Using Spent Fuel Tanks as Habitats

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Abstract: The idea of using an expended liquid fuel rockets as a serviceable container for human habitation and technical spaces is a recurring topic. With the advent of Dr. Robert Zubrin's simulated habitats the concept has achieved a certain credibility, even acceptance, as a state-of-the-art practice. This paper outlines some design considerations for habitats and supporting structures in low-gravity, and is intended to encourage architects with other constraints and considerations to join the conversation.

Keywords: ISRU structures, habitat design, expended fuel tanks.

There emerges from time to time a polite dispute as to whether the long aspect of a cylindrical habitat should parallel the horizon or vertically reach for the zenith. These concepts are usually based upon a rocket’s fuel tank although recent ISRU efforts expect to manufacture habitat shells on the Moon and Mars. There are considerations which will guide our thinking as we architect a design choice, so that each implementation can be considered on its respective merits.

This conversation has new credibility given the operational experience gained by private organizations conducting ‘live’ simulations of Mars and Moon encampments. These efforts employ volunteers over extended intervals in remote sites. The Mars Society[1] is a non-profit organization of space enthusiasts, and has deployed expeditions at the Flashline Mars Arctic Research Station (FMARS), Figure 1, on Devon Island, in the Canadian Arctic. The Society has also established a site, the Mars Desert Research Station (MDRS), in Southern Utah with a similar intent. An unrelated effort is underway to establish a simulation site in Mexico called the MexLunarHab for simulation of Lunar contexts.

Figure 1. FMARS Simulator and Crew

We have accumulated considerable zero-G habitat experience with Skylab, MIR and ISS. While the ‘lessons learned’ are valuable, there exist limitations when attempting to apply them to a tank parked upon the Lunar or Martian surface. The principal psychological difference is the fraction of Earth’s gravity which changes the crew orientation and objects again stick to the floor, as they do on Earth.

So while the expended fuel tank employed as an habitat in orbital zero-G remains little constrained by such notions as ‘floor,’ ‘walls’ or ‘ceiling,’ the planetary-sited habitat will definitely require an ‘up’ or ‘down’ permanent bias. The ratios of cylinder length to diameter would most decidedly have an effect on cylinder deployment under gravity. The inventory of expended fuel tanks available to a Lunar Settlement Team will have to be ascertained by a trade study, although it may be that there are none which can practically serve the need.

For example, the number of Centaur stages in Geosynchronous Orbit approaches one hundred. The skins of the rocket may be too thin to be practically used unless reinforced by wrapping with composites or such. A more likely implementation is for habitats to made almost entirely of Regolith-derived production (ISRU) of structures such as wound fiberglass forms and Chemical Vapor Deposition (CVD). Habitat shells manufactured of indigenous materials would be simpler in design since they are not subject to the rigors of flight. They would, however, still have the same issues of deployment aspect as surplus tanks.

A Comparative Exercise

For our orientation analysis we use a 28 foot long tank with an 18 foot diameter as representative of a rocket stage which could be recycled as an habitat. The following review does not seem to be sensitive to the sizes of tankage but may be effected by aspect ratios (length to diameter).

To acquaint the prospective Lunar Home Builder with some of the concerns and considerations we present an exercise. We first compute the area of the cylinder cross-section in order to derive the useful floorspace and volume of a cylinder:

$$A = \pi r^2$$

$$A = 3.141 \bullet 9^2$$

$$A = 3.141 \bullet 81$$

$$A = 254.4 \text{ ft}^2$$

To determine the cubic volume we multiply this Area by the cylinder's length.

$$V = A \bullet L$$

$$V = 28 \text{ ft} \bullet 254.4 \text{ ft}^2$$

$$V = 7{,}112 \text{ ft}^3$$

Horizontal Option

When installed horizontally the orientation would be similar to an airliner or a submarine. The tank offers a single 18 foot tall bay or two eight foot tall spaces plus a small subfloor volume. In any environment which includes gravity a crew would use only the bottom third of the space, so that a two-floor arrangement would seem more practical than a single bay.

