7.0 Summary and Conclusions

7.1 Critical Design Features of *Domus I*

Domus I is the result of a feasibility study of the Chow and Lin PSSMS concept on the lunar surface. *Domus I* allows separate work and relaxation realms within the habitat. Different functional spaces are able to be designed differently. The torus portion, dedicated to the laboratories, differs in geometry, color scheme, and workstation arrangement from other parts of the habitat. Work spaces are open; walls have windows emplaced to promote a visual sense of spaciousness.

Those areas dedicated to the crew are in the central domed ellipsoid. Some spaces, like crew quarters, have curved outer walls. Translation spaces in the crew quarters are rectilinear, centrally located, and clearly connected to the bounding platforms. The crew has a choice of single or double quarters, personalization is encouraged with interchangeable panels of differing colors, and privacy when needed is assured. The crew support facility is somewhat removed from the private crew quarters. It is designed as an open-plan arrangement with a larger central volume to serve the entire crew and supporting facilities on the perimeter. This area allows interaction among the crewmembers, both visually and socially.

Safety is a prime requirement of any structure housing human life. All levels and spaces in the habitat have been designed with dual means of egress, and the ability to "lock down" a specific area in the event of a system failure or to secure the crew in the event of a solar flare. Communication and computer systems can be accessed in numerous locations throughout the habitat. Provisions for short-term stays in the safe haven area—the crew quarters—have been included.

The rack component system allows for change-out and can be shifted within several areas. These designs respond to the change in the anthropometric alignment of the body in the 1/6th g of the Moon.

As yet, widespread testing of inflatable technology—and of the PSSMS system in particular—has not been accomplished. The theory behind inflatables, e.g., great volume attained with a reduced amount of packing volume, less weight at liftoff relative to great amount of resultant space, etc., are important characteristics dictating further promotion of the technology. Adding the use of rigidizing foam to enhance the structural integrity is of considerable value added.

The results of this design analysis indicate the concept is very feasible from habitability, human factors, and environment-behavior considerations. The PSSMS structure is easily able to be made habitable. The torus versus the inner part of the ellipsoid allows easy separation of work from living areas. The two floor possibility in the ellipsoid allow separation of public crew support spaces from private crew quarters. Orientation and circulation are clear. Translation pathways allow for unobstructed movements of components and crew. Dual egress is assured. Variety of space within tight quantitative space limitations is accomplished. Creating two separate environments within one envelope—the torus and the domed center of the ellipsoid—lessens the number of materials interfacing with one another. In sum, the concept seems extremely feasible and deserves most serious exploration by the various lunar program offices at NASA.

7.2 Critical Design Features of *Dymaxion*

The efficiency of Fuller's design of "dymaxion" has been the driver for this lunar base concept. Zoning takes precedence here as the habitat is divided into two spatial delineations: work and habitation. Initially, the habitat is erected and protected using a telerobotic system. This phase of construction allows for the habitat construction to be well underway by the time the crew arrives, eliminating EVA time. The exact technology for the successful deployment of the initial phase is yet to be discovered, and the preparation of the site will involve equipment currently under study.

Simplicity in design is addressed in the fact that the entire habitat can be delivered to the surface of the Moon in only three anticipated payloads.

The key components of *Dymaxion* are three space station Freedom-type modules, a mission control hub, and a mast containing the structural components for regolith shielding, vertical circulation, and life support systems and environmental controls.

The work environment dominates the lower portion of the base within the hard modules. Each module is connected to the mission control hub, radiating outward and terminated with an airlock. These features provide for redundant means of egress. Six EMUs are located in each module, and in the event of a module failure, there are still enough EMUs for the entire crew.

The protective system for radiation shielding is deployed by robotics. Regolith is translated upward through the mast, and unloaded onto the Kevlar canopy. This necessitates machinery that only needs to remain upon the surface of the Moon. The canopy is sloped to correspond to the angle of repose of the regolith. With the canopy, access is gained to the modules underneath, eliminating the need to uncover a module buried directly.

