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Planetary versus Interplanetary Architecture

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Abstract

This design essay explores the distinction between the design of a crew habitat for interplanetary space travel and one for the Mars surface. It articulates the design implications of the "Being There versus Getting There" philosophy that argues that the interplanetary and surface capabilities are fundamentally so different that it is not possible to optimize them within a single set of habitation elements. Rather, design optimization demands separate interplanetary and surface habitats.

Definitions

EMU:	external mobility unit; the Space Shuttle suit
EVA:	extra-vehicular activity
IPV:	Interplanetary vehicle
IVA:	Intravehicular activity
PLSS:	portable life support system
GCR;	galactic cosmic ray
LEO:	low Earth orbit
SPE:	solar particle event
SR&QA:	safety, reliability and quality assurance
TEIV:	trans-Earth injection vehicle
TMIV:	Trans-Mars injection vehicle

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Introduction

This essay seeks to clarify the distinguishing characteristics of interplanetary vehicle crew habitats and planetary surface habitats: what they have in common and what makes them different. These distinctions derive from the argument that a Trans Mars Injection Vehicle (TMIV) or Trans Earth Injection Vehicle (TEIV) differs so fundamentally from a Mars Surface Habitat in functional and architectural character that no single design can serve both purposes (Cohen, June 1996 & Cohen, July 1996). This line of reasoning presents the *Being There versus Getting There* view of Mars exploration, in which the design problem definition decomposes the mission architecture into two separable parts -- the transportation system and the surface system. By decoupling these major elements of the Mars exploration system, it becomes possible to optimize each for simpler, singular goals, rather than force every piece to become multipurpose -- doing many things, but doing none of them well.

Approach

This analysis takes the approach of identifying the salient characteristics on each type of habitat; those they have in common and those which are mutually exclusive. TABLE 1 summarizes these characteristics. From this data matrix, the analysis leads to the design of schematic cross sections for the two crewed habitats. for both interplanetary vehicles and surface bases.

Nine Points of Distinction between IPV and Surface Habitats

TABLE 1 describes the design parameters for which to compare the Interplanetary Vehicle (IPV) Habitat and the Planetary Surface Habitat (Cohen, June 1996 & Cohen, July 1996). The differences in optimization strategy for most of these parameters are major and unavoidable.

The design parameters of concern are Radiation Shielding, Gravity Orientation, EVA Airlock, Life Support, Laboratory Facilities, Weightlessness Countermeasures, the SR&QA approach and inflatable structures. The discussion for each of these characteristics shows how profoundly different an IPV Habitat is from a Surface Habitat. Weaver & Duke (1993) posit a 50 metric ton mass and 500m^3 volume for a habitat that serves as both an IPV and Mars Surface Habitat, which provides a baseline for the following comparisons. A sphere that accommodates 500m^3 volume requires a radius of 4.92m.

1. Radiation Shielding – Radiation Shielding is the most overlooked feature of proposed interplanetary vehicles. NASA and space industry mission planners consistently underestimate the radiation hazards on a trip to Mars, particularly from the high energy particles known as Galactic Cosmic Rays (GCRs) and thus minimize the shielding to protect against this exposure. The conventional wisdom states: "NASA cannot afford to shield against radiation because the enormous mass penalty will make a Mars mission too expensive." However, a truly safety-conscious approach insists "NASA cannot afford *NOT* to shield effectively against radiation, despite the mass penalties." It is time for NASA and the space industry to face up to radiation exposure as a major concern for crew health and for their ability to carry out a successful mission and to protect the crew against it. The weight of the evidence is definitive (Cohen, July 1996).

Both the possibility of Solar Particle Events (SPEs) associated with solar flares on the sunspot cycle and the certainty of exposure to GCRs are potentially life threatening to the crew and to the success of the mission. Constant isotropic bombardment by GCRs poses a special concern, which mission planners are only beginning to recognize. The concern about GCRs is that their radio-biological effectiveness in tumorigenesis is thirty times as large as a unit dose equivalent of solar particles, (Fry, 1987). ***A careful reading of the requirements for shielding from radiation hazards in interplanetary space indicates the need for substantial omnidirectional shielding on the order of 30 grams/cm^2*** (Campbell, Paul, & Harris, 1992; Fry, 1987; McCormack, Swenberg & Bücker, Eds, 1987; Simonson, & Nealy, Feb 1991; Simonson, Nealy, Townsend & Wilson, March 1990; Townsend , Nealy, & Wilson, May 1988; Townsend, Nealy, Wilson & Simonson, Feb 1990; Townsend, Wilson & Nealy, Oct. 1988). FIGURE 1 shows the installation of such isotropic water shielding in an interplanetary habitat (Cohen, July 1996). FIGURE 2 shows a comparable, but more directional shielding in the surface habitat (Cohen, 1996 p. 477).

