NASA Exploration Systems Enterprise
Request for Information
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Mobitat: Mobile Planetary Surface Bases

A White Paper
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Plug-in Creations

1.0 Candidate Technology

Plug-in Creations has developed the Mobitat concept, a self-contained, mobile pressure vessel habitat for use on the Moon, Mars, and other planetary surfaces (Lai & Howe, 2003). The Mobitat is a combination lander / hopper and mobile rover consisting of two major subsystems: mobile platform / lander and modular pressure vessel. The mobile platform portion can be detached from the pressure vessel for use as a separate crane or mount for drilling and construction implements. The pressure vessel can be docked with others of its kind to create larger outposts and bases (Figure 1).

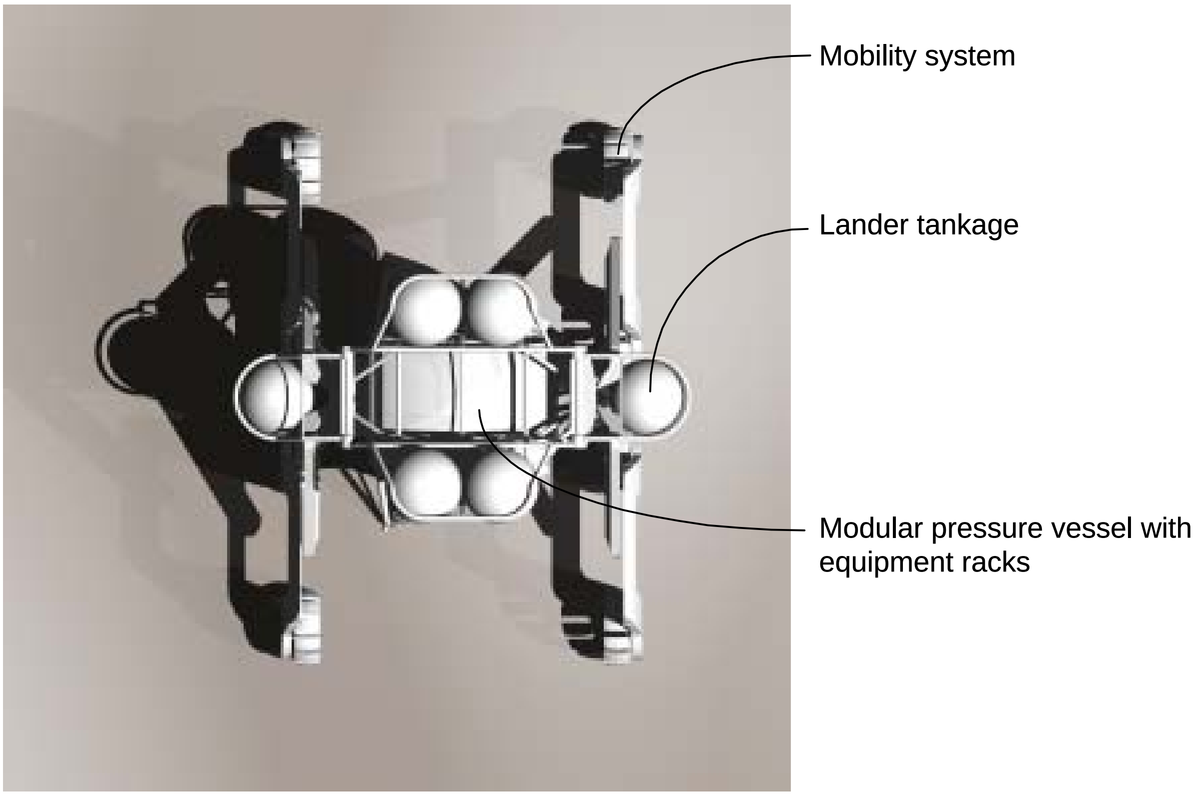

Figure 1: Mobitat top view

The Mobitat system can negotiate over bolders up to 1 meter high and navigate steep slopes both transversely and directly. In travel the pressure vessel hangs from the mobile platform, allowing the habitat to keep a level stance, even through rough terrain. This feature allows the Mobitat to function as a rover able to reach speeds upwards of 20mph across uneven surfaces. In addition, the pressure vessel can be detached from the mobile platform to establish a fixed outpost, where the mobile platform can be manipulated remotely through tele-operation to perform a variety of construction, excavation, and other tasks needing craneage, or other heavy work implements. The Mobitat system is modular, based on Kit-of-parts Theory (Howe, 2002).

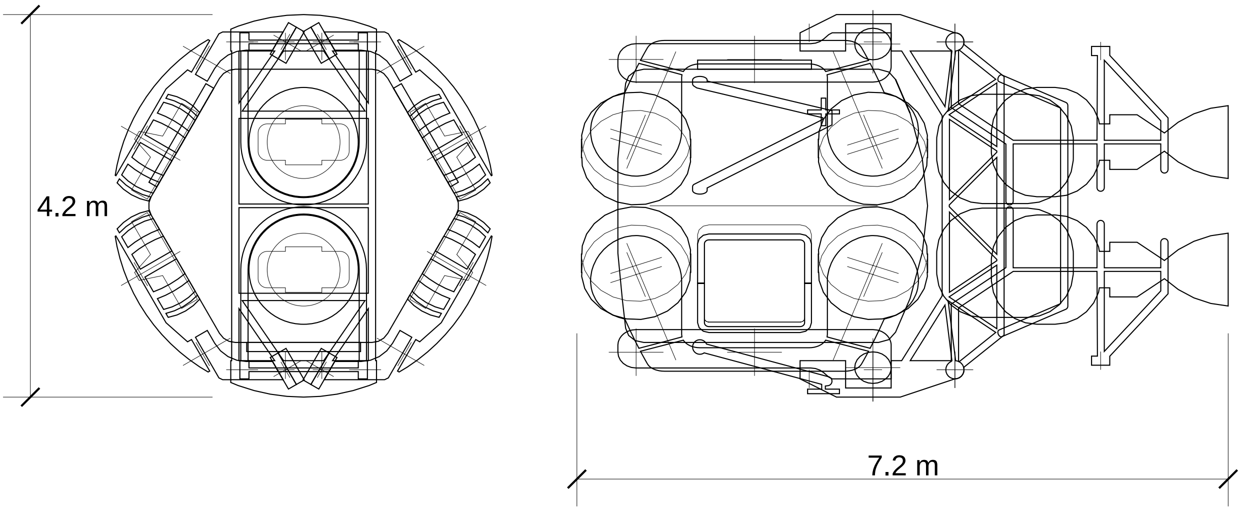

Figure 2: Mobitat in folded package

The Mobitat folds into a package 7.2 meters long by 4.2 meters in diameter (Figure 2). This size will fit into a variety of launch vehicles including the Shuttle payload bay (Figure 3).

