THE DESIGN AND VISUALIZATION OF A SPACE BIOSPHERE

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"All Progress is based upon a universal desire on the part of every organism to live beyond its income." -- Samuel Butler 1835 - 1902

Abstract

Lewis One is a qualitative space biosphere design. It is intended to house 10,000 residents in a cylinder large enough for a 1g rotating habitat module and construction facilities to reproduce the module. The shielding, exterior, and construction bays are non-rotating. Lewis One is compared to the Bernal Sphere space colony designed in the 1970's. Lewis One is visualized using state of the art computer graphics hardware and software to produce a three dimensional, animated, lighted, shaded, texture mapped surface model. One may interactively 'fly' outside and inside the structure to examine features of interest. Interactively controlled planar cutaways at any location and/or orientation are available. Visualization provides insight into, and feedback on, the design to drive improvements and communicate design concepts.

Introduction

The focus of this paper is visualizing an orbital facility designed as a nice place to live where residents construct additional habitats and other large orbital structures; e.g., solar power satellites. Such biospheres must be shielded from radiation and portions must rotate to provide pseudo-gravity. Most early space settlement designs appeared in science fiction. A good survey of this work appears in NASA's *Space Settlements A Design Study*[1] pp. 4-5. The 1970's saw the introduction of several space biosphere designs including the Stanford Torus[1], the Sunflower[2], Island One[2] also known as the Bernal Sphere, and Island Three[2] - a cylindrical colony. These concepts each house large populations in a rotating environment, use reflected sunlight for lighting and shield most areas with a few meters of lunar soil or left over industrial slag.

A series of system studies exploring design parameters for large space settlements are found in the references[1,3,4]. Spheres, cylinders with spherical end caps, tori and various combinations were compared for mass properties and other basic features. M. L. Stuart[5] argued that cylindrical habitats provide a more even pseudo-gravity environment and are thus superior to spheres for raising children since parents are unlikely to risks having offspring with poorly formed bones and muscles.

More recently, a number of studies in the space manufacturing conferences over the years have focused on using shuttle external tanks for small work-camp-like facilities. There is a session on these concepts at this conference. These, however, are intended to be inexpensive approaches to getting started, not a place to make ones home.

There has been little published work on space settlement design in the last decade. Furthermore, existing designs have been rendered in words, equations, models, artist concepts, and two dimensional line drawings. Until Lewis One, there were no three dimensional, animated, interactive computer models or video tapes of orbital settlement designs.

Lewis One

It is a great pleasure to introduce Lewis One, a work-in-progress space biosphere design visualized with some of the best computer graphics hardware in the world and a prototype of the Flora scientific visualization software package developed by Jeff Hultquist, NASA Ames Research Center. Unfortunately, only static black and white pictures may be published in these proceedings. The presentation includes full color pictures and a video tape.

Requirements

Lewis One should provide a nice home in an earth-normal ‘gravity’ environment for up to 10,000 people and substantial micro-g facilities for visitors. Lewis One is required to reproduce itself -- albeit with help from its inhabitants. Full shielding is required for all areas frequented by the population except where this is impossible. Other requirements are taken from the references[1].

Design

Please examine the pictures at the end of this paper before reading this section.

The first picture is the exterior of Lewis One. Shielding, solar arrays, thermal radiators, glass viewing modules, and docking ports are shown. A second set of viewing and docking modules is on the other side of the colony. A NASA space shuttle orbiter is included for scale. Note that the solar arrays point towards the Sun and therefor shadow the radiators.

The second picture is the interior with the exterior removed. The micro-g portions of the interior have been cut open to reveal interior detail. Each of the construction bays is large enough to hold a grav-module.

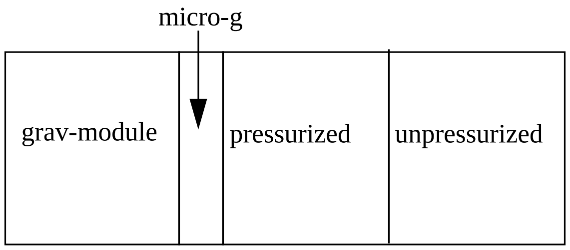
The third picture is a cut away of the micro-g module. The four sections are labels. Viewing and docking modules are included to show their relationship to the sections.

The last picture is the interior of the grav-module. Note the multiple layers for agriculture and the conical ramps from the interior most agriculture layer to the lowest g recreational area (including the swimming pool) and the interface to the transfer module that provides transportation to the micro-g module and construction bays.