Instead of schlepping the interplanetary radiation shielding all the way down to the Mars surface, the Mars environment offers several ways to extract shielding for the Surface Habitat. Simonson & Nealy (1991, Feb, p. 20) recommend the application of Mars regolith to the habitat exterior for shielding to thicknesses of about 75 cm. It will be possible to mine Mars regolith robotically to create shielding to attach externally to the Surface Habitat. It will also be possible to make water from the Mars CO_2 atmosphere, using seed hydrogen through the Sabatier reaction process.

Shielding Options - One recurring feature of the conventional wisdom is the small "solar storm shelter" with about 1m^3 free volume per crew member, into which the crew would retreat for protection from hadrons during a solar storm. A variation of the storm shelter is to place all the sleeping areas inside a very small shielding envelope. The problem with this limited shielding volume is that it confines the crew to a very small living volume for most of their half-year transits to Mars and back to Earth. This notion of a very confined living area from which the crew would venture to carry out their normal productive work is highly unrealistic. The psychological and social dynamics such an arrangement must generate would be unacceptable for crew cohesiveness and well being. This idea -- that some parts of the normal, day to day living and working environment in the interplanetary habitat would be much more dangerous than other parts -- is most questionable. This essay takes the position that it is realistic to shield most or all the pressurized habitats, so that the crew members do not need constantly to choose between performing a task and protection from greater radiation exposure.

Optimum Shielding Geometry: A sphere has the minimum ratio of surface area to volume of any solid, the area = $4\pi r^2$. For a spherical habitat 7m in diameter, the surface area is $154m^2$. For a shielding of 30 grams/cm^2, one square meter of surface has a mass of 300kg. The total spherical area of $154m^2$ will require a shield mass of about 46,000kg, not including attachment hardware. It is necessary to launch this entire shielding mass into Low Earth Orbit, either from the Earth or from the Moon. This omnidirectional shielding may be solid, as in formed aluminum gore panels or liquid, as in water to pump into interior perimeter tanks. Whatever the shielding, it makes no sense to waste the effort, cost, and energy that put it in LEO by landing it on Mars as part of a multi-purpose habitat.

2. Pressure Ports – The function, number, and location of pressure ports differ significantly between the IPV and the surface habitat. The pressure ports accommodate the crew passing from one pressurized volume to another. The pressure ports with mechanisms have a mass of about 250 kg each.

In the IPV, the pressure ports would serve the same function as the *temporary* docking port that joints the Station to the Space Shuttle or the Space Shuttle to the Mir during a rendezvous or link-up. The IPV habitat would most likely need two such docking ports, one to attach the ascent/decent vehicle, and the second to dock to the shuttle or space station to bring the crew and supplies on board. The likely location for these docking ports is axial, to allow the safest and most efficient docking approach and separation at each end of the "mother ship." Although Zubrin & Weaver (1993) show a pressurized rover docked to a lower axial pressure port of a spherical surface habitat, the vertical connection is quite awkward, and the axial pressure ports on a *Mars Direct* TMIV would serve no reasonable purpose for a surface habitat.

In the planetary surface habitat, the pressure ports would serve essentially the same function as the berthing ports that *permanently* connect the Space Station modules to the Space Station Nodes. The preferred location for pressure ports is around the perimeter, to accommodate permanent connections to other pressurized modules of the First Mars Outpost. These additional modules include an inflatable "greenhouse," another habitat, and an EVA and rover support module. The design and deployment of efficient inflatable pressurized habitat volumes will add a significant capability to surface habitats that is unlikely to be available on interplanetary vehicles (Abarbanel, Bateman, Criswell & Sadeh, 1996). The scientific laboratory will need a sample airlock that may nest within a standard pressure port. For the surface habitat, they would occupy at least four perimeter locations to connect to the other surface elements. These perimeter pressure ports would serve no function on an IPV, and would pose a threat of atmospheric leakage that would be costly to replenish.

3. EVA Airlock – The EVA airlock and supporting facilities constitutes the second largest mass impact that distinguishes the surface habitat from the interplanetary vehicle. The EVA airlock requires its own pressure vessel, heavy enough to provide a hyperbaric capacity of six atmospheres (Dowell, 1993), with heavy compressors and pumps to supply pump down and pressurization. Besides this plumbing, the Mars surface EVA system will require a complete ensemble of support capabilities to inspect, maintain, service, recharge and refurbish suits and life support back packs on Mars. At present, NASA employs several dozen technicians in several thousand square feet in Houston to support the Space Shuttle "EMU" space suits. The most effective way to compensate for this ground service is to provide a separate EVA support module. This module would land on Mars separately from the planetary habitat, then roll roboticly to the habitat and connect to a pressure port. If there is no need for the Mars crew to perform unplanned EVA maintenance on the IPV, then there is no need to include the EVA support system in the TMIV. There is probably too great a mass penalty to include complete EVA support capabilities in a combination TMIV/Habitat Lander. The Ascent/ Descent Vehicle may include lightweight EVA suits prepped for contingency use to support a crew transfer to the Habitat. This EVA Access module may also furnish a general repair and maintenance shop for both IVA and EVA equipment.

