Space 2006
19 - 21 September 2006, San Jose, California

AIAA 2006-7337

MOBITAT2: A Mobile Habitat Based on the Trigon Construction System

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This paper describes a preliminary concept for mobile habitats that help illustrate possible uses for the modular robotic Trigon construction system. Modular mobile habitats have been shown to possess the potential to satisfy multiple requirements for initial planetary surface base construction and surface rover mobility. The Habot / Mobitat-style mobile habitats would be mass-produced and operate on the planet surface in groups and clusters to form re-locatable / reconfigurable habitats and bases. However as currently proposed, the Habot / Mobitat-style concept is limited in its adaptability to other uses, especially after the initial need for the mobile habitat is ended. The Trigon system allows for a kit-of-parts approach to habitat construction and vehicle design, such that initial configurations can later be disassembled or reconfigured for completely different requirements in more permanent Class II or Class III surface construction scenarios. A rover, habitat, and other potential applications are introduced.

I. Introduction

It has been suggested that planetary surface construction can be accomplished in three phases (Kennedy 2002). The first phase is Class I pre-integrated construction, where ready-to-use habitats are delivered to the surface and occupied without any additional preparation. Class I structures are limited by the payload size constraints of the launch systems that are used to deliver them, and will most likely be used on shorter missions. The second phase are Class II kit-of-parts structures, where prefabricated materials are delivered to the surface and inflated, assembled, or deployed into larger habitats. Class II structures are not as limited by size, but require effort expended on the site for fabrication and preparation for habitation, and will probably be used in a more permanent base and longer periods of occupancy. The final phase is the construction of Class III in-situ derived structures that use increasing amount of native materials to establish larger and larger permanent settlements. Cohen and Kennedy (1997) explain that each of the phases will be preparatory for the next, and some overlap will occur. In addition, it is stressed that human labor for assembly will not be practical due to the complexity of maintaining a safe environment for labor in harsh conditions, therefore much of the construction will need to be automated.

One form of Class I structure that can also bridge over into Class II construction is the Habot concept (Cohen 2004). The Habot ("Habitat" + "Robot") is a Class I pre-integrated habitat that has an autonomous robotic mobility system for moving across the surface. Several Habot units can be delivered to the surface, whereupon they have the capacity to autonomously find each other and hook up docking ports to form a larger Class II base awaiting the arrival of a crew. Habot units can also be piloted by the crew to function in the capacity of rovers, removing the need to have specialized vehicles for surface transport. The original Habot concept used a legged walking mobility system that would have been too slow for a human crew, who would need to have a more rapid means of motivation. Howe and Howe (2005) derived a wheeled version of the Habot called the Mobitat ("Mobile" + "Habitat") where mobility was optimized and higher speeds could be achieved. However, the original Mobitat concept as a mobile modular habitat compromised other systems for the function of the mobility system, which was large and ungainly.

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Some of the inadequacies of the Habot and original Mobitat concepts are overcome with the Transformable Robotic Infrastructure-Generating Object Network (Trigon) system that can function as a core construction system for planetary primary (Lai & Howe 2003) and secondary structures (Yip & Howe 2003), and mobility in a Class II scenario bridging over to Class III. The Trigon system can be a flexible construction system for habitats and vehicles (Howe 2002).

II. Self-assembling Habitats

In this paper a conceptual design for a Trigon-based mobile modular habitat is introduced, including payload packaging, delivery, deployment strategies, mobile planetary base construction, rover functions, and reconfiguration options. In the original Mobitat concept, pre-integrated hard pressure shells were hung from maximally flexible mobility platforms. The pressure modules could be detached from the mobility platforms and set into a fixed location, connected to other modules with pressure ports, while the mobility platforms would be available for use on their own with fitted implements for drilling, construction, excavation, and lifting. However, the Mobitat2 concept takes an entirely different approach. Trigon panels are fully capable of self-assembly from a compact stack of partially connected panels. In addition, secondary functionality can be incorporated into the panels by the use of special plug-in payloads that are carried by the panels in the process of self-assembly (Howe 2005). Therefore, instead of an over-sized mobility platform as was proposed in the original Mobitat concept, the Mobitat2 mobility system will consist of compact, fold-out secondary structures carried in the plug-in payloads of the Trigon panels, and deployed where needed during the self-assembly. Instead of a hard-can pressure shell as proposed in the original Mobitat, the pressure vessel of the Mobitat2 will consist of an inflatable inner bladder lining, pre-fitted to pressure ports sized to mate with the Trigon system, that inflates to fill a shell consisting of Trigon panels. This paper does not present a fully workable solution for the Mobitat2 concept, but instead will introduce preliminary ideas that are thought to be feasible, for the purpose of discussion, in order to show some potential uses of the Trigon modular robotic construction system.

III. Design Investigation

The design investigation of a self-assembling mobile modular habitat has centered around the ability for the Trigon panels to self-assemble, and carry specialized payload panels in the process. In this section, the Trigon panel self-mobility capacity is reviewed with discussions about specialty payloads, such as inflatable shielding and wheel mobility / suspension systems. Also included in this section is a discussion about core elements (large special items that cannot be confined to payload panels, but are designed to interface with Trigon panel edges), such as pressure hatches, inflatable pressure barriers, legged mobility systems, etc.

A. Stackable Modular Robotic Building Panels:

The Trigon system consists of polygonal panels with uniform edges. The panels have edge actuators for linking to other panels. The edge actuators are hinged with an offset axis in such a way that any two panels can be orientated from 0 to 360 degrees in relation to each other. This ability allows the panels to be stacked during transportation, to keep the payload small and compact. Figure 1 shows a simple volume constructed of Trigon triangular panels, and illustrates how the panels can be folded and stacked.

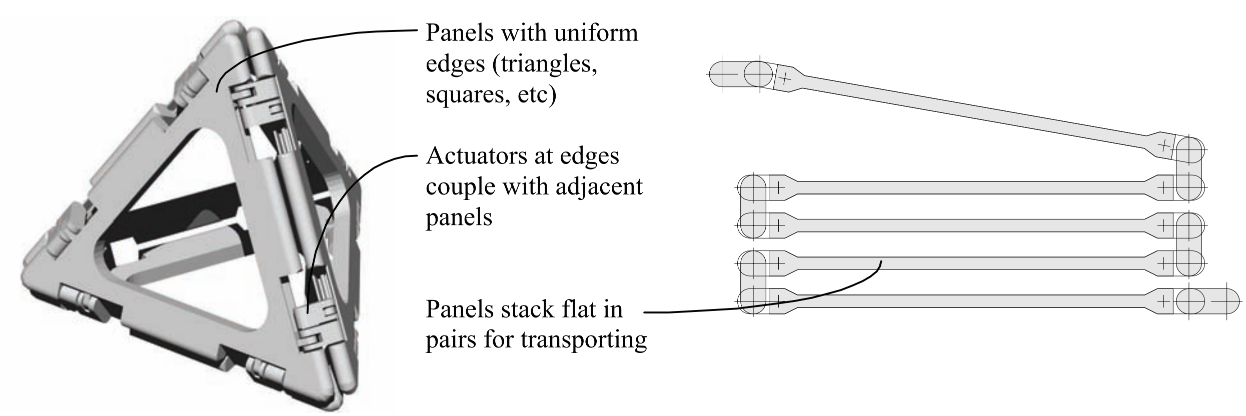

Figure 1: Stackable panels

The edge manipulator actuators control the panel with revolute motion in relation with neighboring panels. These manipulators are called connector arms. Two panels will mate with each other by nesting connector arms, with one panel taking hierarchical dominance over the other by moving its arms to the outside, and the other panel moving the arms to the inside, so that both sets of arms mutually clasp each other. The revolute actuator in each arm set can then cause the panels to reconfigure their orientation with respect to each other.

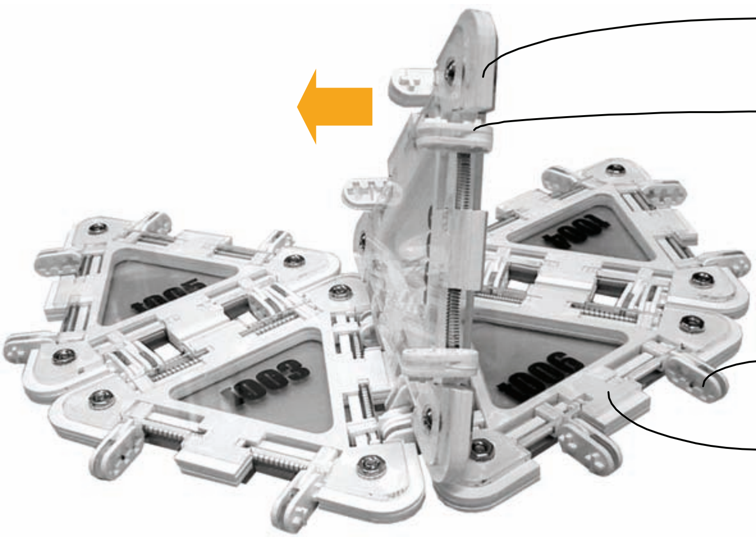

Figure 2: Functional mock-up showing self-assembling structures

Using this technique, Trigon panels can be added to the structure at any location and use the motion of the connector arms to latch on to already completed portions of the structure, and travel or “tumble” end over end, avoiding other traveling panels, to find its own specified location (Figure 2). Triangles can travel over square structure (and visa versa) in pairs (Howe, Gibson 2006a). Using only square and equilateral triangular panels, self-assembling domes, cylinders, trusses, and many other stable construction geometries can be autonomously assembled, or controlled through teleoperation.

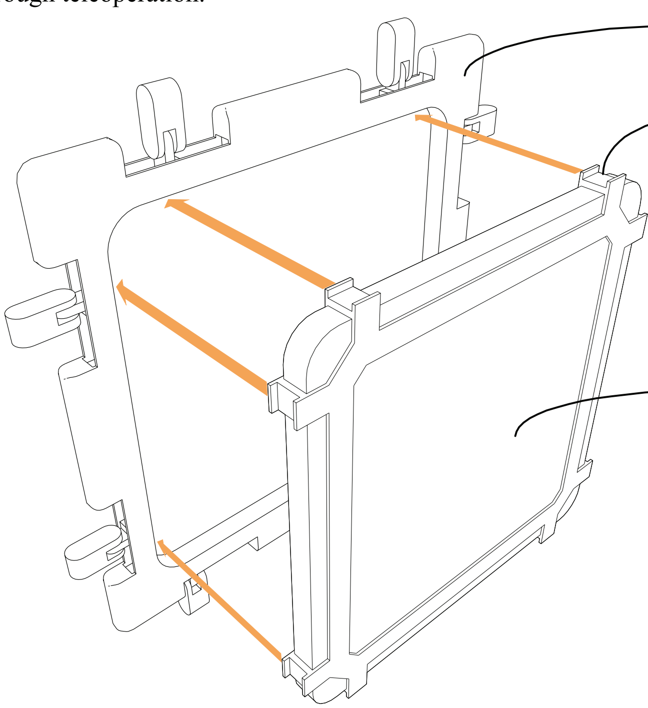

Figure 3: Trigon payload panel

B. Modular Plug-in Payloads:

Trigon panels have all the mechanisms, actuators, sensors, and controllers required for their primary motion function located in a narrow zone parallel to the panel edge. A network of power and communications is formed through the connector arms when the panels mate with each other. This leaves a clear zone in the middle of the panel for specialty "payload" panels, that plug-in to power-communication ports on the Trigon panel to draw power as needed for a variety of deployable manipulators, motors, instruments, mobility systems, etc (Figure 3).

