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Modeling Flexible Mars Greenhouse Prototypes

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ABSTRACT

An interdisciplinary team of designers and researchers are rethinking the design for initial deployment greenhouse modules for the first Martian exploration in order to test the viability of growing enough biomass to support life. Researchers wanted a new model from outside the established aerospace industry's mode of thought in order to question existing strategies for greenhouse design. The resulting schematic ideas awaiting further evaluation represent an architectural sketch for a small modular growth chamber for the surface of Mars.

INTRODUCTION

Typical to the architectural design process is the notion of the sketch problem. It involves profuse amounts of brainstorming, coffee, wads of paper, pencils sharpened down to nubs, and sleep-deprived faculty and graduate students. Throw into the mix a collection of laptops loaded with state of the art modeling and visualization software and you get a fairly accurate depiction of the design process launched to begin rethinking the Case for Mars strategies which begun with the Space Exploration Initiatives. What began as a joint endeavor between faculty and graduate assistants from architecture and molecular biologists and geneticists to digitally visualize designs for small growth experiments to be sent to Mars atop a small lander expanded into discussions about a different concept for larger greenhouse modules as seen through the eyes of architects.

This design process for initial deployment greenhouse systems, nicknamed GRUBs, represents an interdisciplinary research and development project involving scientists, faculty, and researchers of a NASA-sponsored center at the University of Florida, Space Agriculture and Biotechnology Research and Education (SABRE), the University of Florida School of Architecture, and the Rinker School of Building Construction. Beginning with the position that sustained presence on Mars will require a renewable food source grown in Martian regolith, the design team set out to develop an expandable, modular system that can be adapted to the irregular planetary surface and, due to its geometric structure, withstand the extreme conditions endemic to a reduced interplanetary atmosphere. Artwork depicting other design concepts by Akira Ohkubo, Cho Jinsei, Robert Murray, and principally Carter Emmert's work from the Case for Mars II Conference was carefully considered by the graduate research team in an effort to understand the complex issue of creating safe habitats on the hostile surface of Mars.

The initial agricultural environments on the surface of Mars will need to be modular and adaptable systems flexible enough to fit in a relatively small payload yet strong enough to endure extreme conditions. These structural systems will need to be easily assembled by astronauts with somewhat compromised dexterity in Extra-Vehicular Activity (EVA) suits, yet strong enough to withstand sustained winds and reduced atmospheric pressure. The membrane of the system will need redundancy in case of meteorite projectile penetration and be flexible enough to operate either as a translucent light-emitting skin or a projective opaque skin supporting artificial growth illumination within.