4. Science Laboratory – The Science Laboratory Facilities constitute the third largest mass component that distinguishes between the Interplanetary Vehicle and the surface habitat. The Laboratory is also probably the largest volumetric discriminator. The Laboratory will include facilities for a number of disciplines, including Atmospheric Science, Exo-biology, Chemistry, Paleontology, plus a repair and maintenance shop. Each of these functions will occupy the equivalent of about two Space Station Laboratory Racks, roughly 2m wide, 2m high, and 1m deep. The Laboratory Ensemble will include a Mars ambient glove-box, connected to a sample airlock installed in a standard perimeter pressure port. The Laboratory will require open floor area equal to the area of the Lab Racks, if not greater. The total floor area will come to at least $36m^2$. This area projects to a volume of about $72m^3$ -- not including its share of common infrastructure. The Laboratory mass is about 3000kg.

5. Countermeasures Against Weightlessness – On the Interplanetary vehicle, during the conjunction class 120 to 180 day voyage to Mars and the 200 to 300 day return to the Earth, it will be critical to provide countermeasures for the crew against the debilitating effects of weightlessness. While these countermeasures are vital for the Interplanetary vehicle, the crew is not as likely to require them on the Mars surface because of the .38g gravity field. Assuming that spinning the entire TMIV around a large radius is neither practical nor cost-effective, the second greatest volumetric discriminator between the Interplanetary Vehicle and the Planetary Surface Habitat is the on-board centrifuge for crew members. The Life Science Division at NASA–Ames built such a 3.75m diameter centrifuge as part of the Human Exploration Demonstration Project. This centrifuge may be human-powered to provide exercise opportunities along with the benefits of centrifugation. The volume to install the on-board centrifuge in the Interplanetary Vehicle will be about 30 cu m. The mass, including the enclosure, is about 300kg.

In the Surface Habitat, there is probably less need for centrifugation if the .38 g gravity field provides the necessary stimulus to overcome the debilitating effects of reduced gravity.
The common countermeasures will include equipment for both aerobic

exercise and heavy weight training. A combination of these exercise techniques will most likely be necessary to maintain crew health on the Mars mission (personal conversation with Sam Pool, Chief Medical Officer, Johnson Space Center, Houston TX, Sept. 10, 1996).

6. Gravity Orientation – Another aspect of the gravity regime is the spatial orientation of the living and working environment, the definition of up and down. In the Planetary Habitat, the position on the Martian surface and the Martian gravity give a clear orientation cue to the ground. However, in the TMIV/TEIV, this orientation cue is not naturally present. It will be necessary to devise a logical spatial orientation that works for the vehicle in all its trajectories, including Earth and Mars orbit. The different demands of the surface Habitat and the Interplanetary vehicle may pose contradictory requirements upon the spatial orientation. There are no easy compromises between these two gravity orientations although some equipment may work in both gravity regimes.

7. Life Support – The differences in operation between the Interplanetary Vehicle and the Planetary Surface Habitat raise significant distinctions for the Life Support Systems. On the Interplanetary vehicle, which will be out of contact with any potential resupply for up to three years, the Life Support System must run closed loop. On the Mars surface, with the potential of taking advantage of in situ resource utilization to extract O_2 and H_20 from the Mars atmosphere, and possibly to liberate O_2 from the Martian soil, life support can run "open loop." This distinction applies regardless of the allocation between Physical/Chemical and Bioregenerative systems.

8. Safety, Reliability And Quality Assurance – The reliability approach sums up in many respects the foregoing distinctions. At the level of system design metalogic, the primary discriminator between the IPV and the Mars surface Habitat is the appropriate reliability strategy. For the IPV, being part of a propulsive vehicle dictates the need for a pure high reliability strategy, to achieve the proverbial .99999 reliability factor. There will be no opportunity for resupply or repairs to the vehicle if there is a failure, especially while performing critical propulsive maneuvers.

The surface habitat performs no such critical maneuvers on Mars. The habitat does not need to achieve the same "ultimate reliability." Instead, it may adopt a diversified strategy combining reliability with other approaches, including redundancy, resupply, maintenance, and repair. This overall approach characterizes an "availability" strategy, in which the goal is to ensure that the requisite capabilities will always be available rather than nothing critical will ever break down. Instead, it will be more practical and reasonable to design various systems to fail through graceful degradation of capability instead of catastrophically or irreparably. The crew would be able to repair most surface systems, or to install spares in place of failed components. The availability strategy can also take advantage of in situ resource utilization to supplement the supply of consumables including water, air, rover fuel and methane for ascent vehicle fuel. It will be possible to resupply the Planetary Habitat from cargo vehicles both on the main conjunction class launch windows that occur every 26 months, and the opposition class launch windows that occur midway between them.

9. Inflatable Structures - Inflatables will provide a valuable portion of the pressurized volume for the Mars surface base. There is no comparable element on the propulsive interplanetary vehicle. The inflatable structures will accommodate a variety of functions, including the often proposed greenhouse, rover and vehicle servicing, and additional working or recreation space. It is possible to protect the inflatable working and living environment from radiation by covering it

with a layer of Mars regolith. FIGURE 3 shows an example of such an inflatable structure derived from Abarbanel, Bateman, Criswell & Sadeh (June 1996) with a semi-square floor plan of 6m x 6m and a ceiling height of 2.5m. Abarbanel, et al show that the imposed live and dead loads from people and regolith loading are inconsequential compared to the pressurization load. They found that heaping a 1m layer of Mars regolith on the top surface actually ***reduced*** the stress on the kevlar fabric.