The number of possibilities for what these payloads can consist is virtually unlimited. This paper will describe, in diagrammatic terms, several payload functions that would be needed to give a Trigon construct mobility, insulation, and protection from cosmic radiation, but the list could also include antenna, instruments, and deployable manufacturing processes that could make up the walls of a cubical "cassette factory" (Howe 2005).

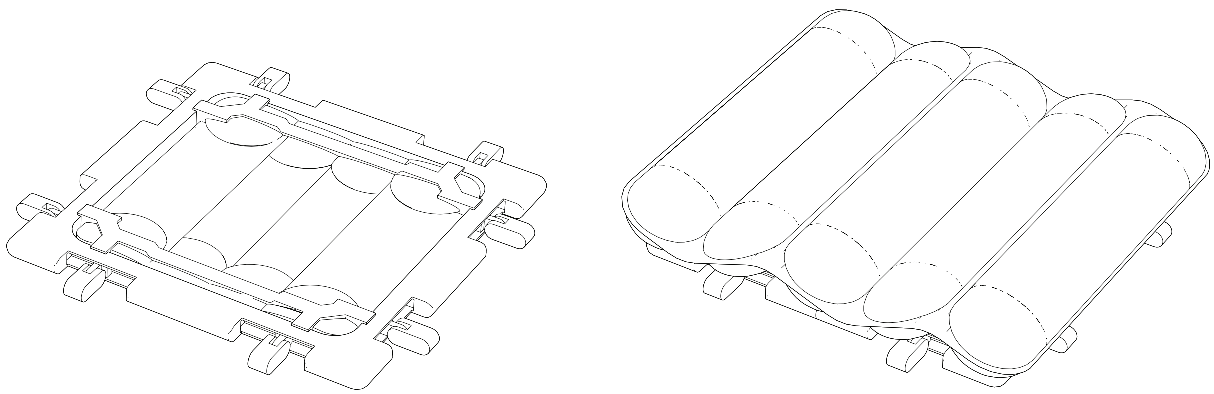

Figure 4: Shielding folded (left) and filled or inflated (right)

C. In-situ Shielding Payload:

One example for a specialty payload would be insulation panels or dense radiation shielding. However, since the Trigon panels by design have gaps between them to accommodate grasping points for "tumbling" panels, it is necessary to have large, "floppy" coverings that spill over to protect the gaps. Figure 4 shows a concept for an inflatable shield that folds up compact into the body of the payload panel while "tumbling", but can be filled with liquid water, hydrazine fuel, or possibly function as sand bags using material gathered during In-situ Resource Utilization (ISRU) processes. The cells in the shielding can overlap in multiple layers to create uniform thickness.

The advantage of an inflatable, or post-filled shielding bag is that the filling material need not be carried or imported from Earth, but can be found at any site. Some of the images shown in this paper are rendered with thin inflatable shields, but the actual shielding can be as bulky as needed, depending on the design of the bag and how it attaches to the payload panel structure and transfers its inertial force loads. Post-filled shielding bags would need either a local mechanism for permanent insertion and sealing of the material, or a central or distributed supply-return infrastructure (such as in the case where shielding bladders are used as hydrazine fuel tanks). These systems can be developed in turn as the need arises and more data is available for precise shielding requirements and there is a clear understanding of the availability of in-situ resources.

D. Wheeled Mobility Payload:

Another critical specialty payload developed in this design investigation is the capacity for a Trigon construct to have its own mobility. Mobility systems may be specially designed as core elements that are too bulky to fit into a payload panel but nevertheless interface with the system (see section E below). However, a deployable wheel and suspension system was devised that folds flat into the body of two payload panels, so that the wheel can be moved across Trigon structures in the normal "tumble" method for flexible placement. The wheel has its own motor for forward and reverse mobility, and actuators for turning, deploying, and tire inflation. A series of schematic diagrams have been prepared to illustrate the concept.

In simplistic terms Trigon panels are shown "tumbling" singly across structure. However, in actuality the panels will function in robotic pairs (Howe, Gibson 2006a). Figure 5 shows a pair of Trigon panels opened up with double wishbone suspension system and deflated wheel packed into their storage position in the payload panels. These loaded Trigon panels can be stacked back-to-back, and manipulated in robotic pair "tumbling" to any location required on the structure. It must be noted that construction algorithms devised for assembling rovers and wheeled habitats would need to take into account a dedicated side for mounting the system to a hull, rather than a symmetric loading that could allow the system to be mounted on either side. This means that when the robotic pair "tumbles" into place, it may need to do additional maneuvers to allow it to position and orient itself correctly so that the deploying wheel system may be aimed toward the planet surface.

To deploy, the two Trigon panels hinge at the "top" and allow the double wishbone suspension system to expand outward (Figure 6). The Trigon panel connector arms and suspension system would act in concert to bring the hub to meet with the wheel and dock with it.

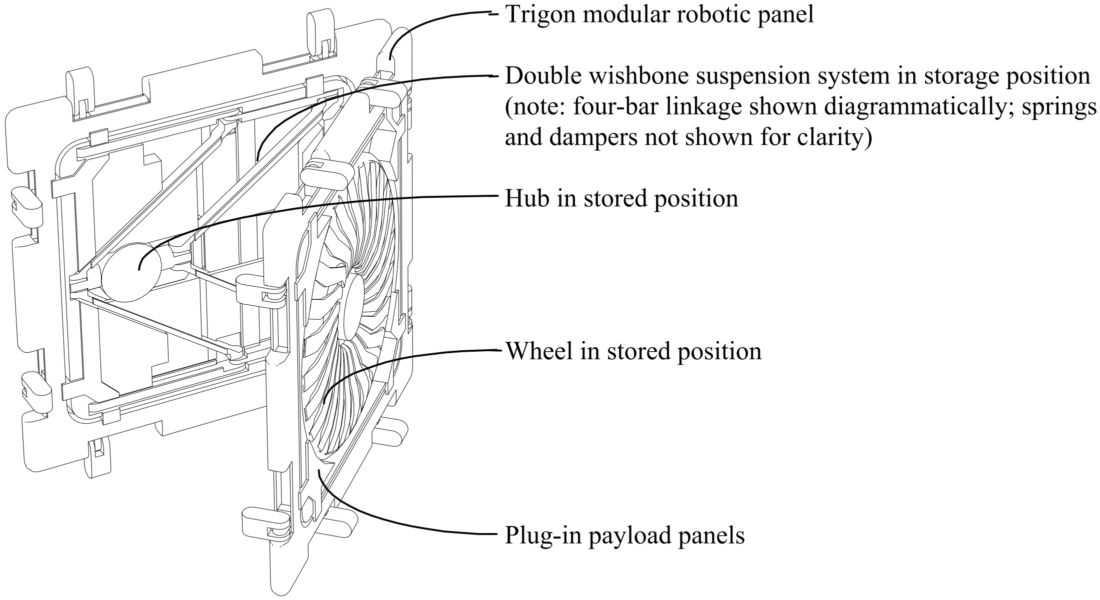

Figure 5: Wheel payload (shown open) includes suspension system and wheel

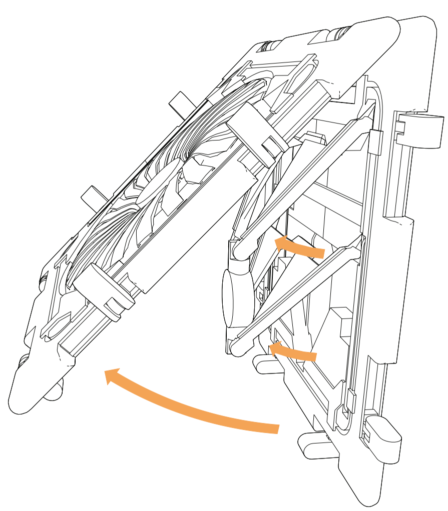

Figure 6: Suspension system deploy diagram

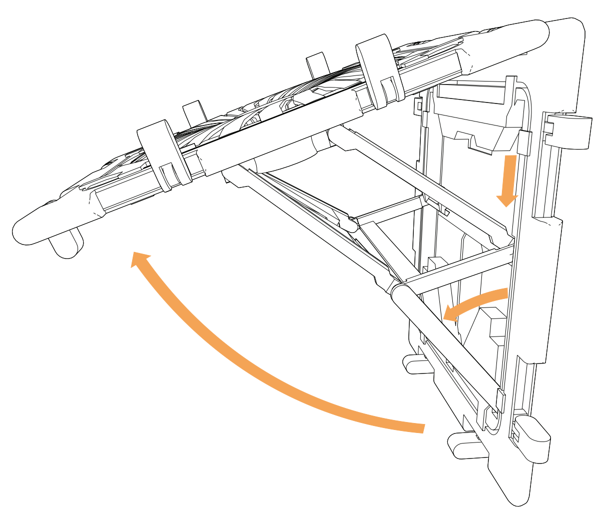

Figure 7: Unfolded wheel diagram

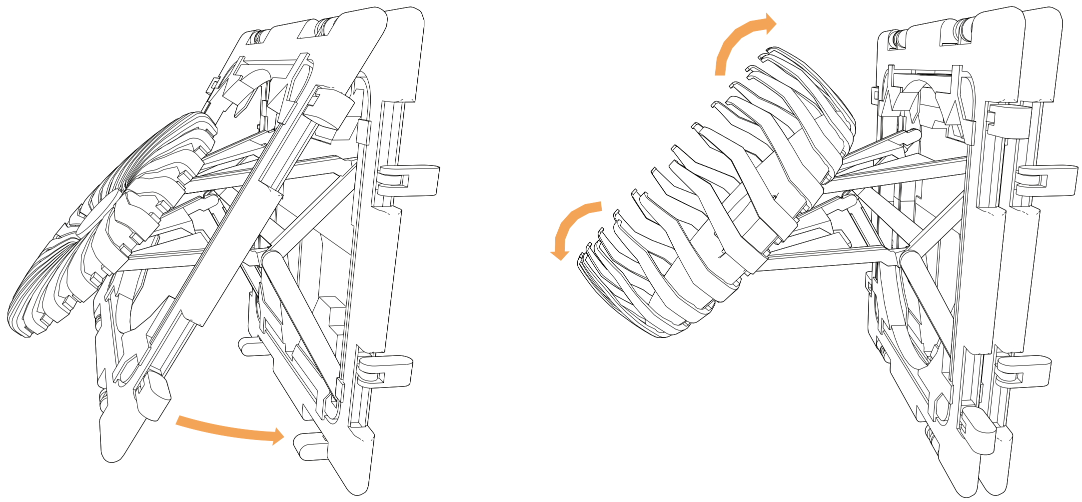

Figure 8: Wheel deploy diagram: wheel panel returns to stack (left), metal treads deploy (right)

Once the suspension system hub has docked with the wheel, the wheel payload can release it and fold back into place back-to-back with the panel containing the suspension system. Figure 7 shows the wheel and suspension system ready for use, except that the wheel itself has not yet deployed. Once the wheel-suspension system set is in place, the wheel can inflate. The wheel consists of a non-stretch gas or liquid inflated bladder, with fold out metal treads that open up like a flower. The tread tips have a spring-loaded band that keep them wrapped tightly around the tire (Figure 8).