A spherical geometry houses the habitation portion of the base. Volumes within this space are generous, allowing for movement of the interior components. Crew quarters contain sleeping accommodations for 3 crewmembers each. The quarters are located centrally, and this location allows for the quarters to serve as a safe haven in the event of an emergency.

The balance of the spherical shape is dedicated to crew support. The recreation area takes advantage of the ceiling form, e.g., projecting images on the interior skin for videos, communications etc. The upper deck area also offers an overlook balcony, creating a visually expansive vantage point.

7.3 Major Strengths and Limitations of *Domus I*

With the technology of inflatables still in the discovery stage, we have developed the habitat under the assumption that living within a pressurized, reinforced-fabric envelope is not only feasible, but most practical. What remains to be determined is the method of packaging the envelope and what is the best strategy to deploy the habitat on the surface of the Moon.

The separation of work and relaxation is vital to the well-being of the crewmembers. It is a feature found in terrestrial architecture and allows the human being time to refresh and regroup. As productivity is a major component in the success or failure of a mission, creating a positive work environment is essential. Related to this issue is the design of personal quarters. We agree with various aerospace professionals who encourage spaces be designed that will allow a crewmember to be alone for some period of time. Space has been allotted for the crew to personalize their territory, not only in their quarters, but also in workstations.

The construction method of the habitat has not been perfected. Yet, it appears that the construction may be relatively easy to achieve. Site preparation that requires little EVA time for the crew will be beneficial.

Outfitting the interior of the habitat ~~in a shirt-sleeve environment~~ will permit the crew to work without the bulk of spacesuits. There are few components to the entire facility. This fact will allow for easy expansion at the airlock locations. Fewer components means fewer interfaces or potential points of failure.

Another feature of *Domus I* addresses the visual and spatial variety of the habitat. Though there are only three major levels of operation, the laboratories, crew quarters, and crew support levels are designed with spaces that flow and blend with one another, while being distinctly different in style and character.

The volume of the habitat is not expansive, yet every effort has been made to have the geometry appear as though it is. When coupled with the component system flexibility, these spaces should serve a wide variety of individuals who will inhabit the facility during their tours of duty.

The limitations of *Domus I* lie in the unproven technology of the construction methods and materials. The construction process will demand the use of various types of equipment yet to be developed. In the interior portion of the habitat, further testing will be required to evaluate locomotion within a torus (in 1/6 g). Postoccupancy evaluation (POE) will be vital as lunar bases of the future are constructed and inhabited for any length of time.

7.4 Major Strengths and Limitations of *Dymaxion*

Dymaxion strives to produce a lunar habitation facility that can be simply deployed without great risk to the crewmembers' lives. Compact packaging is the goal, with the maximum allowable components placed within a known-technology container. A combination of both hard module and inflatable technology will allow for a range in construction testbed experimentation. The spatial variety offered in these geometries will provide the crew with various options for workstation configuration and personalization. It is known that an inflatable envelope can offer a large working volume; yet to be determined is the successful packing of the envelope, and equipment capable of the desired deployment—without human intervention, the robotic assembly might need a form of artificial intelligence.

A cause for concern will be the deployment of the regolith for shielding. Introducing the regolith into the interior of the mast may result in the fine powder contaminating many of the surfaces and connections. It is known that regolith has a charge that complicates its elimination.

An additional consideration is the varied connections utilized to combine the habitat components. The connections between hard module and platform, hard module and mission control hub, those between platform and inflatable, inflatable to the mast, mast to the cupola, and mast to the regolith deployment system demand numerous forms of technology. The simplicity of the concept is diminished with the complexity of the connectors. Advances in technology may eliminate these concerns.

Lastly, with the amount of generous volume available, individual crew quarters could be available. The sharing of the crew quarters by three crewmembers reduces the amount of private space allotted and personalization possible per crewmember. As well, space dedicated to balconies may prove ineffective cost-wise.

7.5 Future Research and Design Development

There remain numerous issues that have not been resolved when considering the design and construction of a lunar base. Some of the issues may not have a conclusion until the actual facility is in operation, and fine tuning can occur. Some of the issues will have terrestrial analogs, and these should be studied carefully, applying appropriate parameters to the lunar concept.