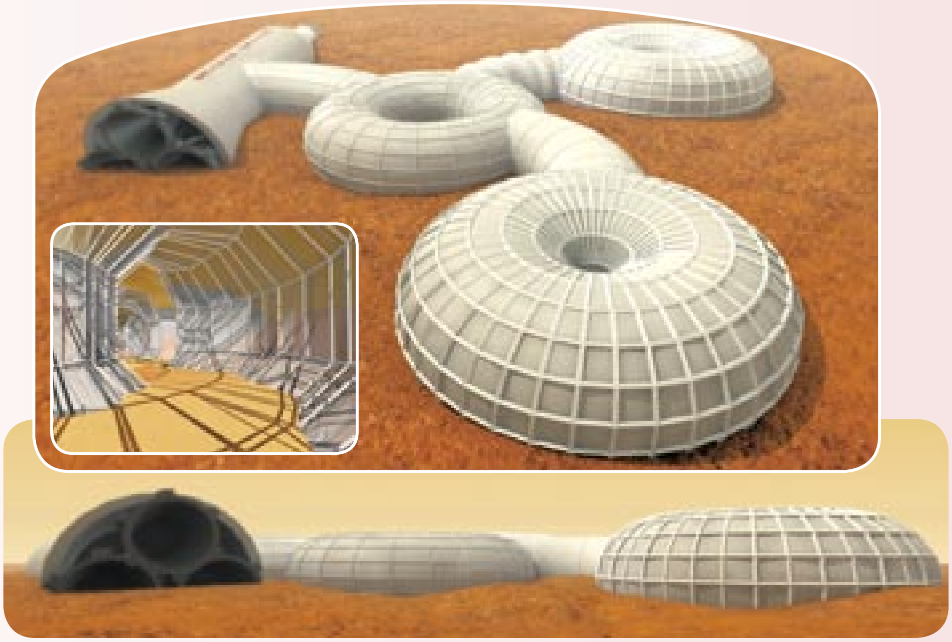


FIGURE 1, 2:
VIEW OF MODULES SET INTO SURFACE OF MARS. SOA/SABRE

FIGURE 3: EARLY CUTAWAY SKETCH OF FACETED MODEL SET INTO REGOLITH. SOA/SABRE

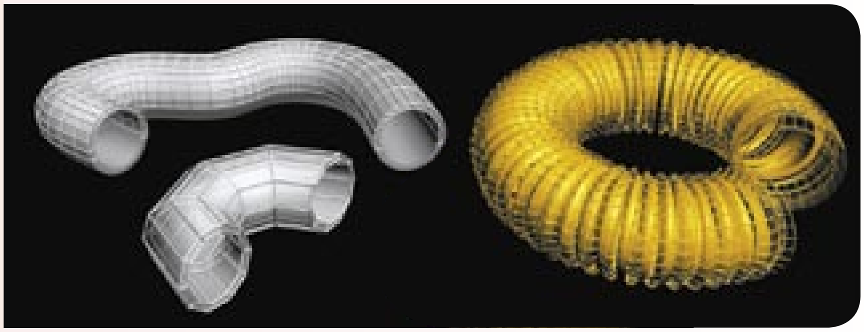


FIGURE 4: EARLY MODELS DEMONSTRATING VARIOUS SHAPES. SOA/SABRE

PROCESS

The goal of the project is to rethink the given shape and structure of Martian greenhouse design. As an architect and educator, the thought process is inherently different than that of an aerospace engineer solving the problem of providing suitable space for the growth of crops for a settlement on Mars. At the onset, the design team began to seek out biological forms and systems for inspiration while researching previous schema for Martian outpost architecture.

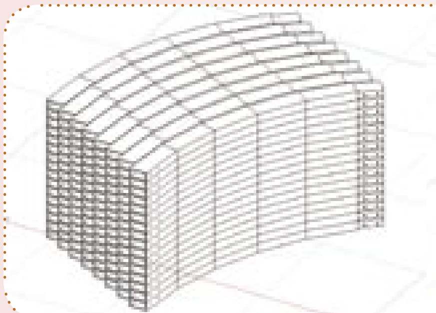


FIGURE 5: RECTANGULAR SECTIONED VERSION DISASSEMBLED.

FIGURE 6: RECTANGULAR SECTIONED VERSION IN QUARTER SECTIONS.

The precarious fragility of a solely-inflated greenhouse structure in a thin atmosphere abundant with meteorite debris became immediately apparent. Instead of deriving inspiration from mechanistic sources, the architectural team looked to nature for geometric and systematic ideas of how to rethink what in previous schemes tended towards large inflatable domes and buried tubes. Based upon biological cellular structures and commonly found constructions in nature including the formal language of red blood cells, bacteria, and spores, the GRUB structures are designed to operate to resist wind shear in the X,Y, and Z axes of impact based upon a cylindrical tubular design rather than the previously prevalent vision of domed greenhouse structures.

The torus shape of the greenhouse modules is based upon the outward resistance that circular geometry provides against the wind load of Martian dust storms. If properly grounded into regolith berms, winds will be channeled up and over the greenhouse, exerting in the process a downward thrust not dissimilar to the aerodynamics of a racecar. The bermed regolith at the bottom prevents uplift that could destabilize the structure. In plan, the circular shape also will channel winds around the structure. Using a rigid frame in addition to 5psi inflation will help maintain the shape of the structure so that the aerodynamics can function properly.

The ring shape, rather than a lozenge shape, allows one of two things to occur, depending on the particular needs of the settlement. The first consideration for whether to leave the center a void revolves around the thought that, by filling the central space with packed regolith, the resulting mass would act as additional structure to anchor the greenhouse to the surface. This would aid in resisting the wind force of the dust storms. A lens-shaped dome that lies flat and close to the ground rather than a semi-circular dome would also reduce the effects of winds (1), but would require a much larger payload of structure and material for an early initial deployment greenhouse environment.

The other consideration is that, with a domed or lozenge shaped structure, there will be a dark side of the greenhouse unsuitable for plant growth. This factor is predicated on a translucent skin to allow for light transmission rather than an opaque one. At this point, the design team was instructed to not base a model upon the transmission of light, and to base decisions on other factors. The assumption is that either a translucent PBO skin with adequate filtration of UV radiation or an opaque skin with a light-emitting system of LED illumination will be developed.

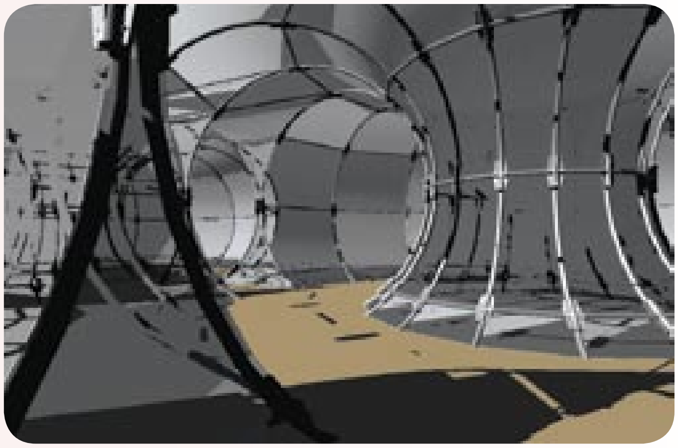


FIGURE 7: VIEW INTO INTERIOR FILLED WITH REGOLITH.