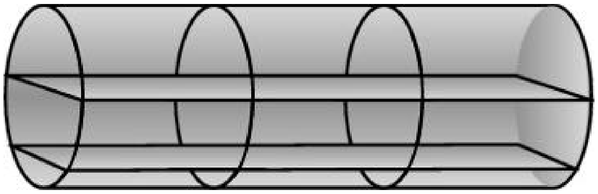

Figure 2. 'Submarine' Horizontal Deployment

To develop the parameters necessary for a comparative analysis we break down the space into useful volumes and apply conventional math, including Pythagoras. An eight foot ceiling is consistent with many conventional homes and isn't known to cause claustrophobia. There is a two foot 'crawl-space' less the thickness of the floor beneath this floor.

The two floors differ in width, area and wall slope; see Figure 3. The lower floor's wall bends away while the upper floor's wall tapers to a peak, much like the attic bedroom at grandma's house.

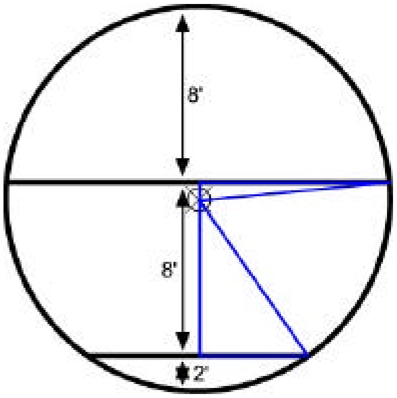

Figure 3. Horizontal Floor Partition

To develop the size of the upper deck we shoot a radius which intercepts the wall at the base of the upper floor, yielding the hypotenuse. Taking the square root of the difference of these two known sides gives up a figure which, when doubled (figure 4), gives us the width of the upper deck.

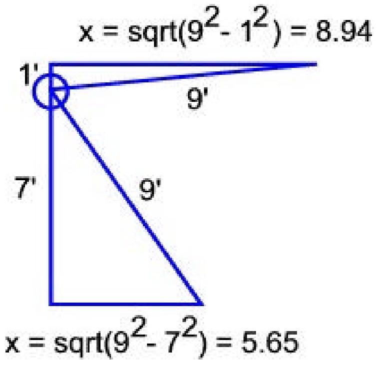

Figure 4. Compute Floor Sections

The lower deck size is similarly ascertained by using a hypotenuse which is a radial meeting the wall at the edge of the deck. The 2' offset for the floor gives us the adjacent side of 7' and once again we invoke the square root of the difference of the squares. Doubling this number yields the width of the lower deck.

Next we multiply each deck's width by the deck's length of 28 ft., which gives the respective area:

$$L1 = 17.88 * 28 = 500.6 \text{ ft}^2$$

$$L2 = 11.30 * 28 = 316.4 \text{ ft}^2$$

The sum of these areas gives us the total floorspace for the structure:

$$L1 + L2 = 500.6 \text{ ft}^2 + 316.4 \text{ ft}^2 = 817.0 \text{ ft}^2$$

The significant negatives for the horizontal deployment tell most of the story and pretty much reiterate that there is no uniformity in the available space. The upper level has sloping headroom which substantially reduces its' utility as space available for equipment racks and storage.

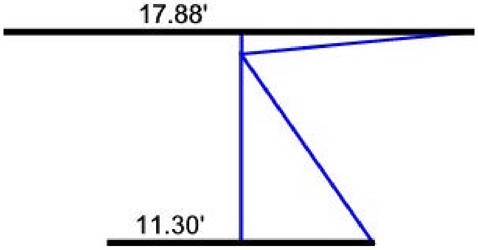

Figure 5. Complete Floor Sections

The subspace is too small to be useful and will encourage the collection of detritus, vermin and fluids, some of which may be corrosive. All of this in an area which is hard to service. It is difficult to pressure seal between the two decks because of the dimensions.

At least 168 ft^2 of area will be consumed with a central aisle at the highest overhead point, reducing the effective area to 648.8 ft^2. This will be very much like living in a business jet, with constant collisions between skulls and furnishings. This 'tunnel effect' is stressful on long-term crew.

Further, this sketch does not allow for the thicknesses of the two decks, which would further reduce the available headroom. Given that decks are constantly a load-bearing structure by definition, the failure mode of these decks is ugly – we can cite the loss of a DC-10 over France some twenty-odd years ago, when the loss of a cargo door caused a collapse of the horizontal deck which avalanched into a severe airframe failure, complicated by damage to electronics and hydraulics mains.

Another point which disfavors the horizontal option is the installation of horizontal decks, a large effort by any measure.