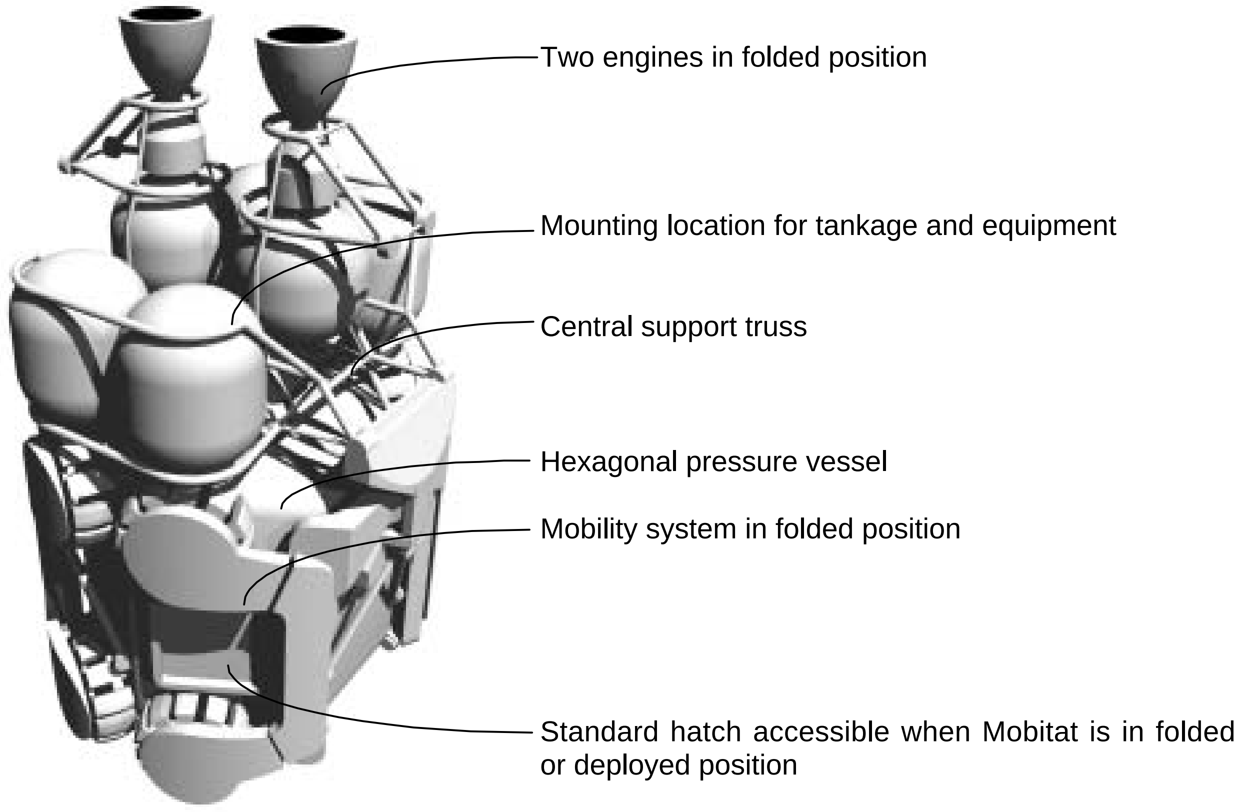

Figure 3: Rendered view of Mobitat in folded position

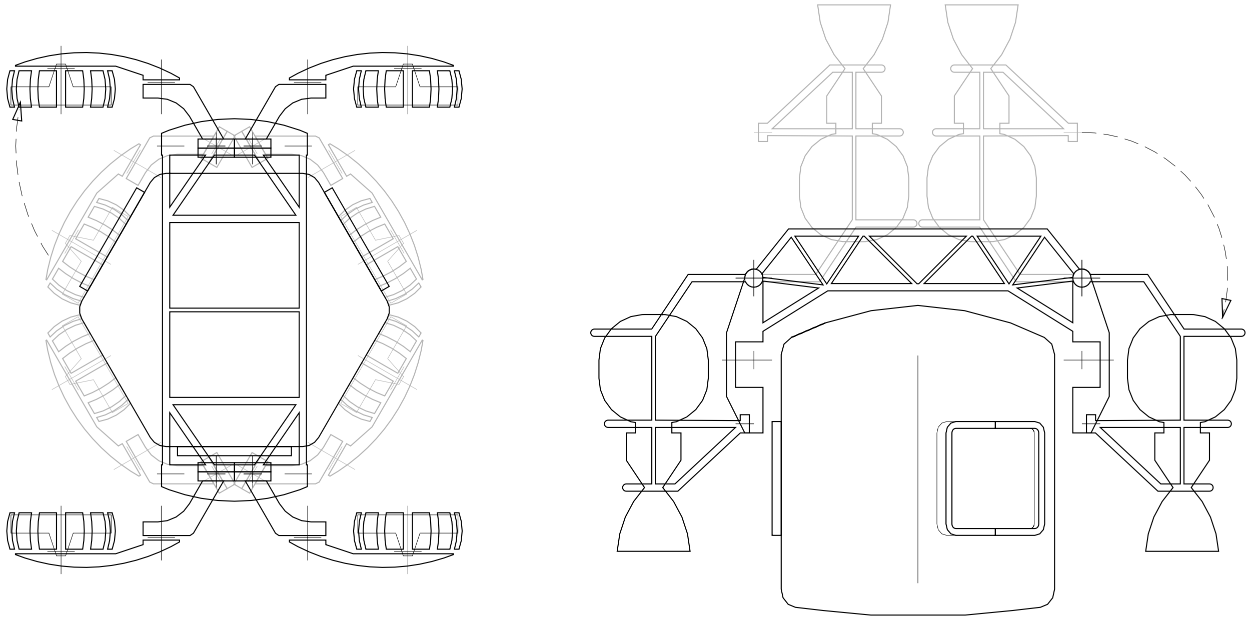

Figure 4: Deployable structures on Mobitat

Preliminary versions of the Mobitat have two major deployable systems. In Figure 4 on the left, the mobility system swings away from the main body and central supporting truss and unfolds. On the right, the engines swing down into position for lander deployment.

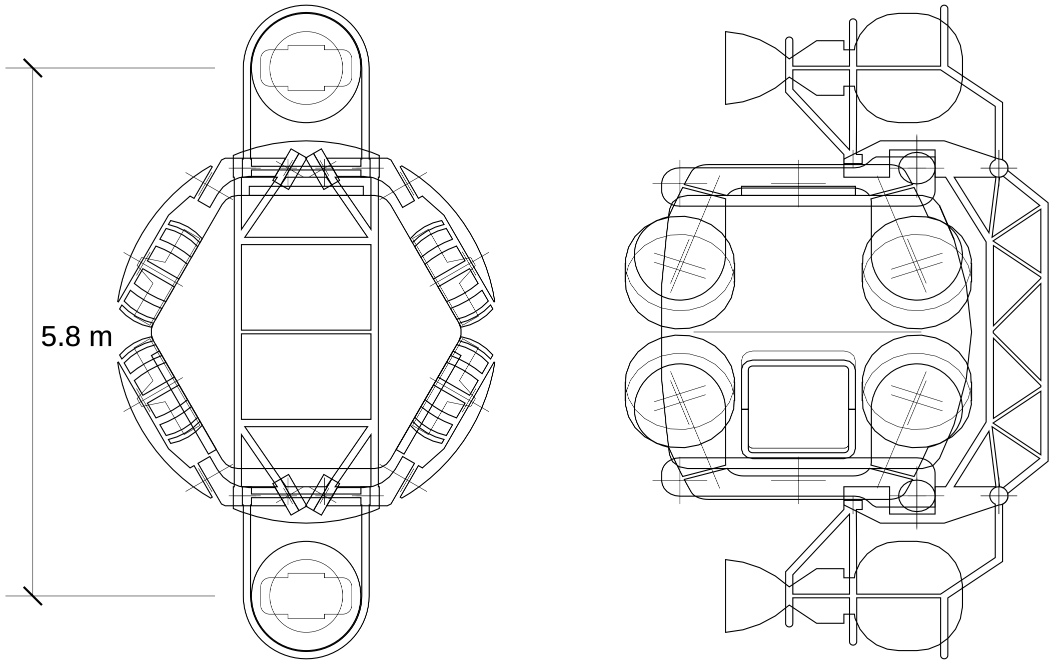

Figure 5: Engines held away from the main body

The engines in their deployed position are mounted on either side of the main body. The thrust force is directed to either end of the central supporting truss (Figure 5 & Figure 6), affecting lift for the vehicle. Later concepts of the Mobitat drop the engines upon landing.

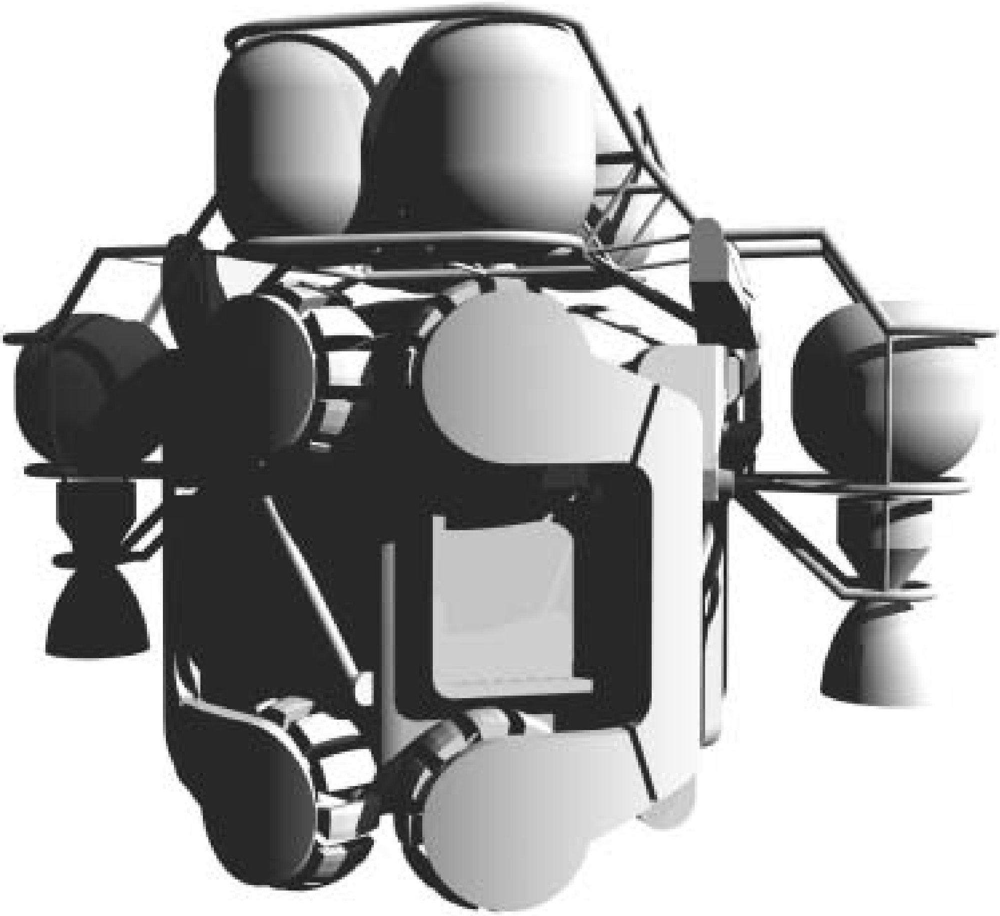

Figure 6: Mobitat in lander configuration

2.0 Applications

The Mobitat can be used as a modular surface exploration vehicle and habitat. Since the pressure vessel and mobile platform can be separated, the combined vehicle can be used as a rover, or separated as a fixed modular base with an un-crewed, remotely controlled heavy duty work platform.