Surface Base Layout

FIGURE 3 shows a schematic plan of a Mars surface base, that integrates the elements of the 1993 NASA Mars Reference Mission (Weaver & Duke, 1993), except for the superfluous additional habitats (Cohen, July 1996, p. 11). The four radial pressure ports on the two main habitats provide the key connectivity to the other elements by flexible pressurized tunnels. These connected elements include the EVA Access Modules, the sample airlocks and associated automated sample stowage, the inflatables, and of course, the link between the habitat cores themselves. The EVA Access Modules serve also for docking to pressurized rovers.

The inflatable volumes also play a major role. Although Abarbanel, et al argue that the semi-square inflatable modules may conjoin side to side, eliminating the need for interior pressure walls, this plan layout employs each unit separately for greater flexibility and utility. The In Situ Resource Production plants that extract oxygen from the Mars atmosphere and store it connect to the habitat cores through the inflatables, which serve as a kind of buffer. This plan arrangement of the inflatables provides the enhanced safety feature of a "racetrack" circulation pattern that affords dual remote egress from each of the major pressurized volumes.

Summary of Mass and Volume Penalties

The mass and volume penalties that apply to the design of interplanetary vehicles and planetary surface habitats present profound implications for the total Mars mission architecture. TABLE 2 enumerates the specific mass and volume characteristics of each. The interplanetary-specific mass penalties add up to a whopping 50 metric tons, roughly 100% of the maximum total landed weight of the planned Mars landers. The surface habitat-specific mass penalty is much less but still considerable at 6,000 kg or about 12% of the landed mass. The volumetric penalties are much closer, at about 85m^3 for the interplanetary habitat and 87m^3 for the surface habitat, although the spatial distribution of these two volume penalties is very different. As a fraction of the 500 m^3 that Weaver & Duke posit for the "common habitat", these volumes come to about 17% of the total. Because there is not a clear identification of the other functional volumes, these results point up the profound consequences that the different mission architectures pose for habitat design. The gravity orientation issue increases these consequences, because, for example, a zero gravity "bed" that is little more than a vertical restraint sack does not adapt to serve as a horizontal bed in a gravity field

Comparison of Mass For Interplanetary and Surface Habitats – Given the above summary of interplanetary-specific and surface-specific habitat mass penalties, it is enlightening to compare the mass budgets for the two elements. This comparison appears in TABLE 3. It is not meaningful to compare volume budgets without make geometry and design assumptions that go beyond the intent of this paper. The mass budgets shown in TABLE 3 rely upon much the same numbers as Weaver & Duke (1993), seasoned with numbers from Zubrin & Weaver (1993), but organized to illuminate the differences between the two habitats. This comparison shows that the interplanetary vehicle at 100 mT requires about twice the mass of the landed dry surface habitat of about 52 mT. This 52 mT falls within the realm of possibility as a payload for a Mars lander, but the interplanetary mass clearly exceeds the limits of this possibility. The next question is whether it is possible to launch the interplanetary vehicle plus the descent/ascent vehicle with aeroshell (an additional 20 mT) in one payload on an HLLV in the Mars Direct mode (Zubrin, Baker & Gwynne, 1991) or whether it demands assembly in LEO from two or more launches. If it is not possible to launch such a massive vehicle direct to Mars, this finding calls into question the Mars Direct idea.

Conclusion: *Being There Versus Getting There*

This analysis reveals the Interplanetary and planetary surface habitats to be substantially different in performance requirements and the design features to meet those requirements. The major mass and volume features of what the habitats must provide differ. Most significantly, the IPV habitat must provide omnidirectional radiation (GCR) shielding, axial pressure ports and zero gravity countermeasures. The surface habitat must provide directional shielding, laboratory, EVA support facility, laboratory, and peripheral ports for the surface habitat. The respective distinctions in reliability strategy make a profound difference in design method. This analysis presented optimized design configurations and content for both the Interplanetary Vehicle Habitat and the Mars Surface Habitat. These configurations correspond to the mission design decomposition of *Being There versus Getting There*. These optimizations show what it is possible and desirable to achieve for these elements of a human Mars Mission Architecture as complete, delivered living and working environments. These examples also show what mission designers will lose if they attempt to force the two habitat elements into a single, "one size fits all" approach.

References

Abarbanel, Jenine E., Bateman, Ted A., Criswell, Marvin E., & Sadeh, Willy Z., (1996, June) "A Framing System for a Lunar/Martian Inflatable Structure," in Johnson, Stewart W., Ed, (1996, June) pp. 1069-1075.

Campbell, Paul D., & Harris, J. D., (1992, December) Crew Habitable Element Space Radiation Shielding for Exploration Missions, LESC-30455, Houston, TX: Lockheed Engineering and Sciences Company, Contract NAS9-17900.