Vertical Option

Another useful configuration of this cylinder is to stand it on end, yielding three floors of 254.4 ft^2, with 9 foot ceilings. This offers a total raw floorspace of 763 ft^2., with three identical volumes of 2289 ft^3.

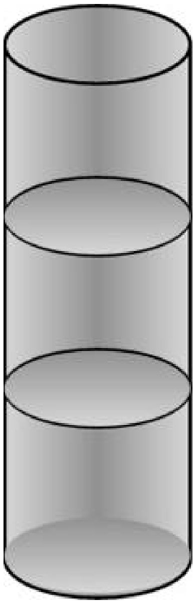

Figure 6. 'Silo' Vertical Deployment

The configuration is consistent with the already-existing tank partitioning into fuel and oxidizer sections and does not offer awkward ceiling slopes, congested headroom or wasted subspaces. It is also easier to implement bulkheads as floors to isolate rooms against pressure breaches. Access from floor to floor can be very conveniently off-center, out of the way, behind a moveable safety rail. Any tall fixture can be positioned anywhere on any floor. This configuration also allows segregation of the engineering space (air and water processing, airlock to outside, power, stores) from living spaces and from technical spaces (labs, communications, libraries, computers). An hoist can be installed on the topmost ceiling for hauling heavy or bulky gear from floor to floor. The heavy equipment would be on the upper floors and the living quarters deeper in the structure for better radiation shielding.

The ergonomics for this living configuration seems quite favorable, and few would have to avoid head impacts with the ceilings. The volume of 'headroom' and the openness of the configuration would seem to be preferrable to a longer, narrow aspect with converging space for one's head and shoulders.

Partitioning a cylindrical fuel tank into vertical segments is entirely congruent with the design intent of liquid rockets. All flooring bulkheads can be pre-installed as an imbedded feature of the manufactured article. The difficulties lay in the ratios required between fuel and oxider volumes and excess of one or the other is likely in order to arrive at *people-compatible* living spaces.

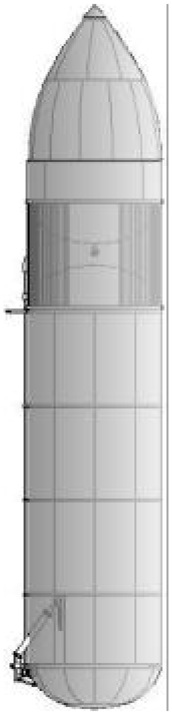

Figure 7. Space Shuttle External Tank

If the 153.8' by 27.6' diameter and 66,000 lbs. of the Space Shuttle External Tank (Figure 7) can be used as a design objective then serious pre-packaged tanks could be configured for direct *single-stage-to-Moon-Orbit* launch. This would have to be modelled, of course, and would offer a flight-rated opportunity to deliver a habitat shell to the Lunar vicinity.

Deployment

While expended rocket tanks are rounded up or ISRU-manufactured habitat cylinders are fabricated the installation site can be 'prepped' by excavation robots. The site is examined with Ground Penetrating RADAR and electronically marked. The robots then excavate the soil by loosening the the regolith, conveying it out of the 'dig' and discharging it away from the site with an electrostatic cannon; see Figure 8, below

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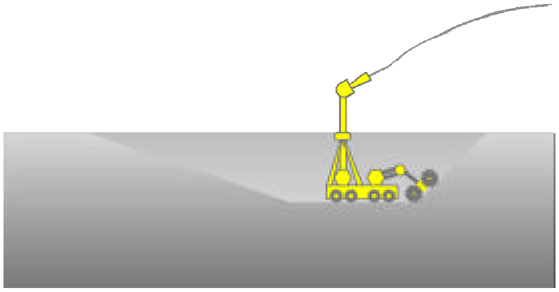

Figure 8. Excavator with ES Cannon

A trench is cut in the bottom of the site and a tunnel cylinder with numerous airlock fittings is installed in the 'basement.' A number of habitat cylinders are then installed vertically and connected to the underlying tunnel. Later interconnecting tunnels will tie habitat clusters (condominiums) together into communities, when economics justify large-scale capital projects.