The landing sequence begins with 1) delivery of folded package to Lunar orbit, whereupon 2) the engines deploy to either side of main body. During the descent (Figure 7), 3) the mobility system deploys leaving 4) the wheel carriage assemblies clear of the thrust exhaust. 5) The wheel carriage assemblies lower themselves just before landing to 6) affect a smooth touchdown on a variety of even or uneven surfaces.

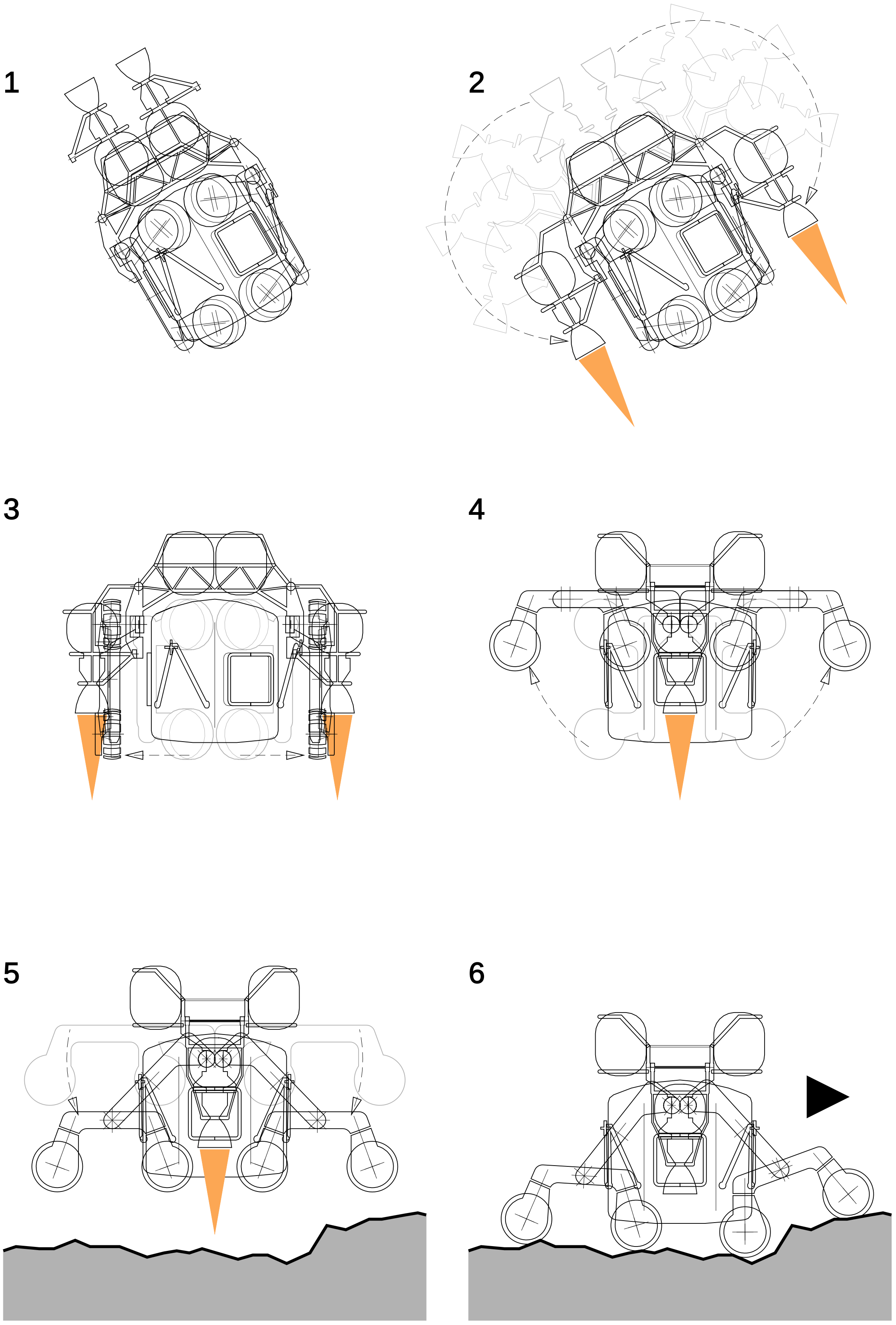

Figure 7: Landing sequence: mobility system deployment, touch down, and Landing complete

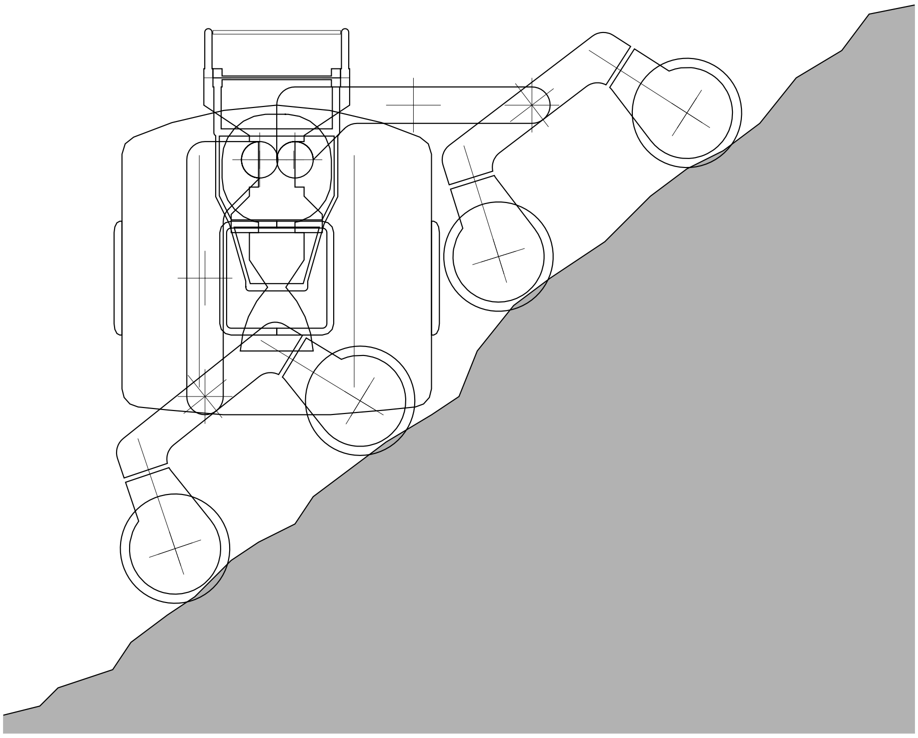

Figure 8: Mobility system on slope

The Mobitat mobility system is designed to handle severe obstacles and slopes while keeping the pressure vessel module level (Figure 8). In most cases, the traction of the wheels on the surface will fail well before the maximum climbing angle is reached. Also, a capacity for shifting the center of gravity is possible to allow “stepping over” large obstacles while maintaining a level stance for the pressure vessel module (Figure 9).