Cohen, Marc M., (1996) "First Mars Outpost Habitation Strategy," in Stoker, C. & Emmart, C., Ed, Strategies for Mars, *Vol. 86, AAS Science and Technology Series*, San Diego, CA: Univelt Publishing Co.

Cohen, Marc M., (1996, June) "The Distinction Between an Interplanetary Vehicle and a Mars Surface Habitat," in Johnson, Stewart W., Ed., (1996, June) pp 984-997.

Cohen, Marc M., (1996, July 8-11) Design of a Planetary Habitat Versus an Interplanetary Habitat, SAE 961466, *26th International Conference on Environmental Systems, Monterey CA*.

Dowell, G. L., (1993, March) "Rationale for a Hyperbaric Treatment Capability at a Lunar Station," in *Aviation, Space & Environmental Medicine*, pp. 243-246.

Fry, R. J. M., (1987), "Radiation Protection Guidelines for Space Missions," in McCormack, Swenberg & Bücker, Eds, pp. 715-728.

Johnson, Stewart W., Ed., (1996, June 1-6) Engineering, Construction , and Operations in Space V, New York NY: American Society of Civil Engineers. *Proceedings of the*

Fifth International Conference on Space '96, Albuquerque NM.

McCormack, Swenberg & Bücker, Eds, (1987) Terrestrial Space Radiation and Its Biological Effects, New York: Plenum Press, *Proceedings of the NATO Advanced Study Institute, October 11-25, 1987, Corfu, Greece.*

Simonson, Lisa C., & Nealy, John E., (1991, Feb) Radiation Protection for Human Missions to the Moon and Mars, NASA TP 3079, Washington, DC: NASA Scientific and Technical Information Division.

Simonson, Lisa C., Nealy, John E., Townsend, Lawrence W., & Wilson, John W., (1990, March) Radiation Exposure for Manned Mars Surface Missions, NASA TP 2979, Washington, DC: NASA Scientific and Technical Information Division.

Townsend, Lawrence W., Nealy, John E., & Wilson, John W., (1988, May) Preliminary Estimates of Radiation Exposures for Manned Interplanetary Missions from Anamolously Large Solar Flare Events, NASA TM-100620, Hampton, VA: NASA Langley Research Center.

Townsend, Lawrence W., Nealy, John E., & Wilson, John W. & Simonson, Lisa C., (1990, Feb) Estimates of Galactic Cosmic Ray Shielding Requirements During Solar Minimum, NASA TM 4167, Washington, DC: NASA Scientific and Technical Information Division.

Townsend, Lawrence W., Wilson, John W. & Nealy, John E., (1988, Oct.) Preliminary Estimates of Galactic Cosmic Ray Shielding Requirements for Manned Interplanetary Missions, NASA TM 101516, Hampton, VA: NASA Langley Research Center.

Weaver, David B., & Duke, Michael B., (1993) Mars Exploration Strategies: A Reference Program and Comparison of Alternative Architectures, AIAA 93-4212, AIAA Space Programs and Technologies Conference & Exhibit, Sept. 21-23, 1993, Huntsville, AL.

Zubrin, Robert M., Baker, D., & Gwynne, O., (1991) Mars Direct: A simple, robust and Cost-Effective Architecture for the Space Exploration Initiative, AIAA 91-0326, 29th Aerospace Science Conference, Reno, NV, Jan., 1991.

Zubrin, Robert M., (1992) Mars and Lunar Direct: Maximizing the Leverage of In-Situ Propellant Production to Develop a Coherent Architecture for the Space Exploration Initiative, AIAA 92-1669, AIAA Space Programs and Technologies Conference, March 24-27, 1992, Huntsville, AL.

Zubrin, Robert M., (1992) "Mars Direct Presented to NASA JSC," Oct. 9, 1992, Denver, CO: Martin Marietta briefing RZ-JSC 9/28/92-32.

Zubrin, Robert M. & Weaver, David B., (1993) Practical Methods for Near-Term Piloted Mars Missions, AIAA 93-2089, 29th Joint Propulsion Conference & Exhibit, Monterey, CA June 28-30, 1993.

TABLE 1. Interplanetary Vehicle and Planetary Habitat Key Design Parameters for Optimization Strategies