The basic design is a 1921m long 267m radius cylinder with flat end caps completely shielded for cosmic rays. This cylinder is Sun synchronous. Thus solar collectors and thermal radiators need not move. Since the solar collectors completely shadow Lewis One, they can be backed by extra shielding to block solar storm radiation. The overall dimensions are driven by a rotating grav-module and a micro-g module for visitors, residents and industry. The grav-module is a 450m long 250m radius flat end cap cylinder rotating at 2 rpm to provide 1-g pseudo-gravity at the rim. The micro-g module is a 100m long cylinder of similar radius.

There are two shielded, micro-g construction bays, one pressurized, the other not. Each is large enough to work on complete grav-modules with 10m radial and 20m axial clearance. The pressurized construction area can be depressurized to move a grav-module under construction to the unpressurized bay for testing. The walls between bays and to the outside are detachable to accomplish the move. The unpressurized area may also be used for industrial processes that produce too much pollution for the biosphere.

Figure 1:



The reason for flat end caps is now clear. Since three grav-modules can fit inside the shielding, every meter the end cap deviates from a plane adds six meters of length to the shielding, and thus increases shielding mass. Flat end caps do require greater structural mass. However, shielding mass dominates the total mass of space biospheres[2].

Living quarters are on the inside of the grav-module rim, with approximately 65 sq m per resident. This non-agricultural space requirement is derived from the reference[1]. Agriculture is on six levels within the grav-module, starting at 1/6 g and working outward in 4m increments. This provides about as much agricultural land as living space per resident since g-level is proportional to the radius for constant angular velocity. 1/6 g is chosen for consistency with the lunar surface[6]. This area more than fills the agricultural space requirements from the reference[1]. If more area is needed, additional levels may be added without major design modifications. Low-g agriculture should be possible according to Soviet findings[7]. These data show very low g-levels, less than a hundredth of a g, eliciting gravitational response in plants. Elevators transfer passengers and freight between levels.

The rotating grav-module is in an unpressurized bay within the shielding. A vacuum avoids wind and drag caused by the relative motion of stationary shielding and the rotating grav-module. The grav-module is kept in place magnetically. Separate pressurized areas (rotating and despun) require an elaborate transfer mechanism between them. This is accomplished by a transfer module that attaches to the grav-module, fills with people and cargo, seals, detaches, spins down, attaches to the pressurized micro-g areas and then opens. The process is then reversed. This mechanism constitutes a single point of failure and adds considerable operational complexity. If the grav-module could be in a pressure vessel with the micro-g module and pressurized construction bay, a less complex transfer mechanism would suffice. A fluid dynamic analysis might determine if winds and momentum transfer generated by grav-module rotation in an atmosphere are acceptable. Such an analysis is planned.

There are extensive low-g and micro-g recreation facilities provided, including substantial space viewing facilities. Such recreation and viewing are cited by astronauts as the best part of orbital living and are an important part of Lewis One's appeal. Low-g recreation includes a variable-g ramp from the most interior agricultural level to a cylindrical low-g swimming as proposed by Heppenheimer[8].

While the construction bay is depressurized occasionally to move large structures out, the micro-g module is never exposed to a vacuum. Separate viewing and docking facilities for residents and visitors are accessed through this area. The module is divided into four sections: visitors, micro-g habitation, resident recreation, and industrial/research. The visitor section provides revenue from tourism. The micro-g habitation section is for individuals -- perhaps disabled-- who trade freedom from gravity for exile from Earth. Resident recreation could well be the site of some spectacular sporting events. The industrial/research section provides revenue and space for facilities to support construction.

All access ports between modules have a 20m radius, as do the docking modules. This provides a uniform maximum size for moving large items within the biosphere.

Interior lighting is entirely by electric lights powered by attached solar collectors and power satellites beaming power to the biosphere. Electric lighting eliminates the complex geometry and extensive windows of early designs employing direct lighting. Electric lighting does require greater solar collection area and possibly reduced aesthetics. However, with the agriculture areas at low-g levels in the grav-module -- which substantially reduces shielding requirements and overall dimensions -- direct solar lighting is probably impossible. The unshielded agriculture found in some early designs seems quite dangerous to the farmers.

Comparison with the Bernal Sphere

The Bernal Sphere space biosphere was designed by Dr.'s Snow and O'Neill in the 1970s. This design has a spherical, shielded habitat with unshielded banded tori (the Crystal Palace minimal mass geometry of O'Neill[4]) for agriculture. The Bernal Sphere uses sunlight through mirrors for illumination. A two dimensional drawing of the Bernal Sphere is included in the pictures at the end of this paper.