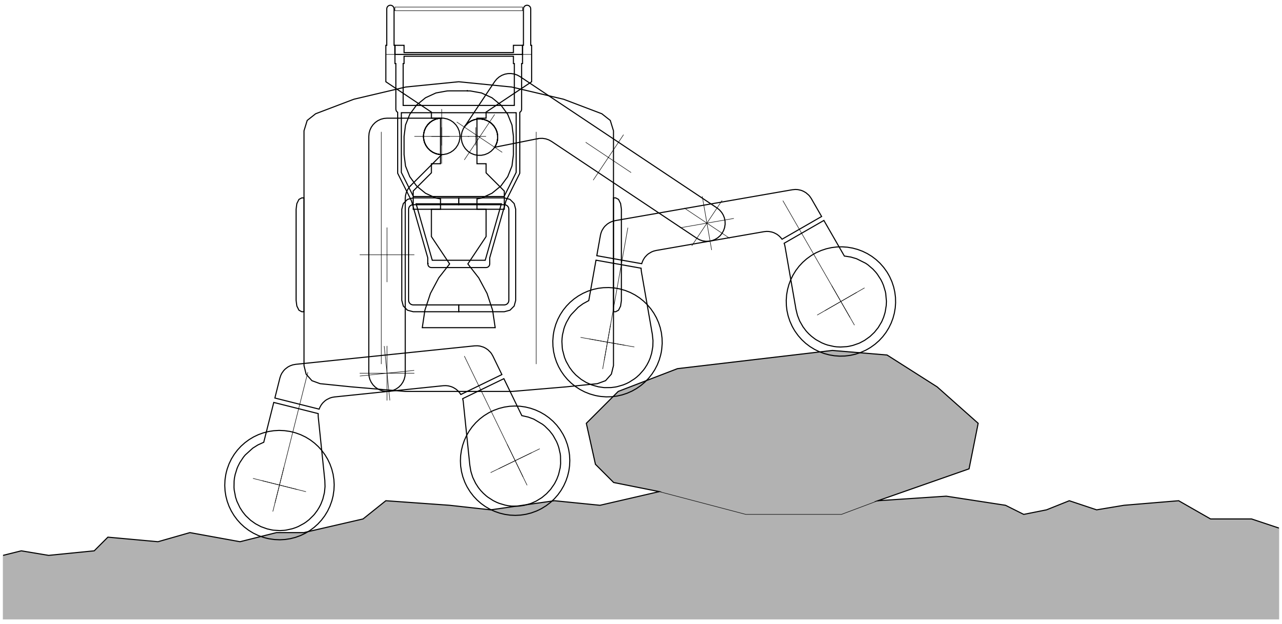

Figure 9: Mobitat can "step over" some obstacles by shifting center of gravity

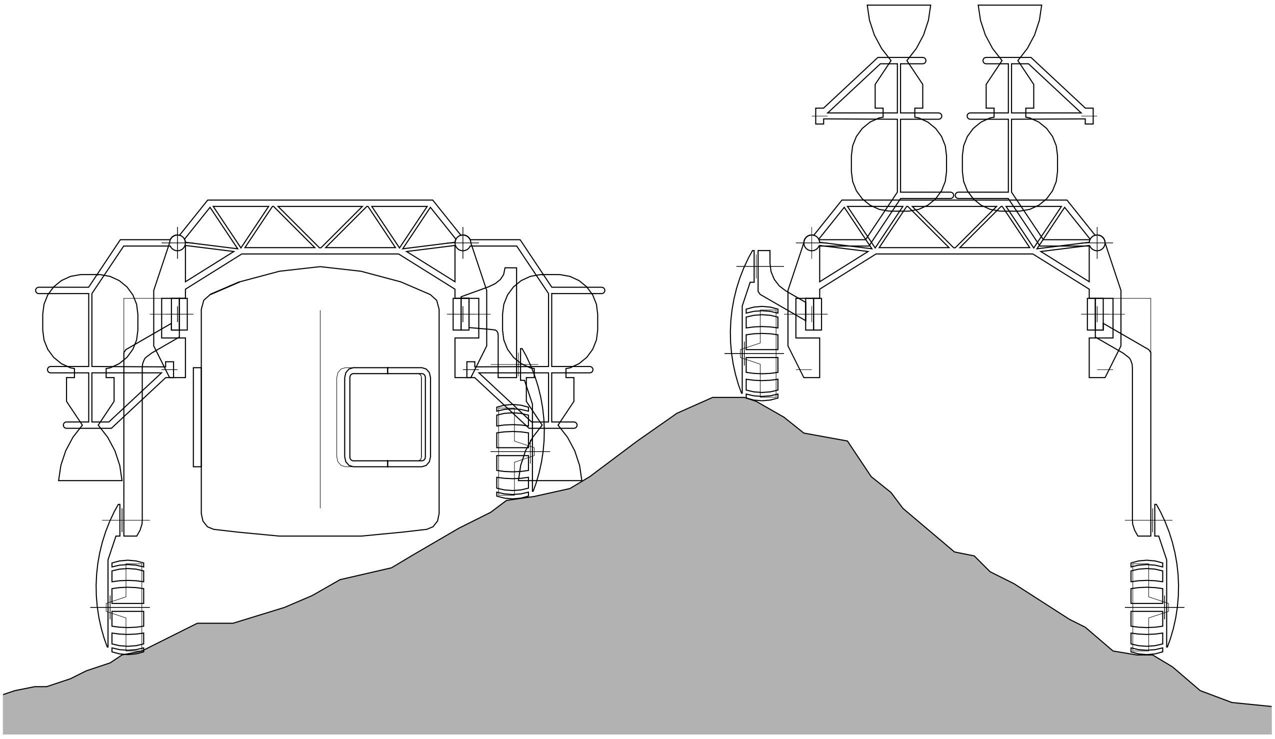

Figure 10: Mobility system on transverse slope

On transverse slopes, the Mobitat has the ability to manipulate wheel carriage assemblies independently in order to maintain a level stance for the pressure vessel module (Figure 10, left). If the engines are stowed (right) and module detached, the capacity for traverse can include severe slopes.

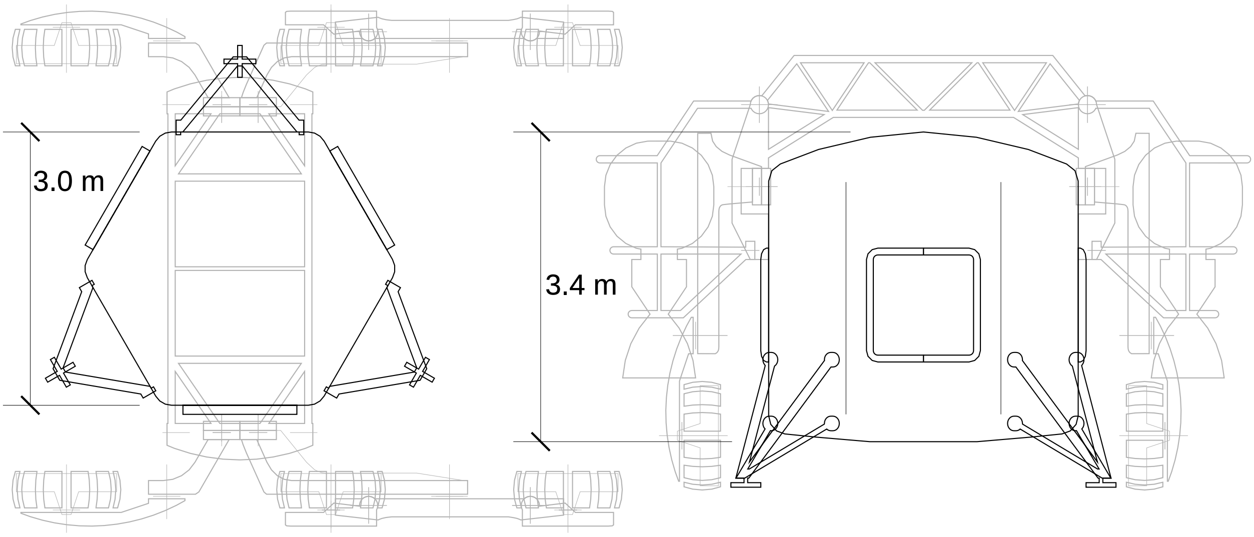

Figure 11: Pressure vessel module

The pressure vessel module is a hexagonal shape (Figure 11). In order to fold in the wheel assembly carriages of the mobility system, the 4.2 meter allowed maximum envelope dictates that the habitable module be 3.0 meters wide. The module is 3.4 meters high.

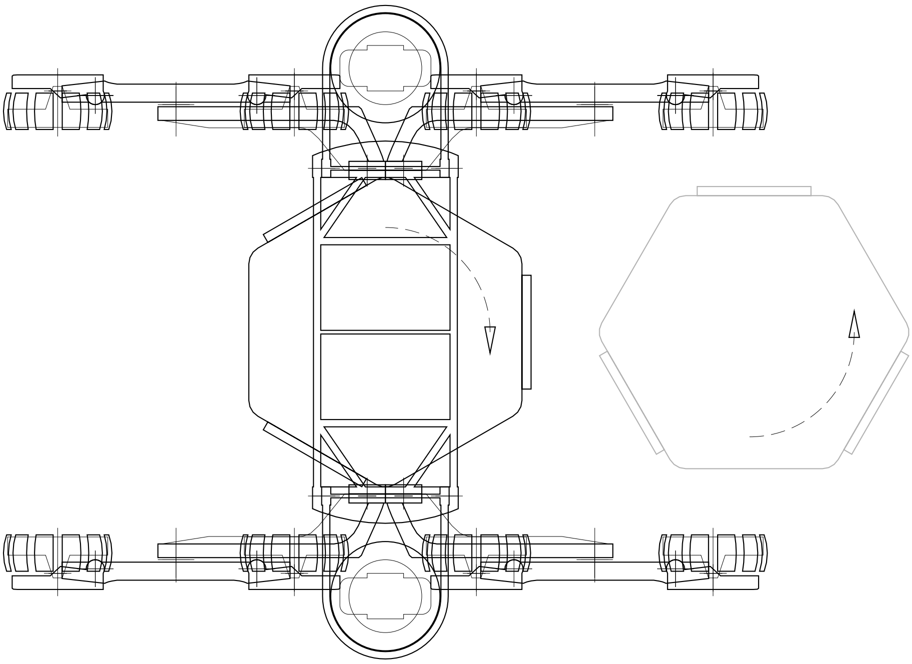

Figure 12: Repositioning of pressure vessel module

The pressure vessel module is attached to the central supporting truss via adjustable interface hardware. The interface hardware can make small local adjustments in order to facilitate the fitting of two or more modules together. The interface can also rotate the module to allow “corner” first or “face” first orientation (Figure 12).