Design Parameter	**Unique to Interplanetary Vehicle Habitat**	**Characteristics Common to Both Habitat Designs**	**Unique to Planetary Surface Habitat**
1. Radiation Shielding	Must launch to LEO, don't want to drag it down to planet surface.	Water possible for both, but derived from different sources.	Can extract water from Mars atmosphere or excavate regolith.
2. Pressure Ports	2 Ports at distal axial ends	dimensions, controls structures and mechanisms.	4 or more peripheral ports w/ dust control
3. EVA Airlock	May incorporate an airlock and Zero-gravity optimized suits .	Both may include a separate, external EVA module.	Separately landed habitat & airlock module allows on-surface assembly.
4. Laboratory Facilities	No use for the Lab Facilities going to Mars, minimal use on return voyage.		Laboratory will provide the center of the Working Environment.
5. Countermeasures Against Weightlessness	Countermeasures such as a small diameter, human-powered centrifuge	Exercise regimens for aerobics and weight training	Zero-gravity countermeasures less important in the .38 G on Mars.
6. Gravity Orientation	Optimize for zero-g IVA operations.	NO EASY COMPOMISES	Optimize for partial-g operations.
4. Life Support	Plan for physical / chemical closed-loop regenerative system, with possible plant-growth unit.	Some common components for physical/chemical systems.	Plan for physical /chemical system that includes local resources (atmosphere) with CELSS component.
8. Safety, Reliability & Quality Assurance Strategy (SR&QA)	<u>Pure Reliability Strategy:</u> Propulsive character demands .99999 reliability		<u>Availability Strategy:</u> Resupply & repair complement standard reliability approaches.
9. Inflatable Structures			Greenhouse & Auxiliary Functions

TABLE 2. Launch Mass and Volume Penalties to the Habitat Module from the Distinctions Between an Interplanetary Vehicle and a Mars Surface Habitat.

	Interplanetary Habitat		**Mars Surface Habitat**	
Feature	**Mass Penalty**	**Volume Penalty**	**Mass Penalty**	**Volume Penalty**
1. Radiation Shielding	46,000 kg w/ 30 gm/cm^2 Omnidirectional in aluminum or water plus tankage	43 m^3 for a 7m dia. spherical surface	2000 kg w/ 30 gm/cm^2 Directional, dry mass of structure & internal tankage	$7m^3$ for a 7.5m dia oblate ellipsoidal head 1m high.
2. Pressure Ports @ 500kg each	500kg for 2 axial ports	$4m^3$	1000kg for four radial ports	$8m^3$
3. EVA Airlock built in to Habitat	3000kg	$8m^3$	0 - Lands in separate module.	0 - Occupies externally a radial pressure port.
4. Laboratory Facilities w/ sample airlock	0	0	3000kg	$72m^3$
5. Internal Human Powered Centrifuge	300kg	$30m^3$	0	0
TOTALS	49,800 kg	$85m^3$	6,000 kg	$87m^3$

TABLE 3 Mass Budgets for Interplanetary and Mars Surface Habitats:
LEO Departure for Interplanetary Habitat & Landed dry weight for Surface Habitat

Item	Interplanetary Habitat Mass in metric Tons (mT)	Mars Surface Habitat Mass in metric Tons (mT)
Physical/Chemical Life Support w/ consumables	6	4
Plant Growth	0	3
Crew Accommodations (cabins, galley, etc.)	5	5
Crew Consumables (food, drinking water, wash water)	17.5	7.5
Health Care w/ consumables	2.5	2.5
Structures	10	10
Electrical Power Distribution	.5	.5
Comm. & Info Management	1.5	1.5
Thermal Control	2	2
Power Generation	1.5	1.5
Spares/Growth/Margin	3.5	5.5
Field Science Equipment w/ consumables	0	3
Crew Members	.5	0
Radiation Shielding, H20	46	2
Pressure Ports @ 250 kg	.5	1.0
EVA Systems w/ consumables	3.0	0 (EVA in separate module)
Laboratory Facilities w/ sample airlock	0	3.0
Human Powered Centrifuge	.3	0
TOTALS	**100.3**	**52.0**