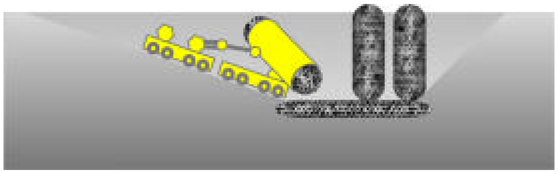

Figure 9. Habitat Installation

Upgrades and Options

Building architectures may be constructed from ISRU-derived structural components, usually fiberglass filaments and fabrics. After the habitat cylinders are installed the next addition might be shelter from micrometeroids and other irritants, to the benefit of habitat airlocks, surface vehicles and robotics, APUs, portable lights, tools, *etc*. – in other words, a garage.

One structural device which lends itself to such implementations is the hyperboloid. This Buckminster Fuller 'tetrahedral' structure is a natural in this role since it should be simply constructed, simply erected on site, and manufacturable from indigenous materials. The hyperboloid can be modular, with a square aspect.

Figure 10. An Hyperboloid Shelter

The huge advantage of this structure is that it can be assembled into larger structures using a recursion of iso-hyperboloids in concentric rings or *m x n* grids. Sharing supports and structure reduces material requirements, providing modularity and extensibility, and substantially increasing the useable area under cover. The usable covered space can also be increased by mounting on pylons (columns) and truncating the 'A'-frames and their resulting 'footprint.'

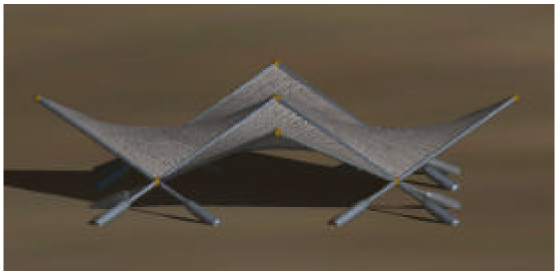

Figure 11. Extensible Architecture

The perimeter of an ensemble may be enclosed with additional fabric panels which then hang vertically to the surface.

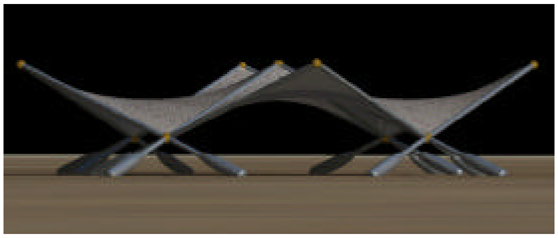

Figure 12. Pedestrian View of the Quad

A 'scissors'-like pivot of the 'A'-frames could be expected to enhance *ease-of-deployment*. In absense of atmospheric winds the shelters don't require elaborate foundations and a concrete pad is optional. Unless the shelter were to be enclosed, a concrete pad would be submerged beneath Lunar dust, somewhat diminishing its utility.

Summary

Space salvage, extended service and ISRU manufacturing will offer various options for erecting building structures on the Moon and Mars. We have offered a few design and deployment options which serve to narrow the field somewhat. We have not investigated the loads on tanks from regolith backfills and other considerations.

We have identified some of the considerations and constraints which emerge upon a cursory examination of a set of possibilities. We were surprised by the number of roles which might be filled by use of ISRU materials, particularly fiberglass products. Another unexpected datum is the number and variety of upper-stage boosters available as derelicts in the vicinity of GEOsynchronous orbit.

Curriculum Vitae

Tom Wray, Space Architect, 3rd Millenium Construction Company

Tom designs and develops advanced and unconventional architectures for residential and commercial buildings. He specializes in high-efficiency energy models and self-sufficient housing. The dual-use aspect of this work has led him into designing structures for space applications which incorporate a ‘fractal’ geometry strongly influenced by R.B. Fuller.

Curriculum Vitae

Gary ‘ROD’ Rodriguez
President and Systems Architect, *sys*RAND Corporation

A nuts and bolts technologist from 'way back, he designs and develops products with electronics or intelligence content for the industrial world. Raised to be a generalist and an artist in a long line of artists, his customers have mass-produced his designs, with avionics flying in commercial and military fleets worldwide as well as the President's Helicopter Fleet, specialized test equipment and numerous other products, including the oil patch. These devices are often, although not exclusively, embedded controllers operating in hazardous environments.

He holds a Bachelor's degree in Math and Computer Science, having grown up with computers since the sixties. He is a VietNam-*era* veteran and a *sometimes-current* private pilot.

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[1] For additional background details see www.MarsSociety.org