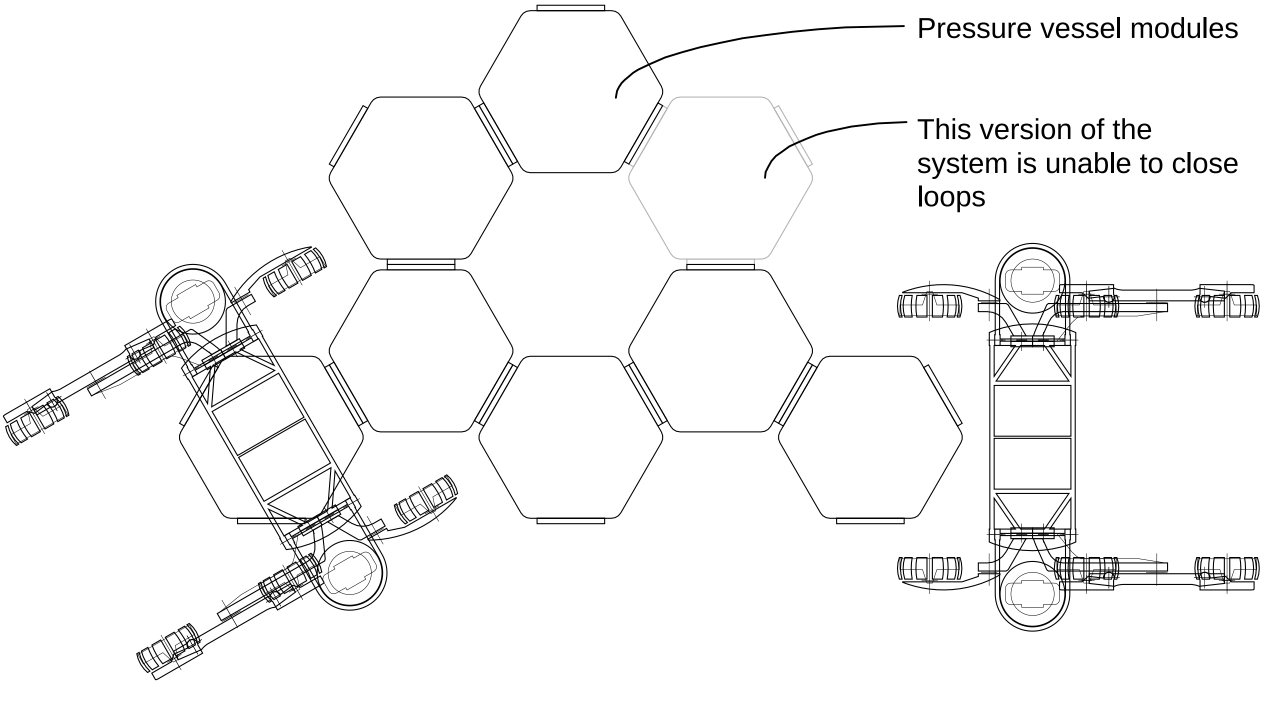

Figure 13: Module assembly into larger outpost or bases

Pressure vessel modules can be assembled into larger complexes to form outposts or bases (Figure 13). The mobility platform can be detached from the module once it has been placed. However, modules cannot maintain attachment to the platforms if they are assembled into groups.

Also, preliminary versions of the system do not allow complete closure of circulation and egress loops, which will be addressed in future design studies. In a modular base, entire modules can be dedicated to egress and EVA functions, such as airlock or rover interface.

Since no site is level, large assemblies of modules would need to have small local adjustment capacity at each hatch.

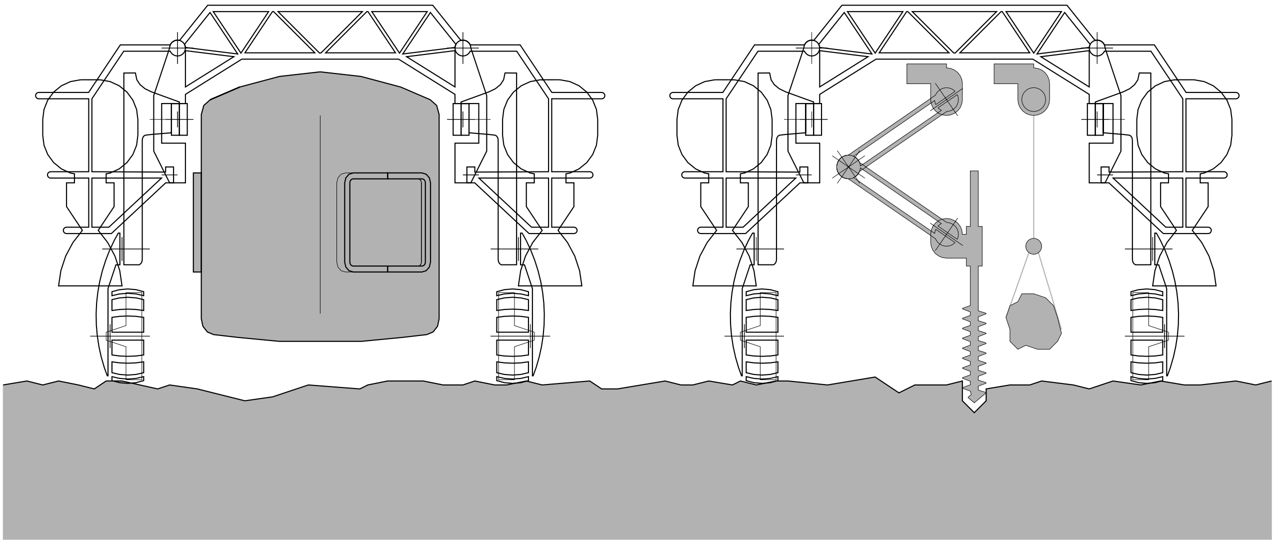

Figure 14: Alternative uses for mobile platform

The mobile platform can be used for a variety of tasks in addition to carrying pressure vessel modules (Figure 14). These tasks can include crane, drilling platform, mobility for excavation and construction implements, etc. Figure 15 shows the deployed surface mode of the Mobitat.