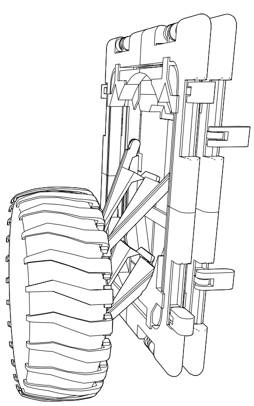

Figure 9: 90 degree wheel setting

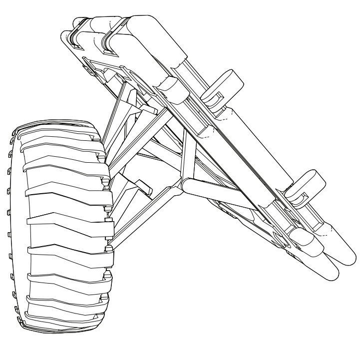

Figure 10: 45 degree wheel setting

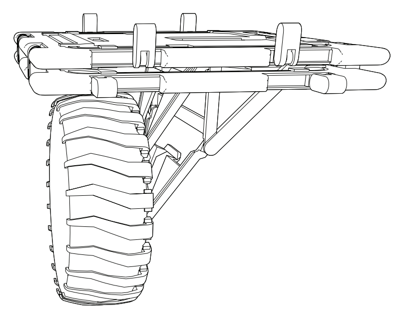

Figure 11: 0 degree wheel setting

The suspension system mounts can be set at any position between 0 and 90 degrees, to accommodate various hull angles. Figure 9 shows the wheel system set at 90 degrees, Figure 10 at 45 degrees, and Figure 11 at 0 degrees. These three settings will be the most common, but other settings are possible between these settings.

E. Core Elements:

Core elements are large, bulky items and equipment that cannot be fit into the constraining size of the payload panels, yet are designed to interface with the Trigon panels structurally. Core elements can include power plants, inflatable pressure barrier lining, pressure hatches, pressurized connector tunnels, windows or viewports, and other special forms of mobility systems such as unfolding legged mobility systems.

1. Inflatable Pressure Barrier Lining

One premise of the Trigon system is that the critical pressure barrier needed for human survival no longer need be rigid or thick, which are necessary in some designs to insure insulative and shielding qualities. However, the Trigon system keeps the thick, bulky, and dense functions located on the panels themselves in the form of payload panels (deployable, inflatable, or post-filled), so that the pressure barrier need only be a thin structural barrier strong enough to support the tremendous pressure differential.

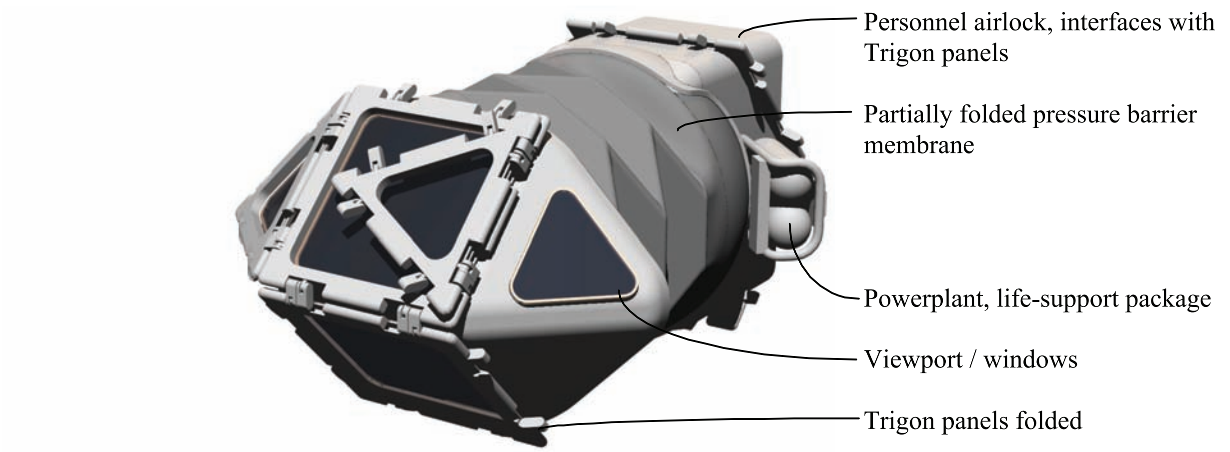

Figure 12: Inflatable pressure barrier partially folded

So far the concept of a thin pressure barrier liner is not proven. However, it must be noted that should the concept fail during subsequent investigations, the Trigon system would still prove to be a valuable method for designing secondary support structures and mobility for standard hard-shell pressure vessels or inflatables designed to interface with the system. Such large pressure vessels would be treated as core elements in the system, using fold-out Trigon mobility systems and other equipment as needed.

A thin-walled pressure barrier liner would still have significant thickness to support itself, provide continuous reinforced seams at pressure ports and viewports, and incorporate hard points for the mounting of internal fittings as needed. A significant challenge to inflatable membranes is how to fold them properly so that they unfold cleanly and do not produce unnecessary stress points. Figure 12 shows a possible scheme for a folding inflatable membrane pressure liner for a rover (see section IV below).

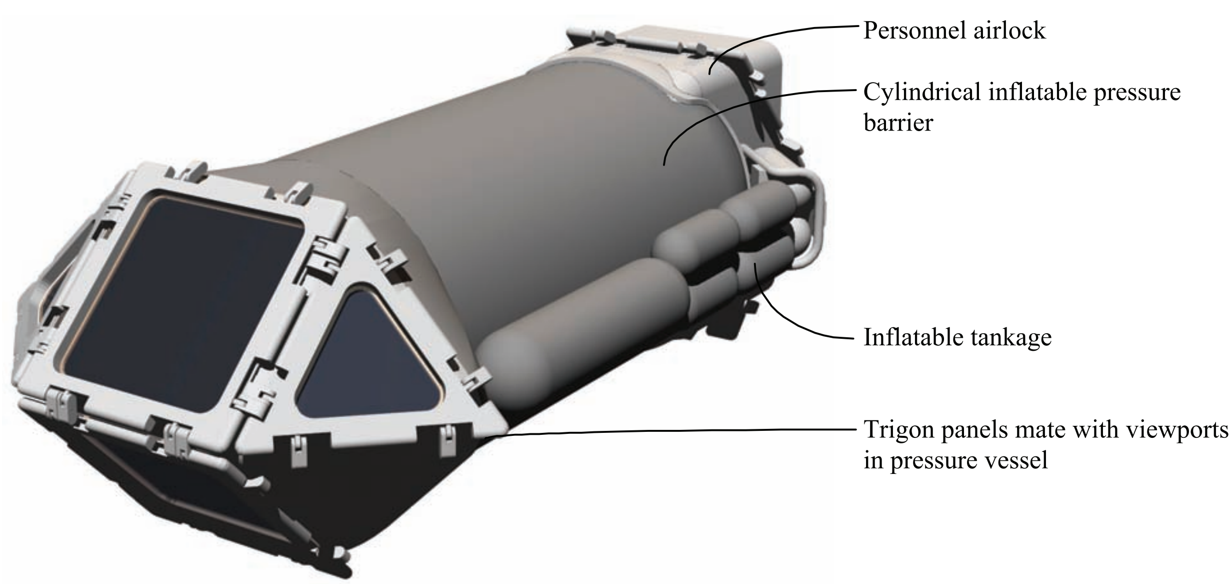

Figure 13: Pressure barrier inflated

Inflatable membrane pressure liners can have built-in supplementary inflatable bags for shielding, tankage, or extra protection at Trigon panel gaps. Figure 13 shows a possible scenario for an inflated pressure barrier lining in a rover. Note that pressure ports and viewports are permanently attached to the membrane.

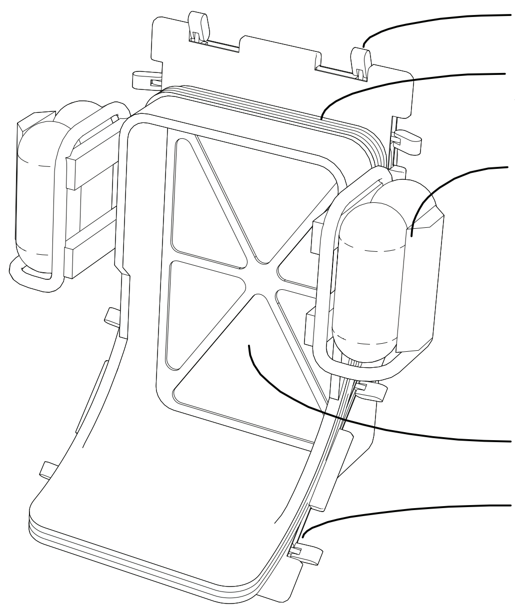

Figure 14: Pressure hatch diagram (interior view)

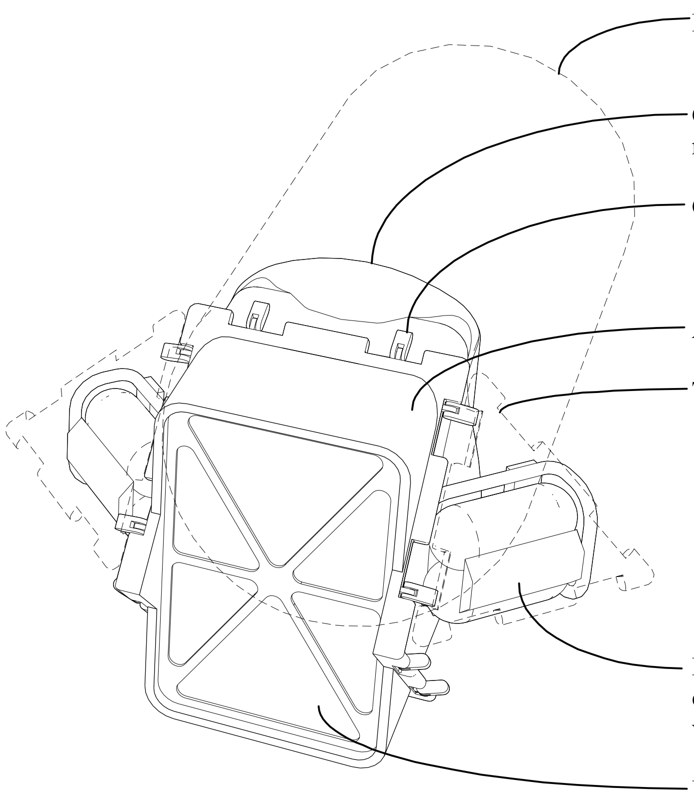

Figure 15: Personnel airlock diagram

2. Pressure Hatches

Pressure hatches are sized according to ergonomic constraints, and therefore may be subject to a separate set of standards than those that determine optimum panel size (Howe, Gibson 2006b). In addition, the pressure port would function as a hard structure that the inflatable pressure barrier liner would be permanently attached to. However, since the pressure port penetrates the Trigon shell, it will need to have edge interfaces that engage the panel edges, including compatible connector arms. Figure 14 shows a schematic diagram of a pressure port, including interfacing panel edges and extendable pressure tunnel connector. In Figure 15, a schematic diagram for a personnel airlock for a rover is shown, designed into a package that includes a hydrazine powerplant, life support package, oxygen tanks, and other equipment. It must be noted that these elements are conceptual at this stage, and do not represent actual sized equipment. The pressure port or personnel airlock (Cohen 2001) would be manufactured as a single piece and permanently mounted to the inflatable pressure barrier lining on Earth under a controlled environment, and then imported to the surface as a package bundled with the necessary Trigon panels and specialty payloads to fit out the entire system.

