 at each base. Suit Requirements: Minimum is Apollo suit capabilities, assisted by enabling technologies in consumables and mobility, in order to extend traverse time, optimize highland traverses, and expand EVA efficiencies. Mobility Requirements: Minimum is Apollo LRV design and capabilities. Two rovers/landing site (4 total). Enabling technologies include increased efficiency in slope trafficability to ensure exploration of the rille and highlands, ability to carry four astronauts (rescue, ability to survive lunar night (‘rover garage’ at base), design lifetime >>500 days.

3. Human-Robotic Mission Types and Relationships: Human Mission Types: These include 8-hour EVAs, 10 km radius of operations, with the possible extension to 14 km using the 7 km circumference “outpost” capability (Fig. 1). Robotic Mission Types: It is clear from the Human EVA 10 km radius of operations and the maximum traversable slope constraints (~20° degrees) that a series of parallel robotic missions will be required to meet the scientific objectives, particularly those in the highlands, and at radial distances beyond 10 km from the landing site, and to ensure Human EVA scouting, interpolation and extrapolation [4]. Human-Robotic Mission Relationships: On the basis of Apollo mission planning and astronaut operational experience, we advise against Astronaut-tended robotic ‘field assistants’ as an inefficient use of crew exploration time on the surface. Instead, we strongly urge the development of independent robotic devices to enable parallel human-robotic partnerships. This allows for generally simultaneous operations, enabling precursor, scouting, interpolation, extrapolation, and post-mission exploration activities [6].

4. Definition of Required Habitats, Enclosures and Related Architectural Elements: 1. Landing Pads (LP): For both Human and Robotic missions; like helo pads; flat, devoid of soil backwash contaminant, retroreflector for guidance. 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 and 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 lunar ‘pup tents’ that will be precursors to the Remote Science Bases (RSB), and then Earth-day sleep-stations on the way to the final Remote Science Bases (RSB). Sample storage stations, geophysical stations; can be resupply/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.

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, and the lunar farside? 8. Assessing Feed-Forward to Mars Exploration: How does the Mars environment modulate and modify these DRM strategies and architectural elements?

5. Identification of Required Key Enabling Technologies and Operational Concepts: a) Upmass Requirements: The multiple base/outpost (RSB)/pup-tent habitat requirements and their necessary range of complexity and ability to survive lunar day/night cycles, as well as robotic LRV remote servicing stations, places huge mass requirements for delivery of construction materials to the Moon. In order to help alleviate this “upmass roadblock”, we pursue two promising technologies:
Human-Robotic Partnerships: Various mission requirements dictate the need for a robotic LRV (RLRV) controlled from the base or the ground (independent of human traverses). These mission requirements include the great distances required to reach all ROSIs, the increase in area as a function of radius from the base (increasing the need for scouting, interpolation and extrapolation), the steep slopes within the rille and on the highlands, as well as the presence of the Elephant-Hide Terrain (EHT), and the trafficability on these slopes. RLRV design and technology challenges include ability to traverse slopes approaching 30°, an advanced suite of remote sensing instruments, constant navigation imaging, near real-time communications with the ground, the ability to collect, document and store individual rock and soil samples, remote operations from base and ground, enclosures (RLRV garages) for lunar night, servicing and sample storage, and a design lifetime >>500 days.

Supply-Resupply Technology and Infrastructure Requirements: Despite alleviation of upmass construction requirements through Myco-Architecture and Inflatable, significant supply (and resupply) (S/RS) requirements are dictated by the widespread and long-duration exploration strategy. Many dozens of human and robotic S/RS missions to diverse locations, delivering different payloads, and ensuring crew cycling, are required by the 500-day DRM architecture. Optimal resupply mission require landing, offloading cargo, and uploading crew, rock/soil samples, and other materials for return to Earth.

Mission Operations and Feed-Forward to Mars: Lunar communications latency (~2.5 sec) presented no difficulties during Apollo, but Mars latency (5-20 min) precludes useful direct communications with the ground during exploration. In addition, after a few days exploring the lunar surface, astronauts will have superior situational awareness (compared to pre-mission planners) and thus be capable of real-time planning and execution of traverses (the goals and objectives of which are planned pre-EVA in consultation with the base/ground). Additional research into optimal operational frameworks for planning, briefing, and de-briefing traverses is necessary due to latency restrictions. We advise that collaborative planning take place between EVAs, and that the highly trained crews are left to execute the pre-planned traverses according to their enhanced, in situ, situational awareness. With the development of mission-planning software, crews will be able to directly access and leverage these decision support tools unencumbered by communication latency with the ground. Such operational frameworks will be required for Mars exploration. Ground will more likely focus on continuous, parallel operations of the RLRV, and integrating these results into the inter-EVA debriefings and planning sessions.

Synthesis: These Architectural Definition concepts and requirements are now used to explore low-upmass in situ building materials [7,8] and inflatable architectural elements [9] for further conceptualization and design of the Hadley Max 500 day DRM.


Fig. 1. Left: Hadley Max region; circles show 2 base sites and 10 and 20 km radius around each. Red dots; selected ROSI [4]. Right: Recent geological map [3]; white box shows left image (LROC WAC) location.