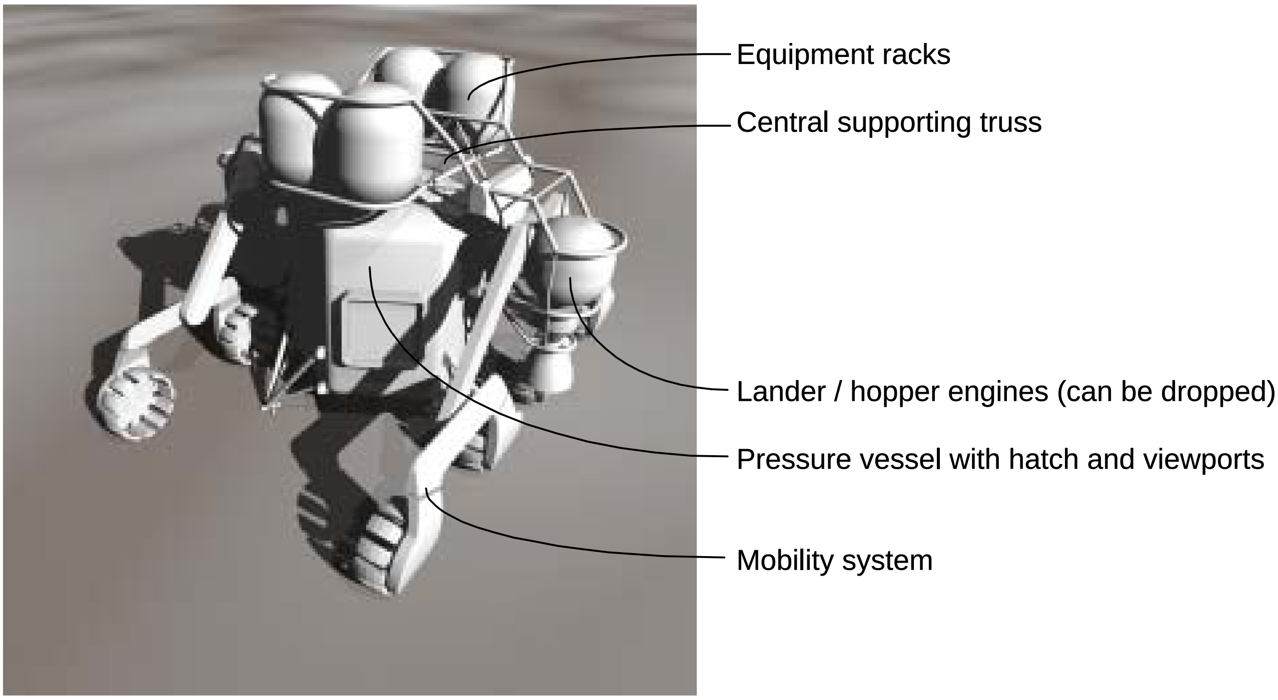

Figure 15: Mobitat in deployed surface mode

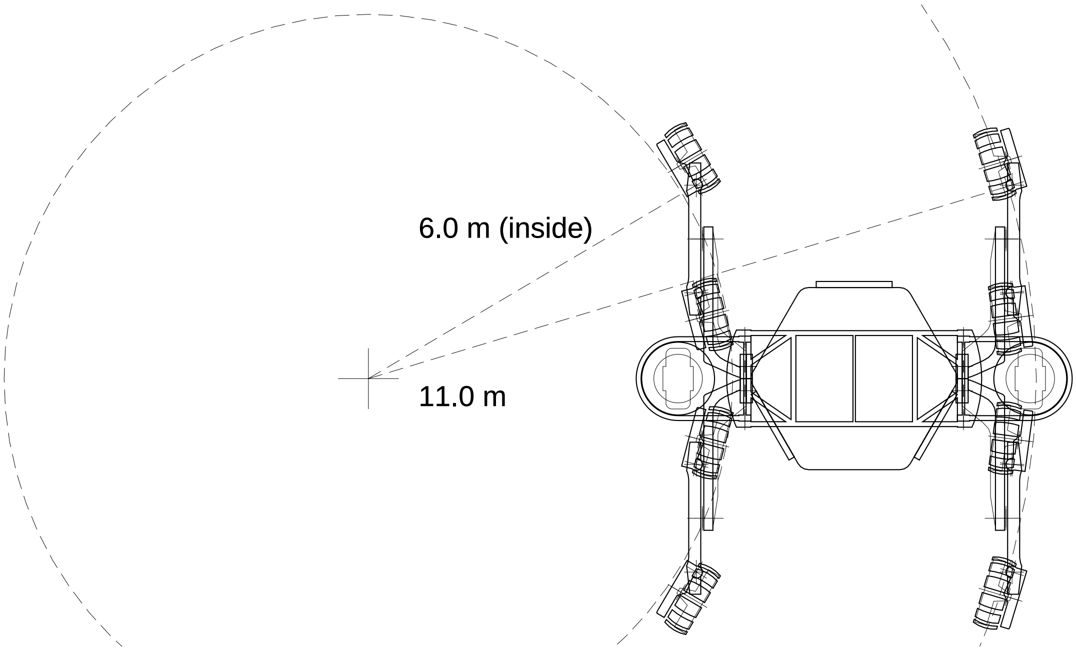

Figure 16: Mobile platform turning radius

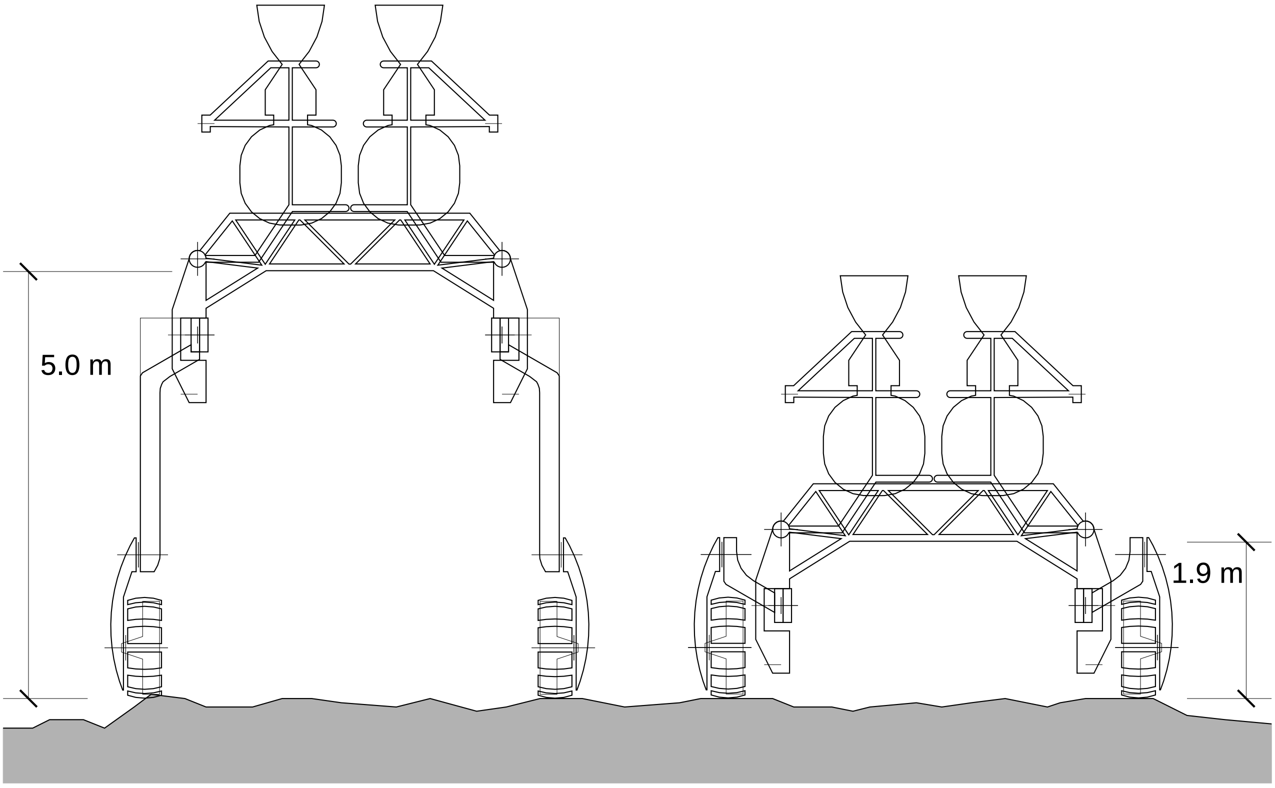

Figure 17: Lift range of mobile platform

The mobile platform has an inside turning radius of 6.0 meters, and outside turning radius of 11.0 meters (Figure 16). In its extended position, the central support truss has 5.0 meters of clearance above a level surface. The minimum clearance is 1.9 meters (Figure 17).

3.0 Relevance to H&RT Strategic Technical Challenges (STCs)

NASA space architects have given a recommended roadmap for technology and development of planetary habitats (Cohen & Kennedy, 1997). The roadmap divides planetary surface construction into three classes, coinciding with a phased schedule for habitation:

- Class I: Pre-integrated hard shell modules ready to use immediately upon delivery.
- Class II: Prefabricated kit-of-parts that is surface assembled after delivery.
- Class III: In-Situ Resource Utilization (ISRU) derived structure with integrated Earth components.

Class I structures are prepared and tested on Earth, and are designed to be fully self-contained habitats that can be delivered to the surface of other planets. In an initial mission to put human explorers on Mars, a Class I habitat would provide the bare minimum habitable facilities when continued support from Earth is not possible.

The Class II structures call for a pre-manufactured kit-of-parts system that has flexible capacity for demountability and reuse. Class II structures can be used to expand the facilities established by the initial Class I habitat, and can allow for the assembly of additional structures either before the crew arrives, or after their occupancy of the pre-integrated habitat.

The purpose of Class III structures is to allow for the construction of additional facilities that would support a larger population, and to develop the capacity for the local production of building materials and structures without the need for resupply from Earth.

To facilitate the development of technology required to implement the three phases, Cohen and Kennedy stress the need to explore robust robotic system concepts that can be used to assist in the construction process, or perform the tasks autonomously. Among other things, the roadmap stresses the need for adapting structural components for robotic assembly, and determining appropriate levels of modularity, assembly, and component packaging. The roadmap also sets the development of experimental construction systems in parallel with components as an important milestone. The Mobitat system falls within the Class I category of pre-integrated hard-shell habitat ready for immediate use on delivery, since the deployable systems activate before arrival.

4.0 Figures of Merit

Performance characteristics of the Mobitat can be evaluated based on robustness of deployable systems and hardware performance. It is proposed that the Mobitat technology maturity can be measured by the following qualitative capability characteristics:

- Performance of deployable systems. In the current version the two deployable systems (landing system and mobility system) must deploy automatically while the package is in orbit over the target planetary surface. The deployment process must be robust since its success is mission critical.
- Performance of mobility system. The mobility system has multiple mechanical elements that can possibly malfunction. The various joints and connections must be protected from dust and thermal expansion.
- Stability. On a variety of terrains it will be clear where the highly maneuverable mobility system may have weaknesses in stability for resistance to overturning, etc.
- Adequacy of landing systems. An alternative to the eccentric dual motor system should be found, preferably that has the ability to be dropped. Since the landing system is mission critical, the performance of Mobitat can be evaluated on the performance of the system.
- Performance of modular pressure vessel system. Pressure vessel thermal and radiation protection, access hatch design, leveling capability for uneven connections between modules, etc are mission critical elements that must perform well.
- Hardware performance. Statistical analysis of sensors, drivers, actuators, etc will be critical.