In the design of core elements such as a pressure hatch or personnel airlock, every effort should be made to standardize the special equipment so that future reconfiguration may be salvageable in a new use.

3. Legged Mobility System

The Robotic Vehicles Group at the Jet Propulsion Laboratory (JPL) has developed a multi-legged mobility system called the All-Terrain Hex-Legged Extra-Terrestrial Explorer (ATHLETE), that consists of a hexagonal platform with compactly folding legs for transport. Though the ATHLETE in its current version is a fixed configuration, the folding leg technology can be applied in a modular way that is compatible with the Trigon modular construction system.

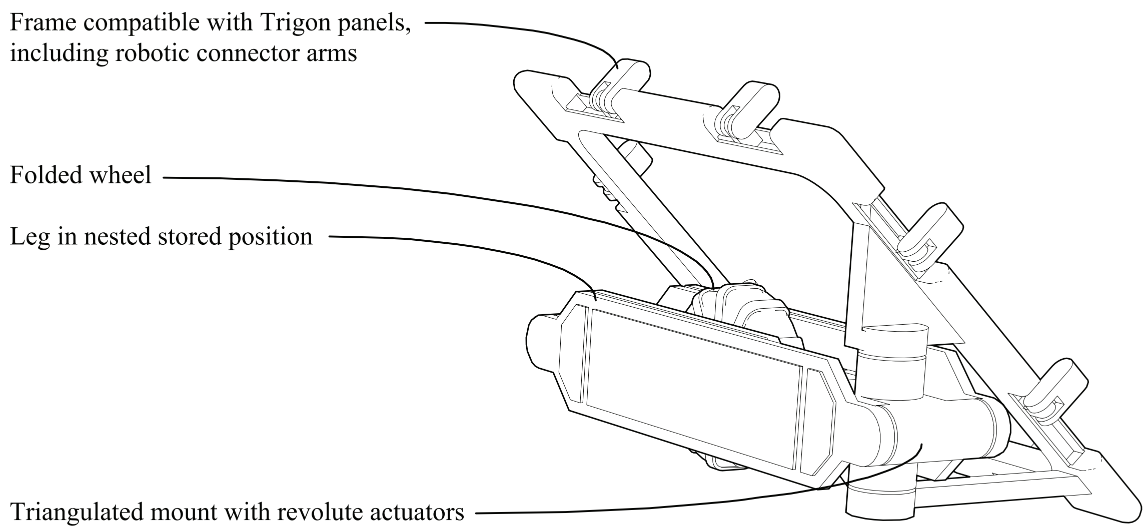

Figure 16: Leg in compact folded form

Figure 16 shows a schematic diagram of a leg in folded position, including mounting chassis that is compatible with the Trigon system. Another schematic diagram of the leg in the open position is shown in Figure 17. The leg consists of three sections that fold into each other, operated by three revolute actuators at the "knees", and an additional vertically oriented actuator that points the leg. Fine maneuvering control can be affected by a fifth revolute actuator that redirects the wheel. The legs can be used to walk on adverse terrain, using the wheels as feet, or roll on level ground. The legs will allow for leveling compensation for a variety of terrain, including uneven slopes.

4. Windows and Viewports

Windows and viewports that must be permanently mounted to the inflatable pressure barrier lining must be fit out as core elements in the Trigon system.

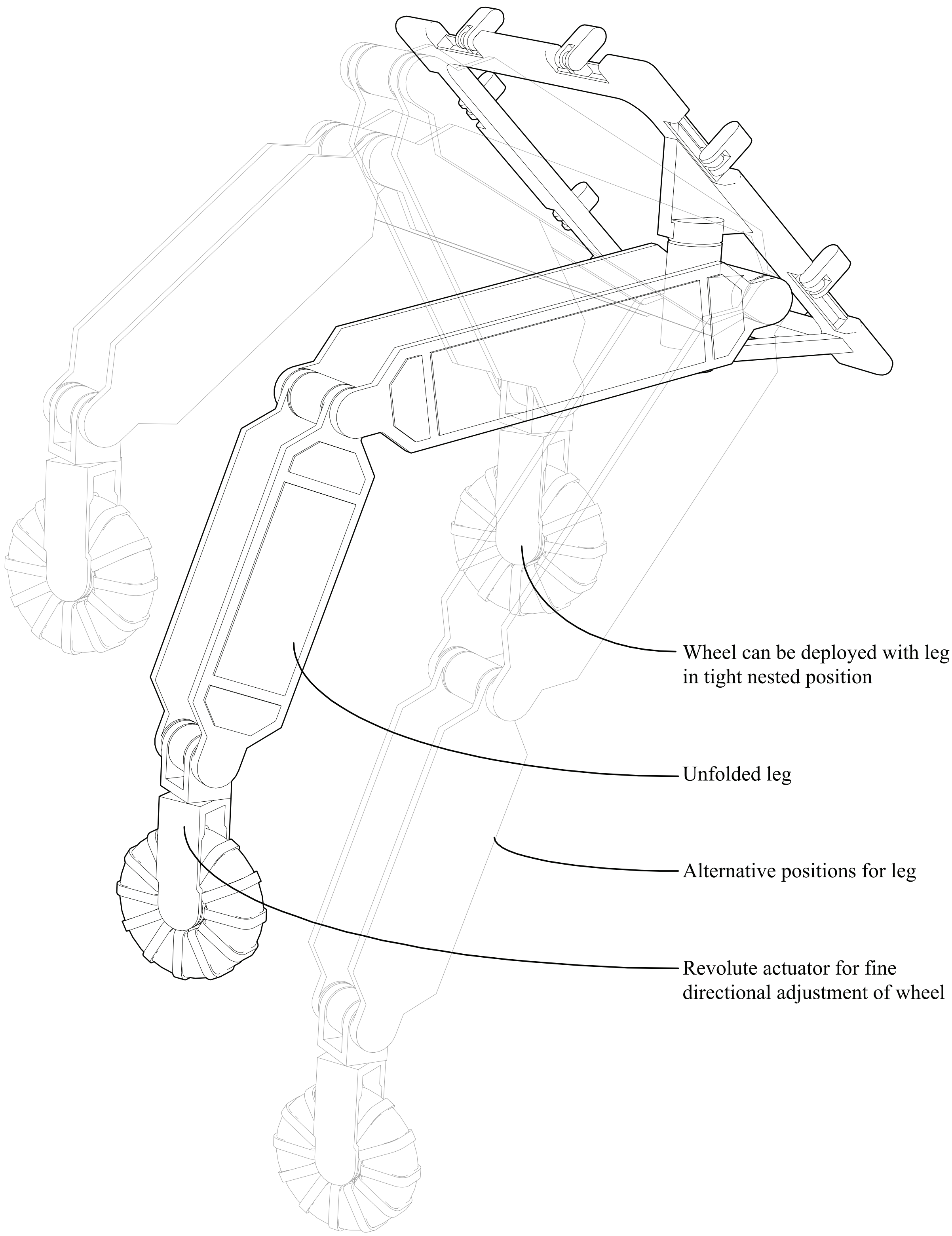

Figure 17: Leg open

IV. Wheeled Surface Infrastructure Elements

Using the modular elements described in section III, rough schematic vehicle and habitat configurations were explored. Figure 18 shows the top view of a small pressurized rover, while Figure 19 and Figure 20 show side and front views respectively of the rover (some inflatable shielding has been removed for clarity).