The Bernal Sphere has a smaller total mass than Lewis One for the same population and illumination is real sunlight, not electric lights. On the other hand, Lewis One has a much simpler more stable geometry, ample space for construction, shielding for all areas used by the population, less stringent pointing requirements, a mechanism for passing from rotating to despun pressurized areas, industrial areas outside of the biosphere for contaminating processes, more detailed recreation facilities, space viewing facilities, provisions for micro-g residence, and a more consistent g environment for living due to the cylindrical design.

Visualization

Lewis One is visualized as a set of surfaces for each module. A surface model of NASA's space shuttle orbiter[9] is used provide a sense of scale.

Most surfaces are created by lathing a series of line segments through space to create objects of rotation. The resulting polyhedra are given separate surface properties for front and back sides. Surface properties may be manipulated to create different effects and colors. Lights of various colors are placed within the model (such as an infinite light source from the direction of the Sun) to illuminate the surfaces. The properties of the lights (color, location, etc.) interact with surface properties to shade each polygon. The solar collectors, thermal radiators and portions of the interior are texture mapped with synthetic 2D images blended with surface shades. A aerial photograph of NASA Ames Research Center texture mapped onto the grav-module.

To see the interior of Lewis One, the visualization is clipped with one or two cutting planes. One is along the long axis of the cylinder to expose all sections of the interior. The other is parallel to the end caps to examine the grav- and micro-g modules in cross section.

Part of the justification for this work is to provide a demanding application to fully utilize the latest graphics capabilities of the new workstations procured by NASA's Numeric Aerodynamic Simulation (NAS) division and to push the drawing capabilities of Flora, a scientific visualization environment under development at the NAS Applied Research Branch. It would certainly have been simpler, and in some ways better, to use a traditional computer aided design package and commercial post-processing software. However, the latest workstation capabilities have not yet been integrated into such packages. Flora was flexible enough to incorporate them relatively quickly. Furthermore, Flora provides complete programmability -- at the cost of a great deal of programming!

The Flora visualization environment is written in a combination of C [10] and an object oriented extension of Scheme[11]. Scheme is a dialect of Lisp used primarily in the academic community. Object oriented programming was developed on the SmallTalk project at Xerox PARC[12]. C is used for those sub-routines requiring high performance. Scheme is used for complex or poorly understood portions of the code for its great flexibility and power. Since Scheme is interpreted, it provides an excellent command language for interactively exploring visualization issues - such as the best texture map for Lewis One's solar collectors.

The Lewis One visualization is implemented in Scheme using Flora's object classes. Each module is represented by a software object. These objects have methods to replace their surface properties, geometry, and/or miscellaneous properties. Thus, portions of the visualization may be updated separately and interactively. The size of the modules is calculated from a small set of parameters, grav-module radius, length and clearances, micro-g module length, shielding thickness, transfer radius etc.

Flora was modified by Hultquist and the author to provide a tree structured graphics capability similar to PHIGS[13] and AIDDE[14]. Each node in the tree may have geometry, child nodes, and attributes (color, material, transformation matrix, clip plane, lights, textures, etc.) that control the appearance of the geometry in the node and its children. Additional modifications provide a ‘flying’ capability to produce a video examining Lewis One.

The workstation used to visualize Lewis One is a Silicon Graphics Inc. (SGI), IRIS Power Series VGX 320 with two 33Mhz MIPS processors each with hardware floating point, 64 Mbytes main memory and several hundred megabytes of disk space. This machine has a great deal of special purpose graphics hardware to perform polygon rasterization, vertex transformations, texture mapping, lighting, shading, clipping etc. This workstation is networked to file servers and super-computers. The supercomputers were not used in this work.

Discussion

The Lewis One design is mostly qualitative. To visualize a space biosphere one needs a point design. All of the existing designs lacked facilities the author felt were essential but there was not sufficient time to complete a quantitative design. The design needs quantitative analysis and substantial refinement. The visualization, while promising and perhaps somewhat useful, is not sufficient to give one a strong feeling for life in an orbital habitat. Better surface properties and textures are needed, more attention to lighting, animation of key operations such as moving grav-modules under construction, human figures in the settlement and many other elements could be added to improve the visualization and increase its impact. An artist’s eye, as opposed to a programmer’s, could be of great value.

Conclusion

This visualization of the Lewis One space biosphere design may be useful in communicating the excitement of space settlement to the general public as well as a few new habitat design concepts to engineers and scientists. This work is very preliminary. A great deal of effort will be needed to produce highly polished visualizations.

Acknowledgments

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