5.0 Current State of the Art: Technology Readiness Level (TRL)

The current version of the Mobitat is highly conceptual, estimated at TRL2. The design has been analyzed computationally, mainly concentrating on the kinematic functionality. The kinematics and robotic systems are workable, but several questions remain, such as the robustness and size of a deployable engine, including flexible fuel connections, etc. As a lander the dual engine approach provides eccentric thrust and therefore does not follow engine placement geometry conventions. As a hopper such an issue would not be as critical, or dropping the motors after landing would increase the flexibility of the mobile platform.

Also, sizes for many members are approximated at this time and would need to be designed more precisely should further development of this concept be pursued. Essentially the Mobitat can function both as a habitat and a rover, with advanced performance of suspension and mobility systems. An advantage of this system is that the mobile platform can be used for a variety of uses in addition to the relocation or conveyance of pressure vessel modules. However, disadvantages include the inability to keep the platforms attached when two or more modules are to be assembled together. Multiple Mobitat modules each have their associated lander / mobile platforms, so an assemblage of several modules may result in multiple redundant unused mobile platforms sitting around.

It has also been proposed that intelligent modular panel construction systems like the Trigon self-constructing / self-reconfiguring system could be used as a reconfigurable outer shell for the Mobitat's pressure vessel (Hang & Howe, 2003). The Trigon outer shell can act as a reconfigurable outer skin having the function of thermal insulation, radiation & impact protection, and structural support for a very thin inflatable pressure membrane.

6.0 Assessment of Research and Development Degree of Difficulty

The research and development for the Mobitat is progressing toward the following targets and milestones:

- Redesign of mobility system to be smaller and more compact "Mobitat II", R&D3-I
- Computational analysis of kinematic aspects of "Mobitat II", R&D3-I
- Manufacture of functional scale model for kinematic simulations. R&D3-I
- Fully functional scale model for validation in laboratory environment, R&D3-II
- Performance validation in relevant environment, R&D3-III
- Full-size working prototype with all integrated technologies, R&D3-III

7.0 Exit Criteria

Research and development on the Mobitat may be aborted if it is found that the mobility system cannot be redesigned to be lighter and less obtrusive, or poor hardware performance creates insurmountable difficulties.

8.0 Other Relevant Programs

Research on the Mobitat is currently being conducted by Plug-in Creations Architecture, LLC as part of investigations into Kit-of-parts Theory and component-based building systems for harsh and extreme environments (Howe & Howe, 2000).

9.0 References

Cohen, M.M., Kennedy, K.J. (1997). Habitats & Surface Construction Technology & Development Roadmap. *Proceedings of Exploration Technology Team Meeting, Executive Summary*. 10 July, 1997. NASA Johnson Space Center.

Hang, Y.W. & Howe, A.S., (2003). Deployable Secondary Support Structures for Planetary Construction. *Online proceedings of the Space 2003 Conference*. 23 – 25 September 2003, Long Beach, California. Reston, VA: American Institute of Aeronautics and Astronautics. Available online at: http://www.aiaa.org

Howe, A.S. & Howe, J.W. (2000). Applying Construction Automation Research to Extraterrestrial Building Projects. *Proceedings of the 30th International Conference on Environmental Systems (ICES2000),* 10-13 July 2000, Toulouse, France. 400 Commonwealth Drive, Warrendale, PA: Society of Automotive Engineers.

Howe, A.S., (2002). The Ultimate Construction Toy: Applying Kit-of-parts Theory to Habitat and Vehicle Design. *Online proceedings of the 1st Aerospace Architecture Symposium (SAS2002),* 10-11 October 2002, Houston, Texas. Reston, VA: American Institute of Aeronautics and Astronautics (AIAA). Available online at: http://www.aiaa.org

Lai, Y.H. & Howe, A.S., (2003). A Kit-of-parts Approach to Pressure Vessels for Planetary Surface Construction. *Online proceedings of the Space 2003 Conference*. 23 – 25 September 2003, Long Beach, California. Reston, VA: AIAA. Available online at: http://www.aiaa.org

10.0 Contact information

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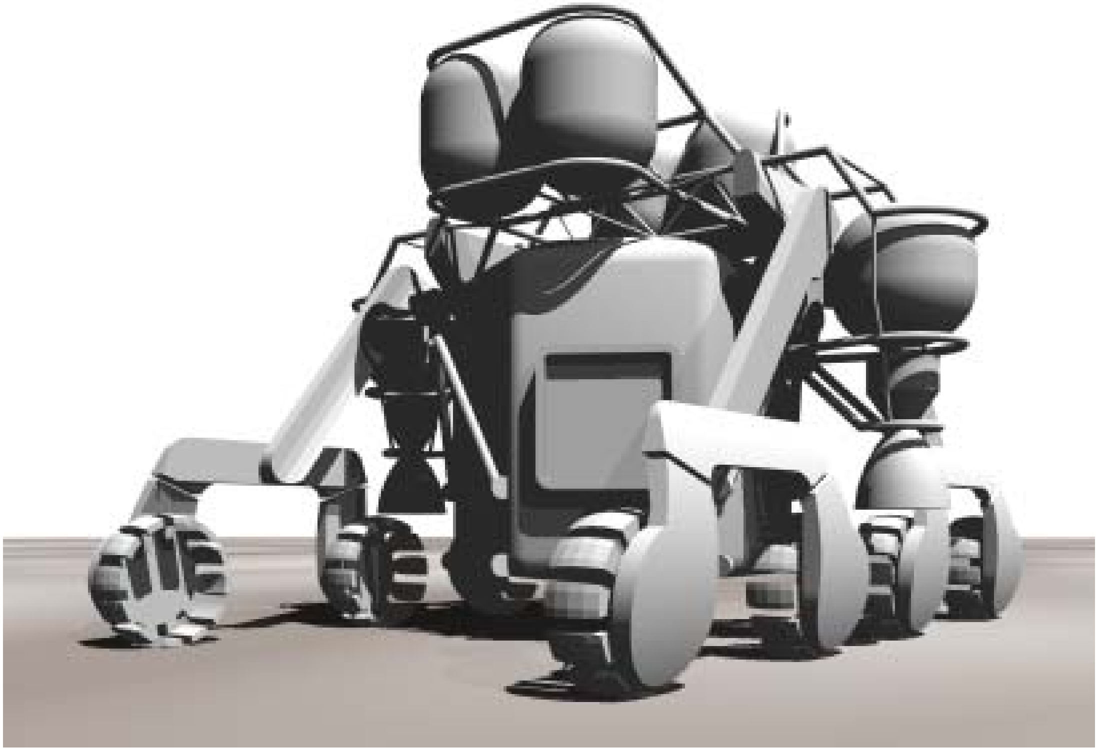


Figure 18: Mobitat in surface deployed configuration

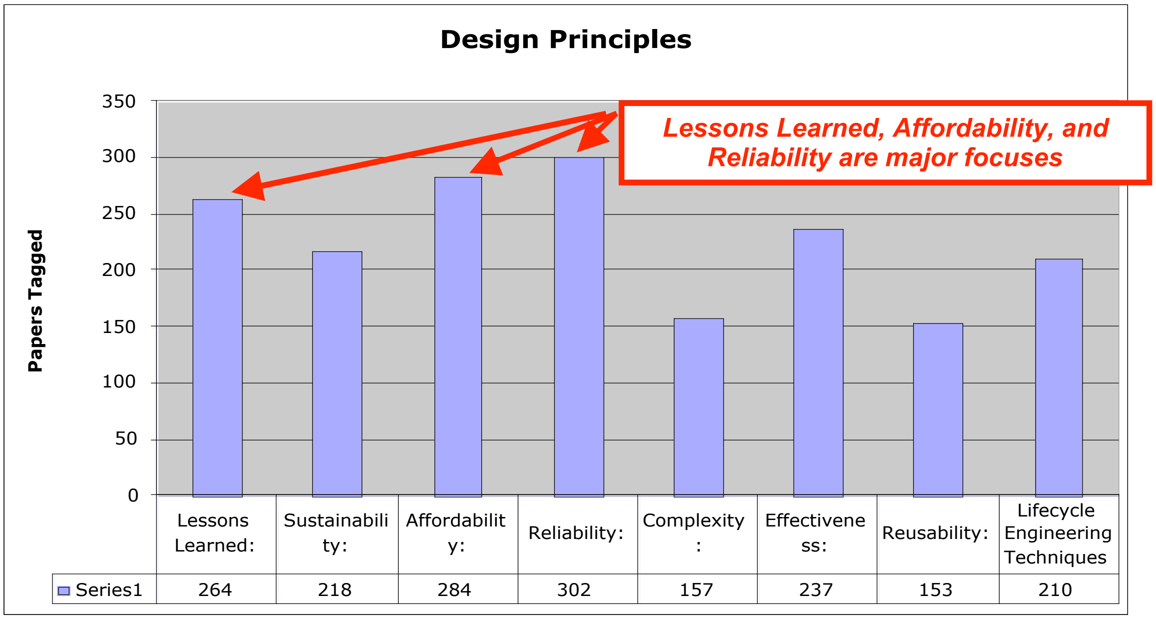
Dear RFI Respondent A. Scott Howe,

Ten weeks ago, you contributed to a crucial first step in NASA's implementation of the Nation's new Vision for Space Exploration. In a broadly-focused Request for Information, the Office of Exploration Systems sought white papers analyzing key technical and programmatic issues relevant to the execution of a sustained campaign of human and robotic exploration of the solar system.