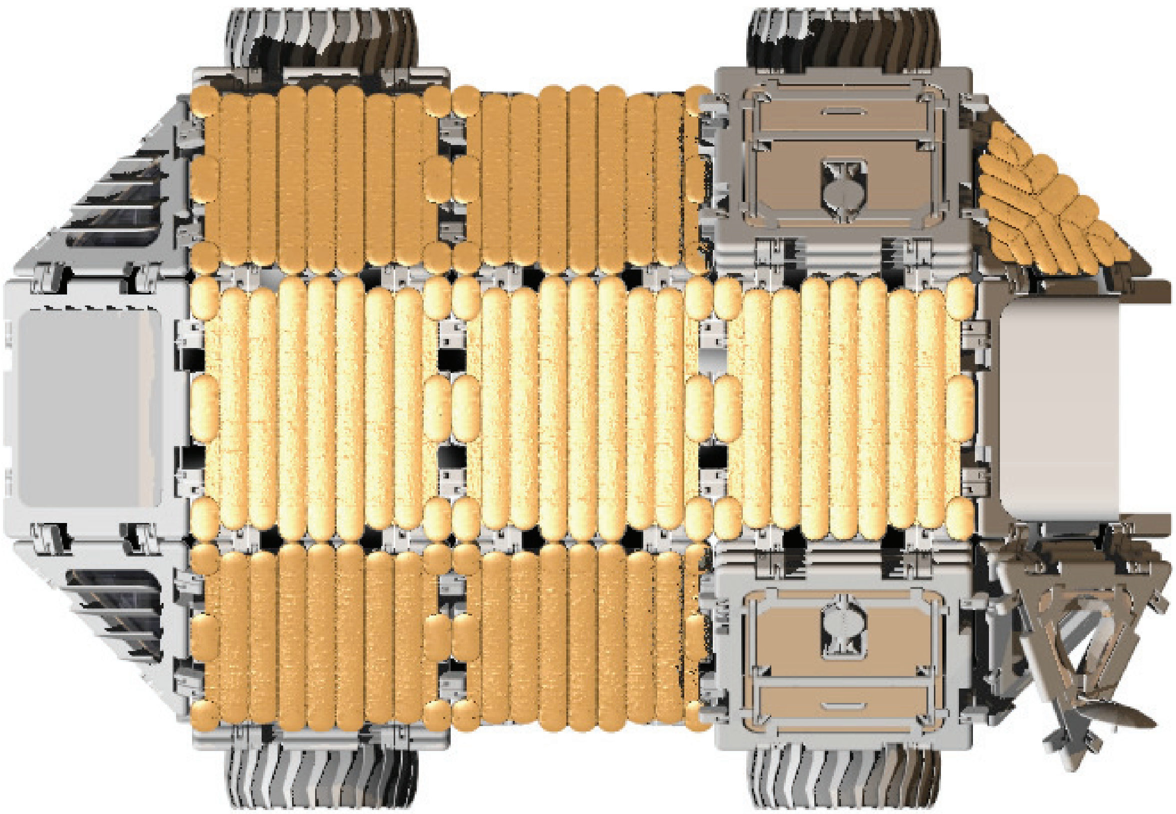

Figure 18: Pressurized rover top view

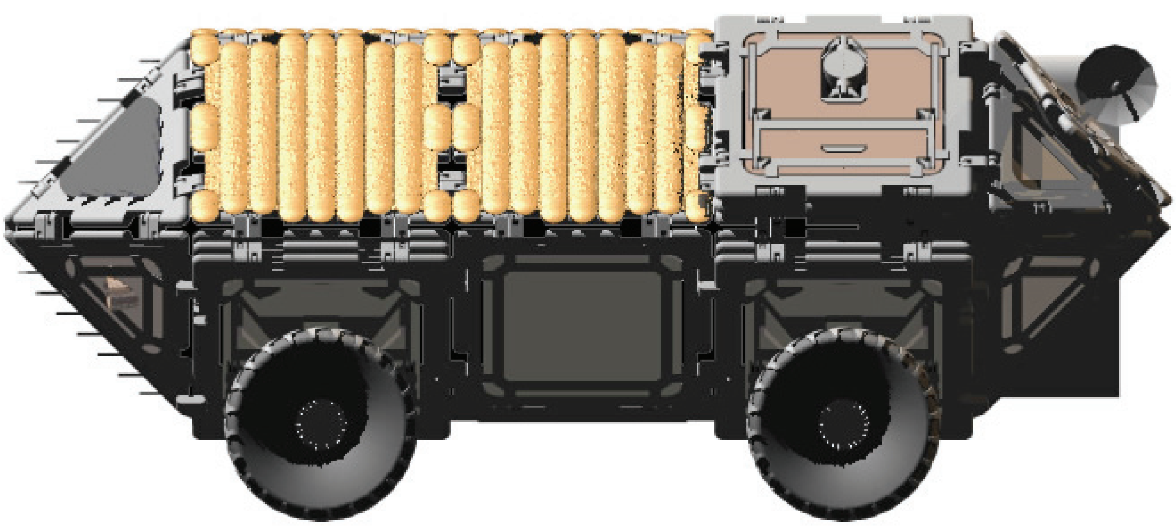

Figure 19: Pressurized rover side view

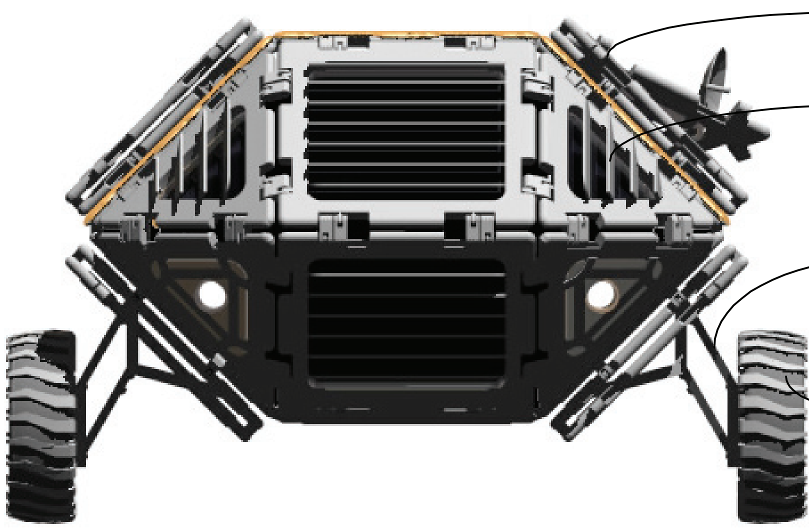

Figure 20: Pressurized rover front view

A rough estimate of the mass of the rover (for comparison purposes) is shown in Table 1, with a total mass of 2,700kg. These figures are very rough, based on a flat volume calculation of 100kg/ m^3 density for each of the components (Howe, Gibson 2006b), and require more detailed validation. The mass figures also do not include consumables, in-situ materials acquired locally for shielding or fuel purposes, or interior fitout, and may under- or over-estimate core element masses which are only conceptual at this stage. However, for the comparison of various Trigon habitat and vehicle configurations in this section the figures will be appropriate.

Element Description	Quantity	Rough Unit Mass	Total Mass
Trigon triangle panels	10	6 kg	60 kg
Trigon square panels	32	14 kg	448 kg
Triangular shielding payload panels	6	17 kg	102 kg
Square shielding payload panels	18	40 kg	720 kg
Suspension system payload panels	6	40 kg	240 kg
Wheel payload panels	6	40 kg	240 kg
Antenna payload panels	1	17 kg	17 kg
Personnel airlock / powerplant core element	1	500 kg	500 kg
Inflatable pressure barrier lining core element	1	260 kg	260 kg
Triangular shielded viewport core element	2	17 kg	34 kg
Square shielded viewport core element	2	40 kg	80 kg
Total Mass (rough preliminary)			**2,700 kg**

Table 1: Rough preliminary mass estimates for a small pressurized rover

Figure 21 shows a detail of the rear of the rover, with the personnel airlock pressure hatch visible (inflatable shielding has been removed from this image for clarity). Figure 22 illustrates a scenario with a pair of rovers at work on the surface of Mars.

In another study, a six-wheeled rover-type habitat concept was explored (Figure 23, shielding not shown for clarity). The rover-habitat carries four extra suspension system wheel sets, two pressure ports, and a personnel airlock package combined with hydrazine powerplant and life-support system. Rough mass estimates for the rover-habitat are shown in Table 2, with a total rough mass estimate of 4,440kg. Multiple rover-habitats can dock up in various configurations, either using side pressure port hatch to port hatch, or port hatch to rear personnel airlock using an extendable pressurized tunnel (Figure 24).

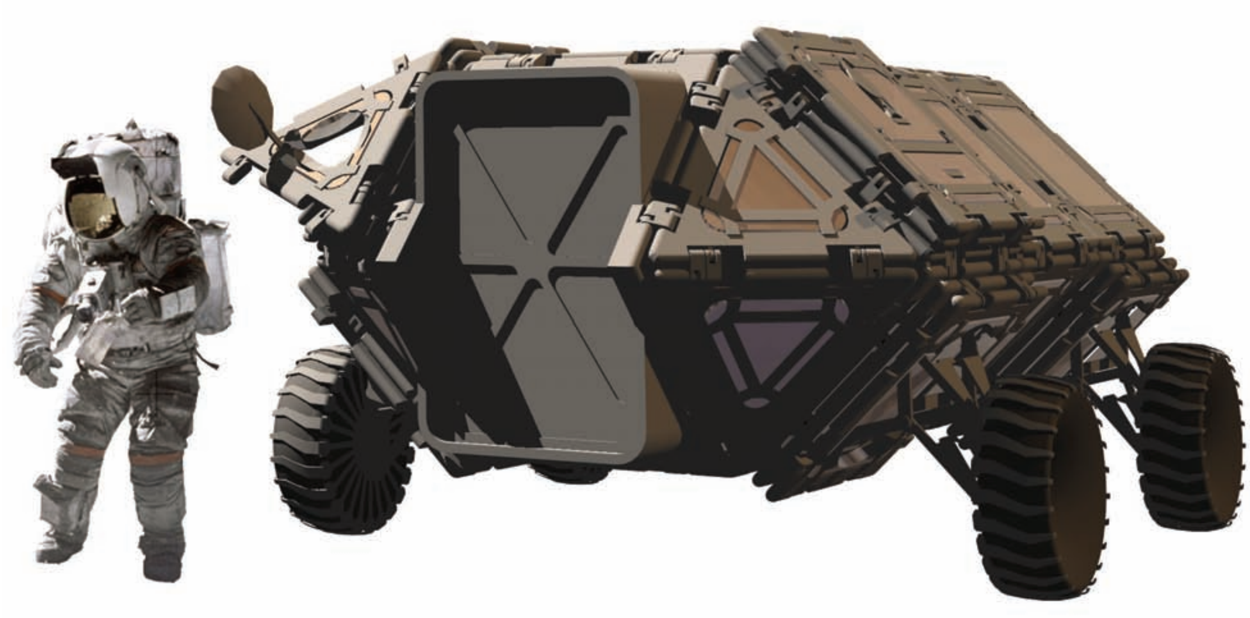

Figure 21: Pressurized rover pressure hatch

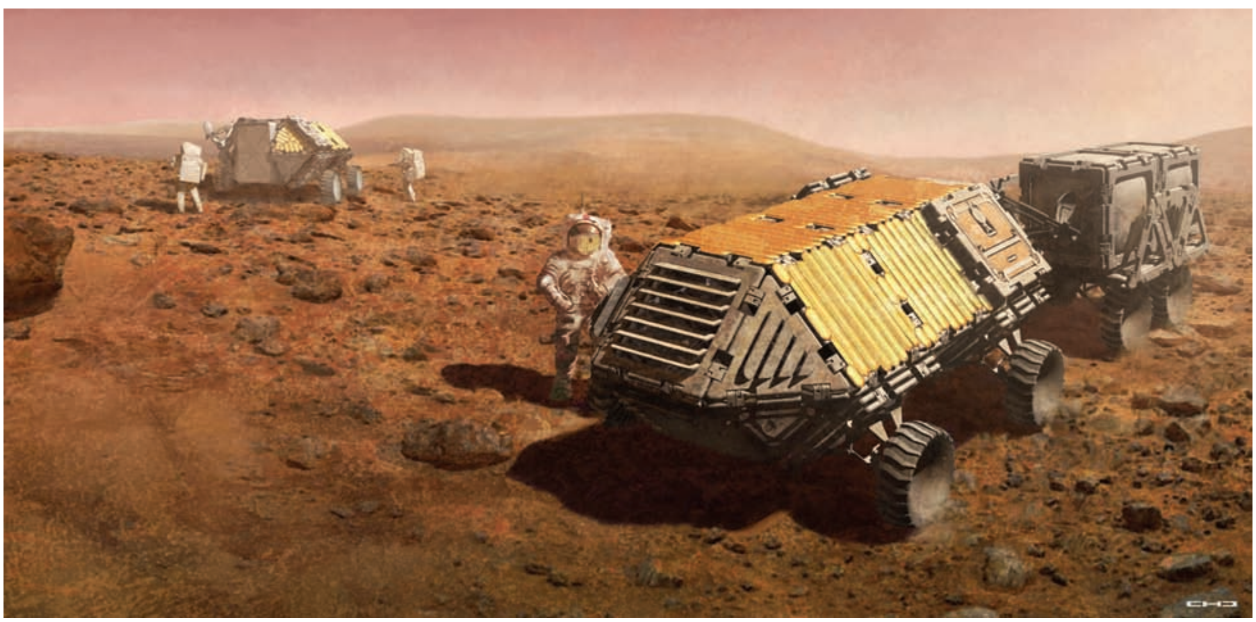

Figure 22: Pressurized rover in use on Mars with utility trailer (rendering: Chris Howe Design)

A third study of wheeled infrastructure elements explored a concept for an unpiloted modular workhorse tractor that can be used to lift and carry cargo and provide generic mobility to a host of scientific, construction, mining, and exploration instruments. In Figure 25 on the left, an unengaged tractor is shown with partially opened “jaws”. The “jaws” can be widened for double and triple-wide loads, or to insert bulldozer blades, drilling units, or a host of other modular implements. In Figure 25 on the right, the tractor is closing in on a cargo crate also constructed of a framework of Trigon panels. The tractor is capable of locking onto the crate and lifting it to twice its own height. Rough mass estimates for the modular tractor are shown in Table 3, totaling out at about 640kg.