Table of Contents | Next Article >

The composite tubular structure affords an unforeseen flexibility in deployment, allowing for closed torus-shaped assemblies as well as irregular, curvilinear arrangements to respond to Martian geology. The ring shaped structural ribs allow for a highly flexible and expandable system. The interior volume is increased by adding more ribs and increasing the radius of the greenhouse. Additional sections of the endo-dermis and exo-dermis can be zipped into place in order for the space to expand.

The ring shape provides a structural integrity not easily possible, or as efficient, as with rectilinear structural shapes. The geometry also allows for sections to be assembled as tubes rather than rings for circulation corridors or connector pieces. Each ring is stored in payload as quarter sections, stacking vertically and nesting horizontally in transport. The rib sections are gently facetted rather than curvilinear for the sake of providing straight sections of tube where they connect together to form the complete rib.

Polybenzobisoxazole (PBO) fiber composite comprises the bulk of the structural shapes. PBO is stronger than the previously used Kevlar, and has decreased flammability in oxygen enriched environments (2). The structural ribs, telescoping struts, and connector struts can all be made of PBO to reduce weight in transport. The skin is comprised of redundant layers of PBO fabric 1 mm thick. The exo-dermis layer could see an additional thickness for shielding UV radiation and meteorite projectiles. The goal in material and modularity selection was maximum strength, compactness and adaptability as well as interchangeability of parts for longer-term maintenance.

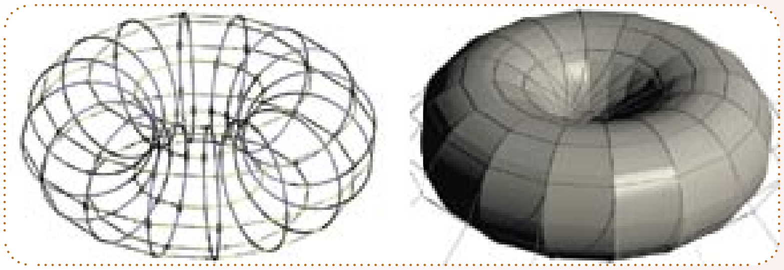
DEPLOYMENT

The first stage of assembly involves the zipping together of the exo-dermis and inflating it. This creates an inhabitable staging area for erecting the remainder of the structure. The second stage of erection is the assembly of the ring shaped structural ribs within the exo-dermis. Telescoping struts are attached to the ribs by a coupling that also reinforces the joint between rib quarter segments.

The third stage of assembly is the unfurling of the endo-dermis within the structural ribs and zipping it together. This dermis is then inflated as a bladder which, as it expands, pushes the structural ribs into place and snaps the telescoping struts to their optimum length. At maximum inflation, the endo-dermis sandwiches the structural framework between it and the endo-dermis, providing additional rigidity and stability. The redundant skins decrease the chance of deflation due to meteorite penetration.

The fourth stage of assembly entails the berming up of regolith against the lower portion of the outside circumference to resist uplift. Regolith would also be carted into the interior of the GRUB greenhouse module for growth. This additional mass would act as ballast while providing a flat walking surface while crops are planted and tended.

The final stage of assembly is the addition of the tie-down anchors. The tie-down cables are braided nylon fiber that essentially drape across the top of the greenhouse module like a spider's web and attach to aluminum anchors embedded into the surface. Several GRUB greenhouse modules can be clustered together and joined with an integral joint system (Fig. 8). This allows for segregation of crop typologies or of uses for each GRUB module.



FIGURES 8, 9: SINGLE ISOLATED GRUB FRAME WITHOUT SKINS, AND WITH SKINS AND TIE DOWNS.

CONCLUSIONS

The intention of this research and sketch problem is to show that a highly transportable and adaptable system can serve to initially test the viability of growing edible biomass using the Martian regolith. If proven successful, then larger-scaled growth environments could be transported and assembled to support larger exploration teams. It is too early in the schematic design phase of this sketch problem to ascertain the viability of such a strategy, however these models are proving highly useful as catalysts for discussion and debate with researchers at IFAS and KSC. GRUBS is a relatively simple idea conceived with rigorous naivety from outside the aerospace engineering community. Perhaps an idea such as this, based upon the concept of biomimicry, could offer plentiful solutions to the dramatic challenges facing a mission to the red planet.

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FIGURE 10: VIEW OF JOINED GRUB GREENHOUSES, LIVING MODULE OR SPACECRAFT REMOVED FOR SIMPLICITY AND DETAIL OF CONNECTOR SLEEVE.