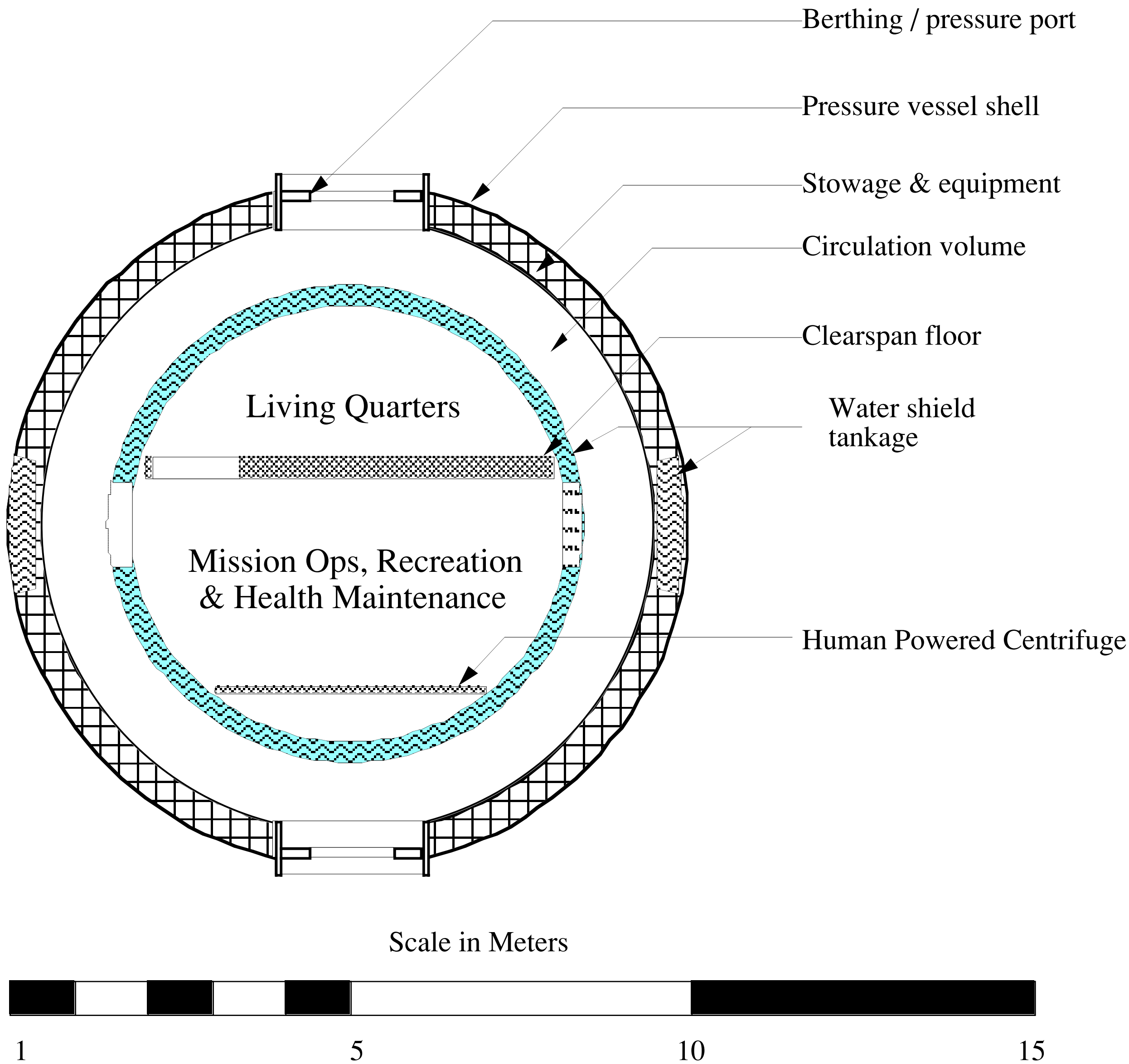

FIGURE 1. 10m Diameter Spherical Interplanetary Habitat

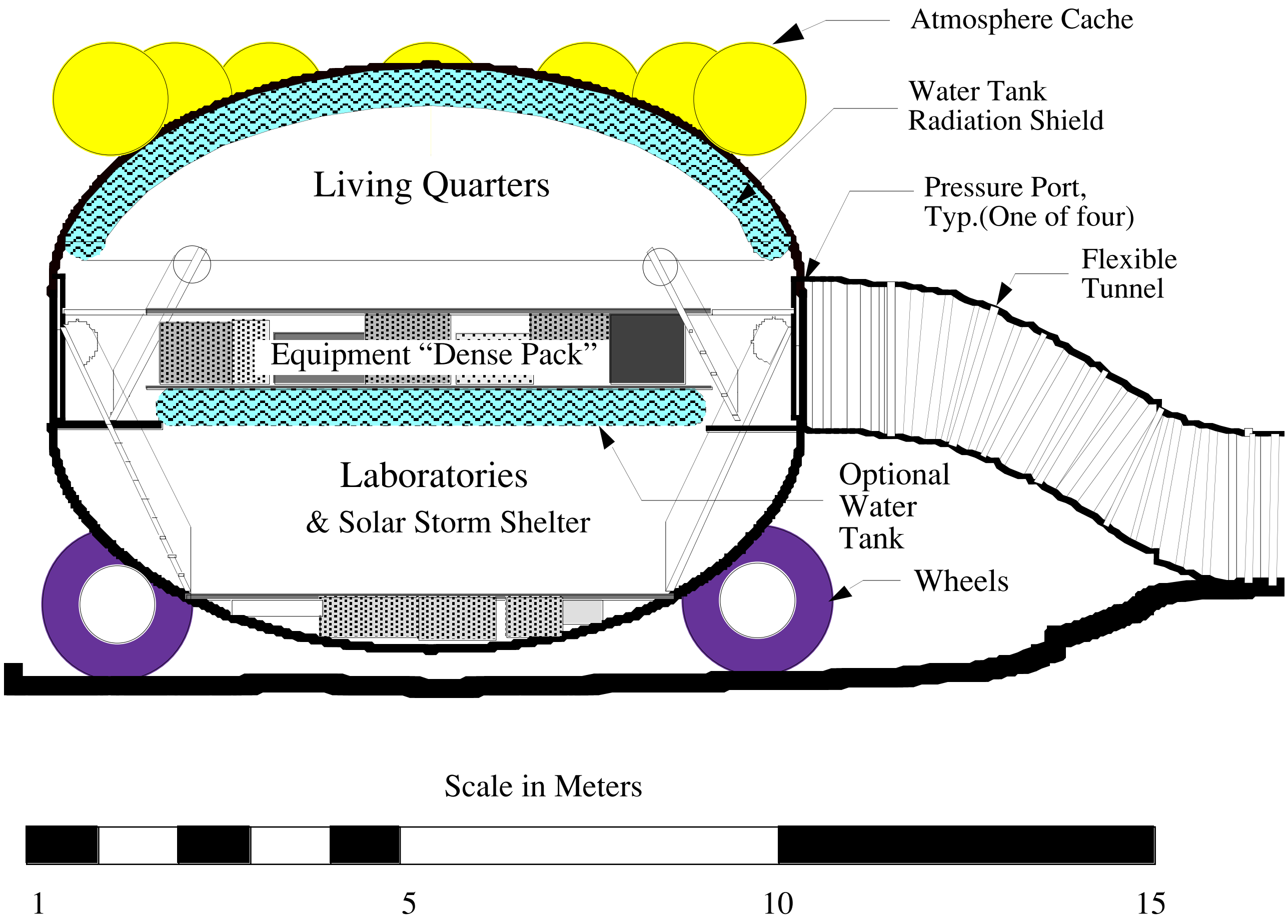

FIGURE 2. Schematic Section