Figure 23: Six-wheeled rover-habitat

Element Description	Quantity	Rough Unit Mass	Total Mass
Trigon triangle panels	10	6 kg	60 kg
Trigon square panels	56	14 kg	784 kg
Triangular shielding payload panels	8	17 kg	136 kg
Square shielding payload panels	32	40 kg	1,280 kg
Suspension system payload panels	10	40 kg	400 kg
Wheel payload panels	10	40 kg	400 kg
Antenna payload panels	1	17 kg	17 kg
Pressure port core element	2	100 kg	200 kg
Personnel airlock / powerplant core element	1	500 kg	500 kg
Inflatable pressure barrier lining core element	1	460 kg	460 kg
Square shielded viewport core element	4	40 kg	160 kg
Total Mass (rough preliminary)			**4,400 kg**

Table 2: Rough mass estimates for a rover-habitat

Element Description	Quantity	Rough Unit Mass	Total Mass
Trigon square panels	16	14 kg	224 kg
Suspension system payload panels	4	40 kg	160 kg
Wheel payload panels	4	40 kg	160 kg
Hydrazine powerplant core element	1	100 kg	100 kg
Total Mass (rough preliminary)			**640 kg**

Table 3: Rough mass estimates for modular tractor

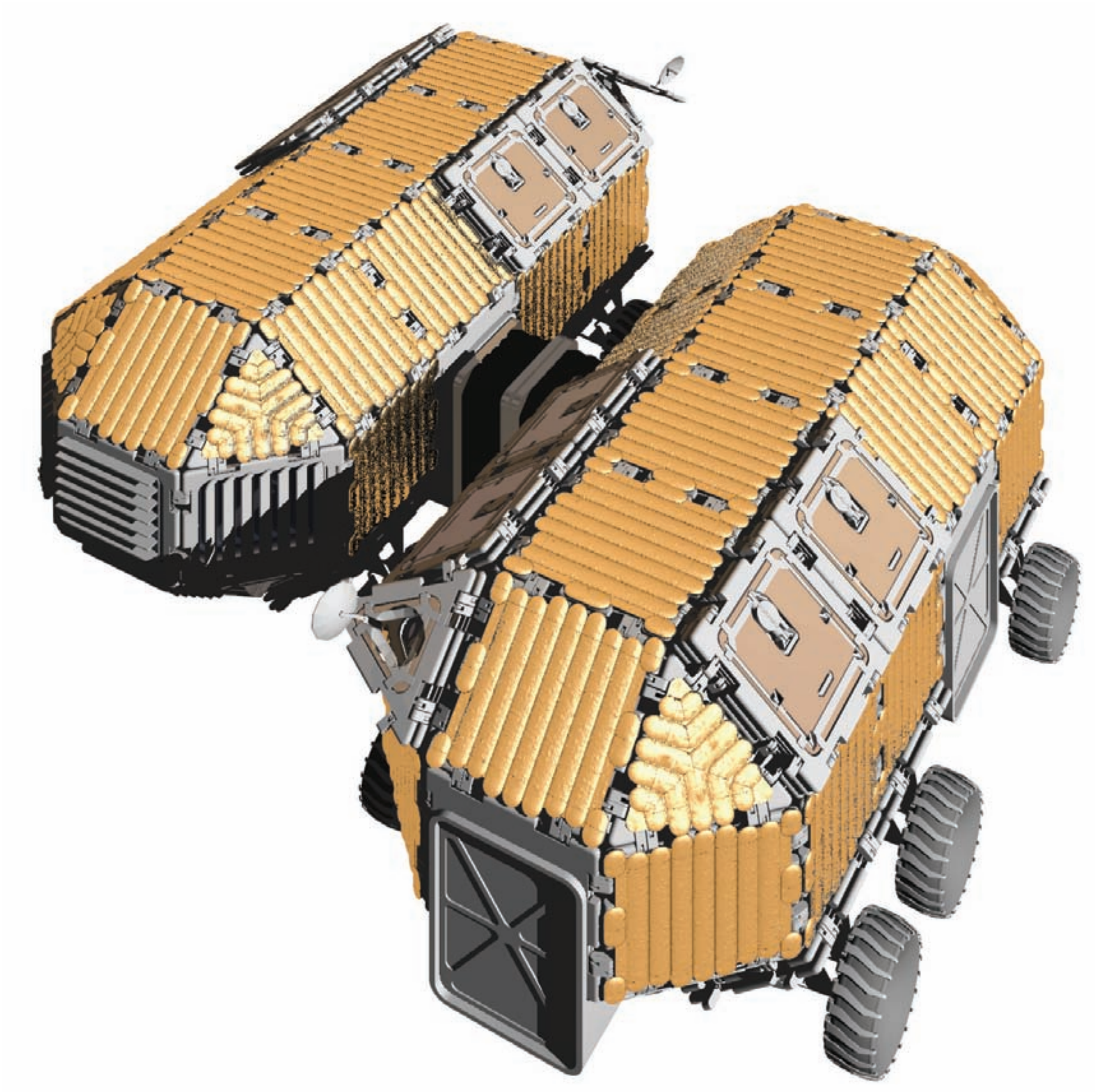

Figure 24: Two rover-habitats in docking mode

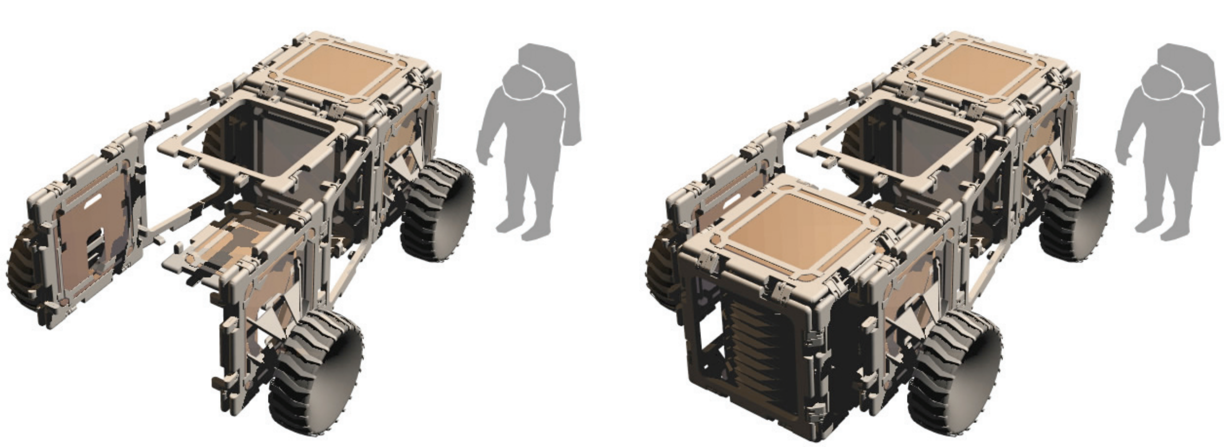

Figure 25: Modular tractor without implements (left), preparing to lift cargo crate (right)

V. Legged Surface Infrastructure Elements

Using the modular elements described in section III, legged habitats and vehicle concepts were explored. The primary mobility system uses ATHLETE-type folding legs that fall into the category of core elements, since they are too large to fit into the dimensions of a payload panel. One study explored a four-legged pressurized rover concept with eccentric pressure ports (Figure 26). The rover would function similar to the original Habot, where an entire dedicated vehicle would function as an airlock, and grouped vehicles would each have dedicated functional uses.

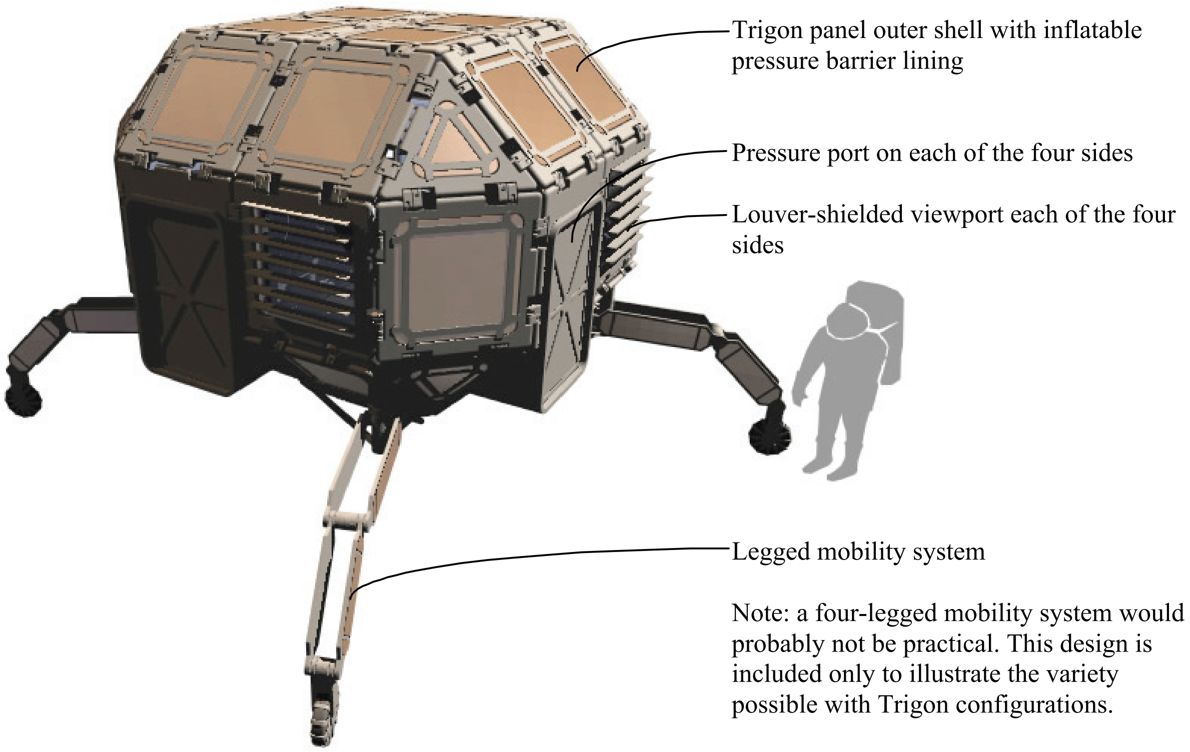

Figure 26: Four-legged pressurized rover

A four-legged mobility system would have little trouble with rolling mobility, but would be less stable with only four legs for walking in rough terrain. In a large obstacle step-over scenario, three of the legs would need to position themselves such that the center of gravity of the rover is stabilized above them while the fourth leg is lifted above the surface to be guided toward the next step. This means that the free leg must be carefully placed to insure that a new stable triangle stance can be maintained while the second leg is lifted. Rough mass estimates in Table 4 put the total at 3,300kg.