Site planning and base master planning: there exist too few close up details regarding the lunar surface to select one site for construction. Further reconnaissance must be accomplished prior to choosing a final site. As well, determination must be made as to whether the site for the FLO will be the site for a permanent facility. Scientists would like to take advantage of multiple FLO sites to gather widespread data for evaluation. Does a permanent facility begin to satisfy that desire? Additionally, the aerospace and scientific communities need to develop mutual strategies for gathering the data.

Construction technology: terrestrial methods may offer suggestions on how to accomplish a portion of the necessary construction. Given the change in gravitational pull, though, equipment will either have to be adapted or completely redesigned. Construction methods to prepare the site as well as build the facility need to be evaluated.

Materials: the two concepts in this report make use of inflatable technology. Materials engineering needs to advance with further testing accomplished prior to deciding what material is appropriate for the Moon. Strict use of inflatables may not be the best strategy — a combination of inflatable and hard module design may be best. Further evaluation and testing of the two methods is warranted. There may well be a hybrid alternative yet to be designed.

Geometries: the most appropriate geometry for a vacuum environment has yet to be determined. These forms are dependent upon the material utilized. Toroids, spheres, and cylinders dominate current thought. Each has inherent challenges in outfitting the interior volume. Given the expense and weight involved in transport, these geometries will be modest. Research must continue on which geometry will offer the greatest volume, flexibility, and allow the human a productive environment.

Modular component systems: practically speaking, modular components allow for flexibility, change-out, and adaptive reuse. Questions have been raised as to whether modular systems used extensively will lead to an environment that is sterile and monotonous. A modular system can be designed to allow for not only the entire "rack" to be changed, but the smaller portions of the system can be reconfigured. Panels can be switched, reversed, removed, etc. This flexibility is an asset for the crew. Modular systems for particular geometries need further research and development.

Interior configurations: space is at a premium and designs cannot afford to waste any portion. Dependent upon the geometry, configurations need to be flexible and efficient. The lunar gravity alters human movement through space. Configurations need to address that change, and assist the crewmember in translating from place to place.

Volumetric requirements: careful study needs to be conducted addressing volumes for habitat and laboratory spaces. There exist many suggested measurements - ranges from 227 m^2, 349 m^2, 552 m^2, to over 1800 m^2. This range indicates that the optimal volume has not been discovered. Further research must be conducted to reduce this range to a more closely-related group of figures. Additionally, will the volumes change as the missions lengthen and crew sizes increase?

Life support systems: both projects did not address these systems in this report. These need to be evaluated closely with determinations made for volumetric requirements.

Connections: design concepts and evaluations need to be conducted regarding the interface between like and unlike materials.

Interior components such as bounding platforms need to be evaluated; the discussion continues as to their merit in 1/6 g — whether or not the platforms or possibly stairs are more appropriate.

An efficiency analysis must be conducted against other proposals for lunar habitats with application proceeding to cost analysis.

Laboratory analysis must be conducted and determinations made as to whether the scientific functions on the lunar surface can share equipment, lab spaces, and we must understand how these laboratories would function in the lesser gravity.

The dynamics of small group interaction should be evaluated, especially groups in isolation and confinement. These dynamics can then be related to the design process.

Noise and vibration control and abatement needs to be researched, especially when considering the use of multiple types of materials.

Lighting and energy requirements should be closely examined and a full illumination analysis should be conducted on the base concepts.

As with laboratories, the medical facility needs further investigation, not only in the design but in understanding the functioning of medical practice in lowered gravity. The extent to which medicine will be practiced needs to be delineated, from triage to recuperation.

The packaging concepts and delivery to the surface of the Moon demand closer examination. Simply creating a concept for experimentation and habitation will not evaluate the entire picture. Future launch and delivery systems must be examined in parallel when conceptualizing extraterrestrial habitats.

The list of future research topics is complex and extensive. Priorities need to be established, and the level of depth to which lunar concepts are examined will demand close interaction with the aerospace community. The UW-Milwaukee Space Architecture Design Group continues its involvement in designing concept designs and design development for various architectures for the Moon and Mars. We welcome evaluation and critique from traditional architectural professionals and members of the aerospace community.