Elevation through a Mars Surface Habitat

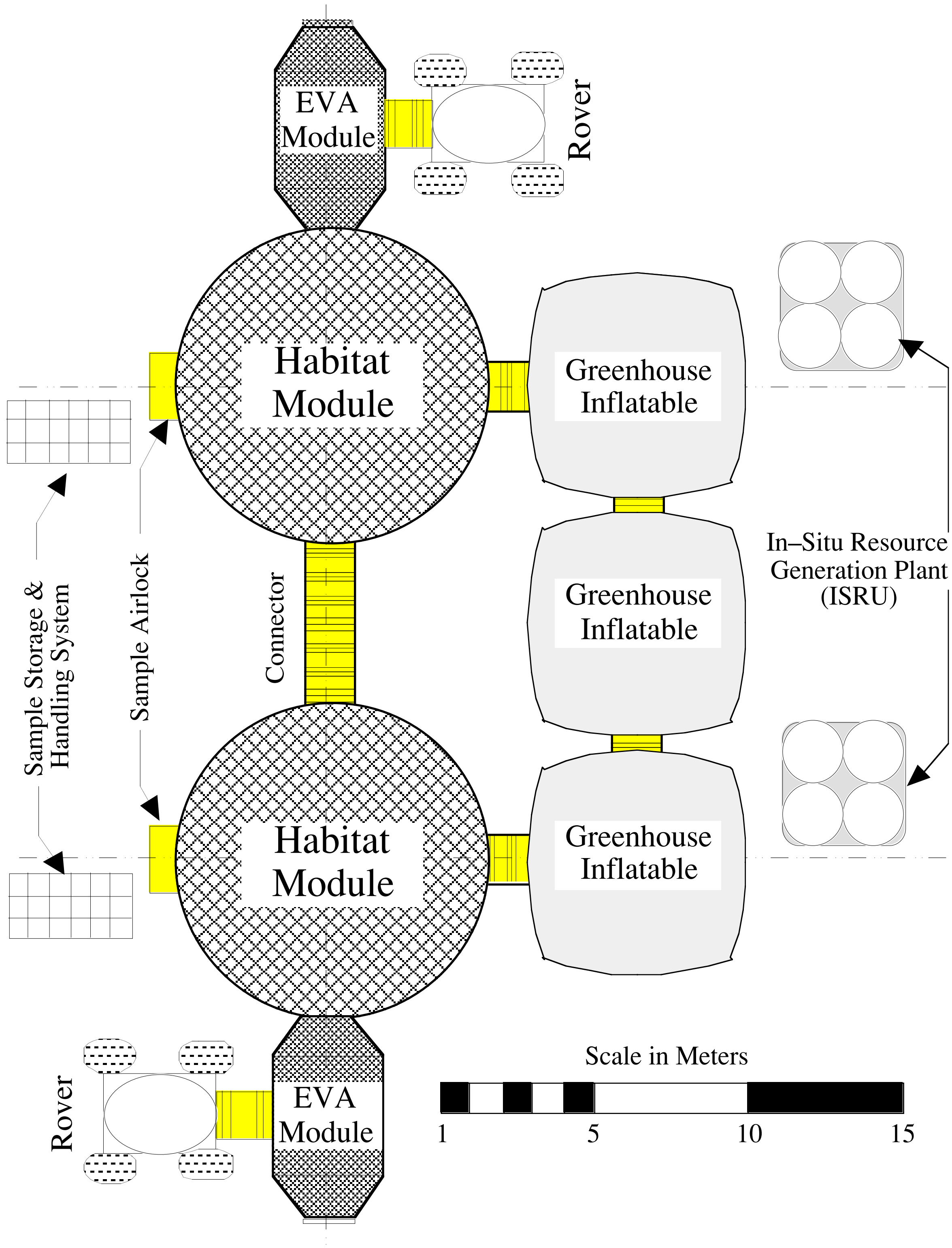

FIGURE 3. Schematic Plan of a First Mars Outpost Base after Four Launch Opportunities.