Element Description	Quantity	Rough Unit Mass	Total Mass
Trigon triangle panels	10	6 kg	60 kg
Trigon square panels	28	14 kg	392 kg
Triangular shielding payload panels	8	17 kg	136 kg
Square shielding payload panels	28	40 kg	1,120 kg
Antenna payload panels	1	17 kg	17 kg
Pressure port core element	4	100 kg	400 kg
Leg core element	4	100 kg	400 kg
Inflatable pressure barrier lining core element	1	400 kg	400 kg
Powerplant core element (attached to a pressure port)	1	100 kg	100 kg
Life-support core element (attached to a pressure port)	1	100 kg	100 kg
Square shielded viewport core element	4	40 kg	160 kg
Total Mass (rough preliminary)			**3,300 kg**

Table 4: Rough mass estimates for a four-legged pressure rover

Figure 27: Mobitat2 habitat in parked position

Figure 28: Mobitat2 in walking / rolling mode

Finally, a second legged surface infrastructure concept was explored – the Mobitat2 habitat. The Mobitat2 has an eight-legged mobility system, with pressure ports centered on each of the four sides. Figure 27 shows the Mobitat2 in parked position with the legs folded underneath it (shielding not shown for clarity). The maneuverability of the legs in both folded park mode and walking / rolling mode (Figure 28) allows for very fine adjustment in a full six degrees of freedom for horizontal, vertical, yaw, pitch, and roll to insure neighboring pressure ports line up for docking. A legged habitat also is able to adapt to extreme slopes or variation in the surface of the terrain.

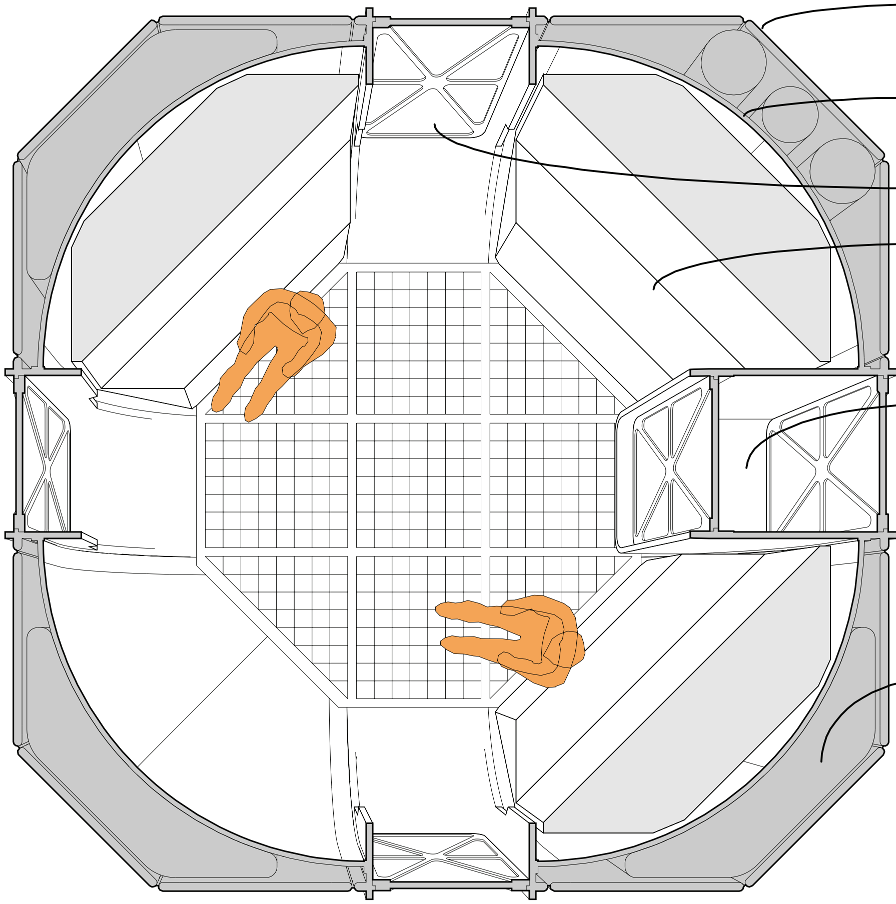

Figure 29: Mobitat2 schematic plan view (shielding not shown for clarity)

Element Description	**Quantity**	**Rough Unit Mass**	**Total Mass**
Trigon triangle panels	10	6 kg	60 kg
Trigon square panels	66	14 kg	924 kg
Triangular shielding payload panels	8	17 kg	136 kg
Square shielding payload panels	66	40 kg	2,640 kg
Antenna payload panels	1	17 kg	17 kg
Pressure port core element	4	100 kg	400 kg
Leg core element	8	100 kg	800 kg
Inflatable pressure barrier lining core element	1	780 kg	780 kg
Powerplant core element (attached to a pressure port)	2	100 kg	200 kg
Life-support core element (attached to a pressure port)	2	100 kg	200 kg
Square shielded viewport core element	4	40 kg	160 kg
Total Mass (rough preliminary)			**6,300 kg**

Table 5: Rough mass estimates for the Mobitat2 eight-legged habitat

Figure 29 shows a schematic plan view of the Mobitat2, with a cylindrical inflatable membrane pressure barrier lining. Since the Trigon panels in this geometry create a square with mitered corners, the cylindrical pressure barrier leaves odd gaps that can be filled with inflatable tankage, extra shielding, or equipment. Figure 30 shows a schematic sectional view of the Mobitat2, including an interior lightweight floor partitioning the space into two floors, or one floor and one loft.

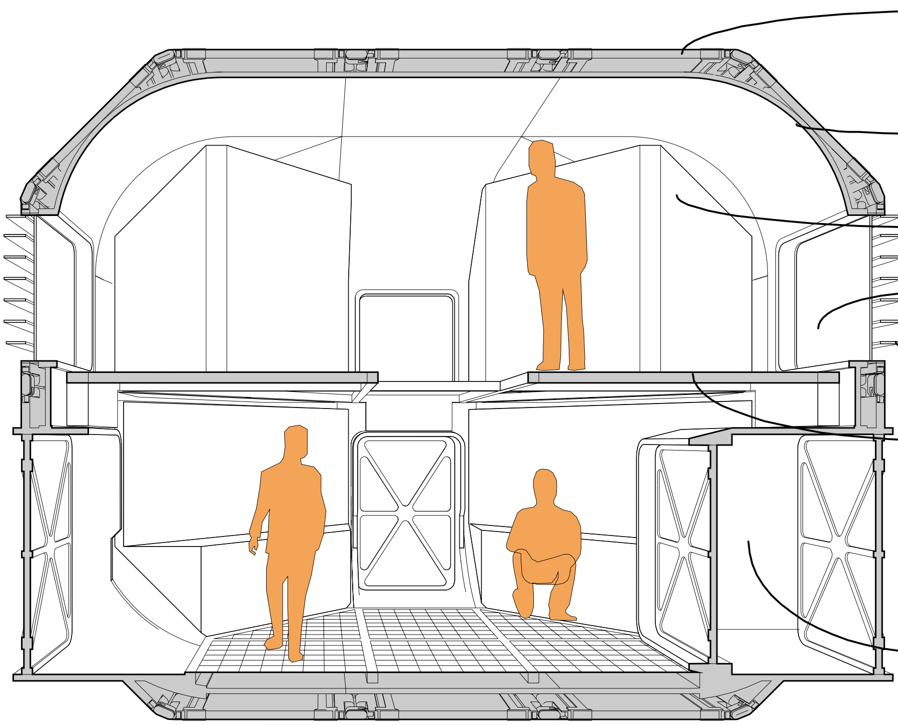

Figure 30: Mobitat2 schematic section (shielding not shown for clarity)

Figure 31: Moon base scenario using the Mobitat2 habitat (rendering: Chris Howe Design)

Rough mass estimates for the Mobitat2 habitat are shown in Table 5, which totals at 6,300kg. As was mentioned previously, consumables and in-situ derived shielding material, hydrazine, water, etc. are not figured into these numbers. Figure 31 shows a moon base scenario with Mobitat2 units in place, and on the move (shielding is deployed in parked habitats to protect the crew, but can be dumped or shed when autonomously operated for relocation.

VI. Landing Systems

The Trigon system can be used as secondary structure to construct support frames for a variety of core elements that are too bulky to fit into the size constraints of a payload panel. Core elements can also include rocket motors, propellant tankage, navigational hardware, gyros, antenna, maneuvering thrusters, and other systems required for a lander (Figure 32).

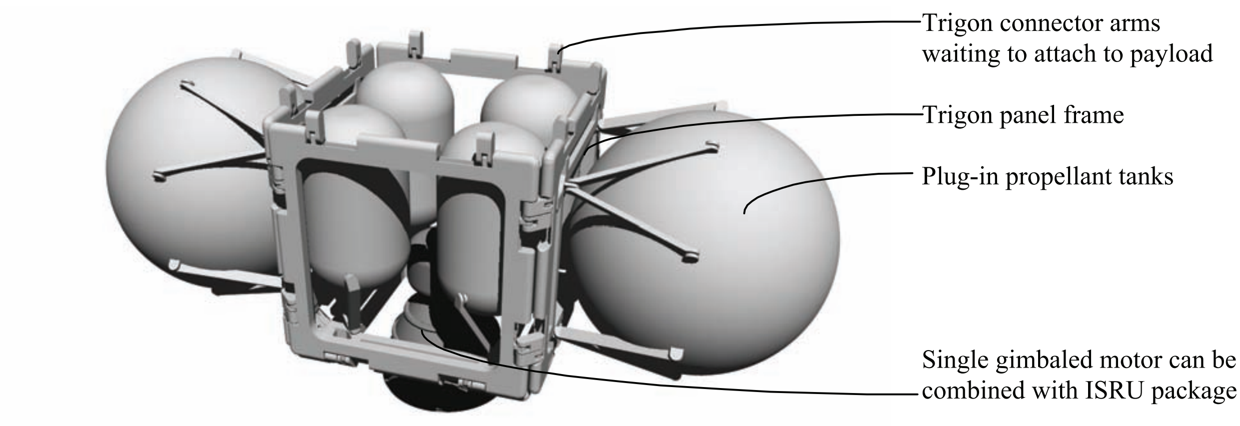

Figure 32: Basic modular landing system using Trigon frame structures and plug-in propellant tanks