The complement of 998 responses that we received have not only affirmed a high level of external interest in the Vision, but have stimulated and refined our formulation of requirements, technology portfolios, and acquisition strategies. Responses came to us from a diverse array of government research centers, private companies, university research laboratories, student organizations, non-traditional sources ranging from architects to computer game developers, and at least two Nobel Prize winners.

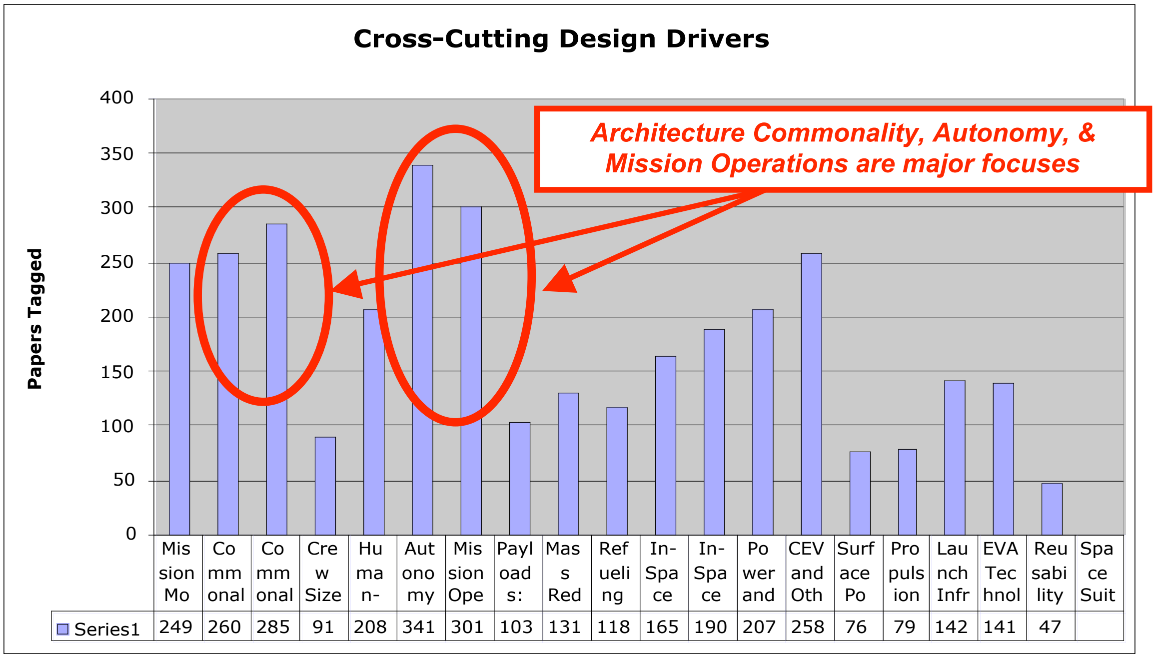
Upon our receipt of the responses, we commenced an evaluation process that judged submissions on their demonstrated effectiveness, innovation, and potential to improve performance in cost, schedule, or risk. In this process, our evaluators also tagged submissions for relevance to multiple RFI focus areas, Work Breakdown Structure (WBS) elements, and technology types. In combination with keyword searches, these evaluation metrics and metadata now support our utilization of RFI contributions for purposes of formulating requirements and program plans.

Generally, we were impressed by the high number of quality submissions provided in the "Program Management" RFI Focus Area, where responses focused on Requirements Formulation, System-of-Systems Development Strategies, and Modeling & Simulation. We noted that a high number of submissions emphasized the importance of lessons-learned, affordability, and reliability in the "Design Principles" Focus Area. Among "Cross-Cutting Design Drivers," respondents cited commonality, autonomy, and mission operations as critical elements of optimal exploration architecture. (See following charts.)



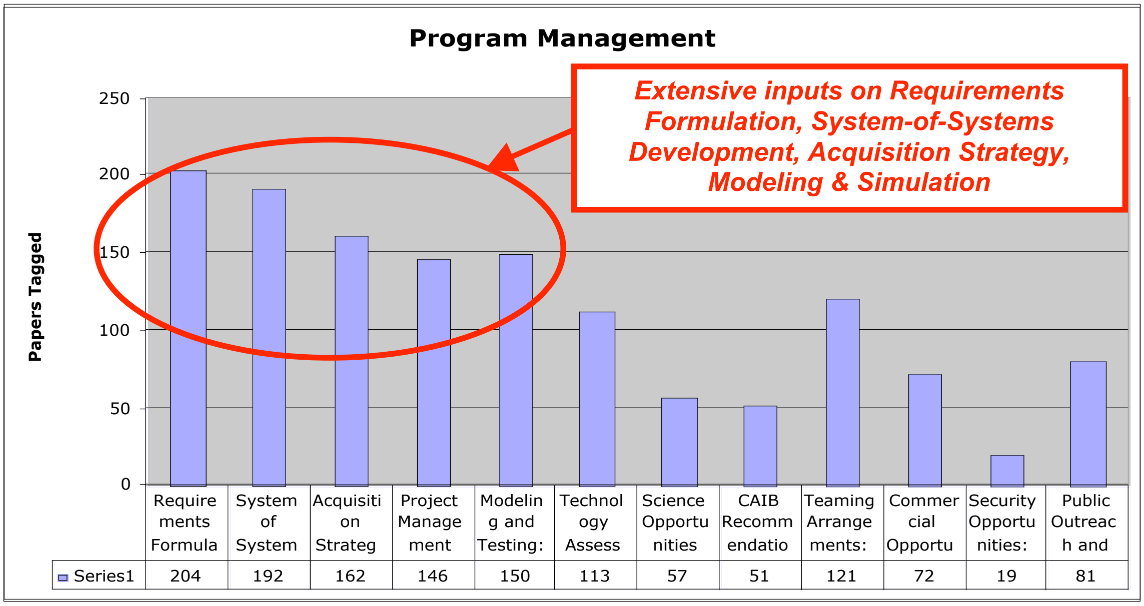
	Lessons Learned:	Sustainability:	Affordability:	Reliability:	Complexity:	Effectiveness:	Reusability:	Lifecycle Engineering Techniques
▫ Series1	264	218	284	302	157	237	153	210

Lessons Learned, Affordability, and Reliability are major focuses



	Mission Mo	Commonal	Commonal	Crew Size	Human-	Autonomy	Mission Ope	Payloads:	Mass Red	Refueling	In-Space	In-Space	Power and	CEV and Oth	Surface Po	Propulsion	Launch Infr	EVA Technol	Reusability	Space Suit
▫ Series1	249	260	285	91	208	341	301	103	131	118	165	190	207	258	76	79	142	141	47	

Architecture Commonality, Autonomy, & Mission Operations are major focuses



Extensive inputs on Requirements Formulation, System-of-Systems Development, Acquisition Strategy, Modeling & Simulation

In the evaluation process that concluded in June 2004, your paper, which was submitted in the Crosscutting Design Drivers and Architecture Elements category, received the following scores:

Demonstrated Effectiveness / Technological Maturity: 2
Innovativeness / Variation from Historical Approach: 4
Potential Improvement in Cost, Schedule & Risk: 5

These scores were based on a one- to five-point scoring system, five being the highest possible rank. The scores were compiled based upon comprehensive evaluation guidelines, which can be viewed with other relevant updates on the RFI at the Acquisition Portal of the Exploration Systems website at http://exploration.nasa.gov. While these metrics are a useful piece of metadata that we use in searching our RFI database, they are only one element of the techniques we employ in mining high-value ideas and proposals.

In the coming months, we will be using your RFI response in concert with hundreds of others to inform government analyses and priorities as we bring on an increasingly large population of contractor teams through Broad Agency Announcements and Requests for Proposals. We hope that you will continue to contribute to our nation's implementation of the Vision for Space Exploration by submitting proposals through the mechanisms appropriate to your organization and domain of expertise.

Your input has already served an important role in kick-starting our efforts at NASA, and will continue to be a valuable resource as we proceed. Thank you, and please join us in the years ahead, as we design and build the next generation of systems that will humans and robots on exciting missions to the moon, Mars, and beyond!

Very respectfully,

Craig Steidle
Associate Administrator
Exploration Systems Mission Directorate
NASA Headquarters