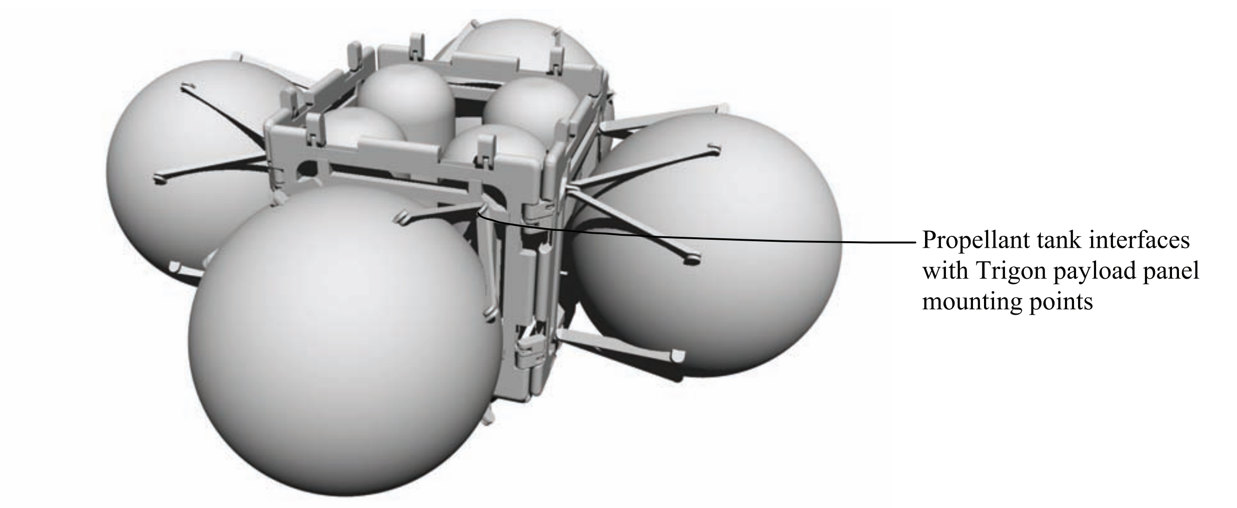

Figure 33: Additional propellant tanks can be added symmetrically

Using the plug-in modular nature of the Trigon system and payload panels, additional propellant tanks can be added as needed (Figure 33), to single motor or multiple motor configurations (Figure 34).

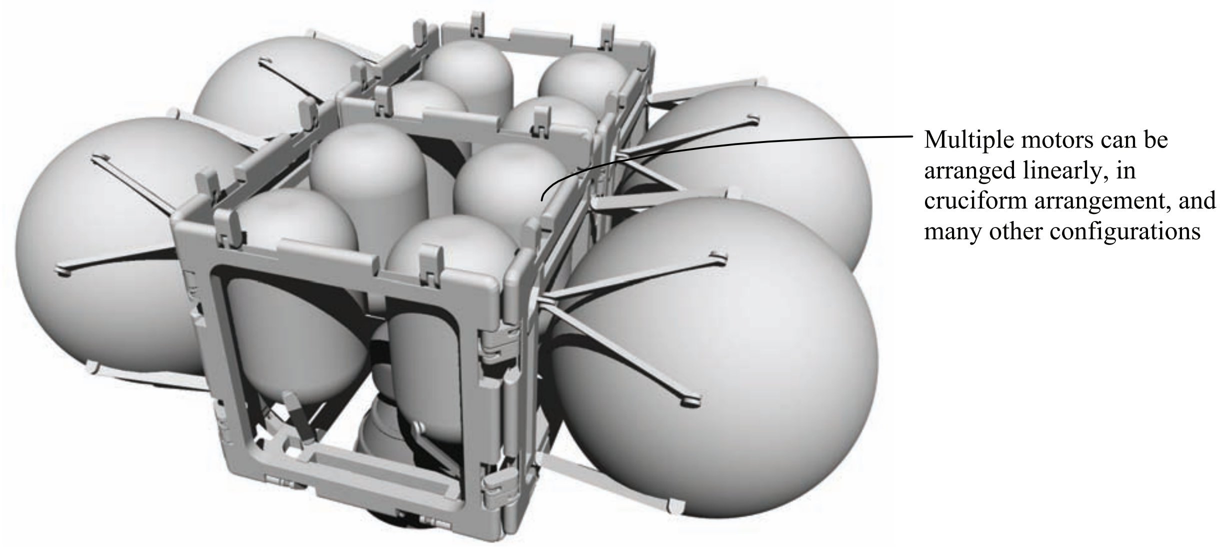

Figure 34: Multiple motors with additional propellant tanks

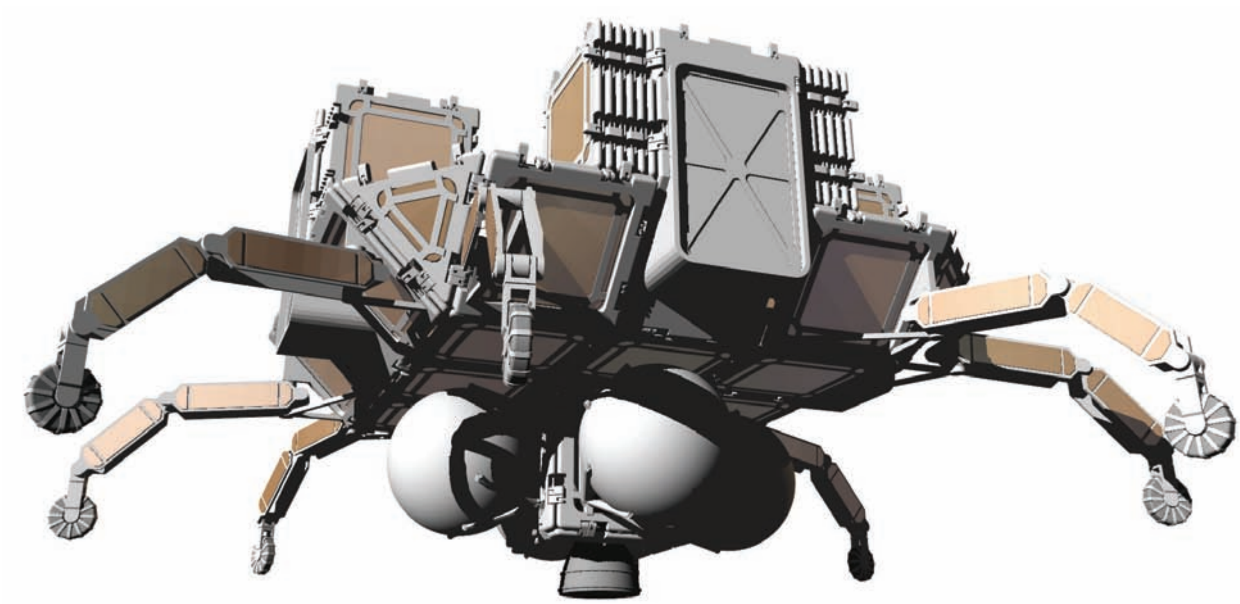

Figure 35: Mobitat2 habitat folded into compact form and attached to lander

Using Trigon support frames, payload packages of stacked panels and core elements can be attached anywhere on the lander frame via the connector arms of the packages (Figure 35).

When the lander reaches the surface, the payload packages unfurl or detach and self-assemble into various target infrastructure elements that have been discussed earlier. In addition, the lander motor and core can either be disassembled so Trigon frame elements can be used elsewhere, or set up as an ISRU processing plant for processing oxygen, hydrogen, hydrazine, and other reserves for use as fuel and human consumables. In addition, the lander core / ISRU plant can be fitted with wheels (Figure 36) or attached to a pair of modular tractors to add mobility so that it may follow the other mobile infrastructure elements to new locations. The concept of an ISRU processing plant combined with a lander system is very preliminary at this stage, and simply assumes that the propellant tanks could be used over again to fill with ISRU-derived fuel dumps. Actual sizing of ISRU processing equipment, and how it would configurationally fit with a gimbaled motor would need to be validated.

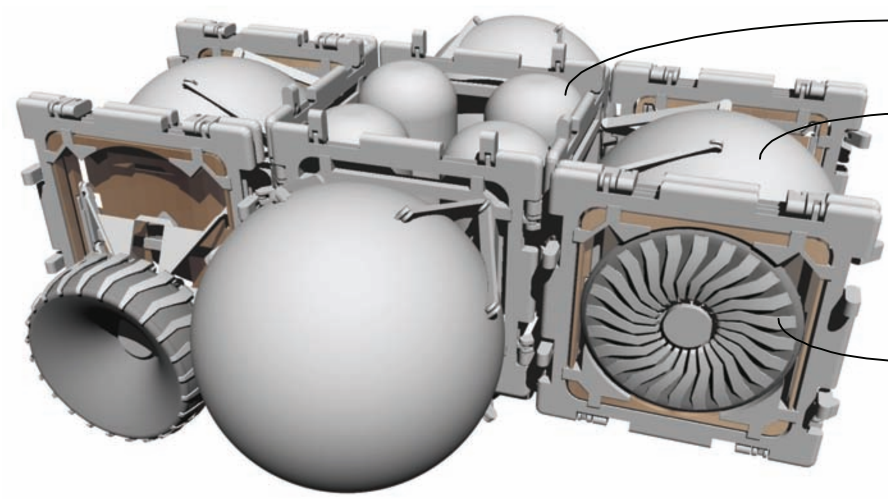

Figure 36: Lander with ISRU plant can be fitted with its own mobility system (wheel deployed left, in compact storage right) without configurational disadvantage

VII. Analysis

Using the Trigon modular robotic construction system, a variety of potential surface infrastructure applications have been described in a brief, conceptual manner. The flexibility of the system, and its capacity to re-configure itself into various typologies according to current need illustrate the merit of continued development and investigation for this promising system.

For example, a vehicle with compact core elements and panel stacks may be optimized for landing, after which it will be able to reconfigure itself for surface operations and crew occupancy, then back to lander mode for relocation. Since all the components for lander, habitat, rover, tractor, etc are identical, they can be used as spares for each other and can be reconfigured into each other.

The tools are fully in place for further investigation, including panel optimization (Howe, Gibson 2006b) and robotic functionality (Howe, Gibson 2006a). Potential problems that need to be solved include investigations into the feasibility of using thin inflatable pressure barrier linings in order to create pressure vessels, dust protection for the mechanical connections, shielding in the gaps, robust kinematic and engineered design of mobility systems, etcetera. Many of the figures presented in this paper are preliminary, having use in comparison only, and will need to be updated when validated information becomes available.

VIII. Conclusion

Modular design elements are introduced that will give mobility to structures assembled using the Transformable Robotic Infrastructure-Generating Object Network (Trigon) system. In addition, specialty functions can be incorporated into the payload panels of the system to increase the functionality without limit. Using these modular elements, several conceptual explorations for surface infrastructure elements in the form of vehicles and habitats are introduced.

With the conceptual feasibility of the practical application of the system, the authors recommend that the Trigon system be used as a foundation for the design of future structures in the ultimate goal of establishing self-assembling, self-replicating, self-manufacturing, and self-sustaining building systems (Howe 2005) that can be delivered autonomously (or teleoperated) to a planetary surface, build copies of itself for further distribution, and await the eventual arrival of human crews.

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Nomenclature

AIAA	=	American Institute of Aeronautics and Astronautics
ATHLETE	=	All-Terrain Hex-Legged Extra-Terrestrial Explorer: a six-leg wheeled autonomous mobility platform with nesting legs (developed at JPL)
JPL	=	Jet Propulsion Laboratory
NASA	=	National Aeronautics and Space Administration
Trigon	=	Transformable Robotic Infrastructure-Generating Object Network system: a modular robotic construction system