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Space Architecture: Lunar Base Scenarios

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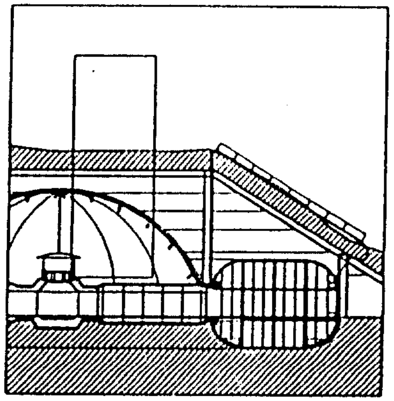

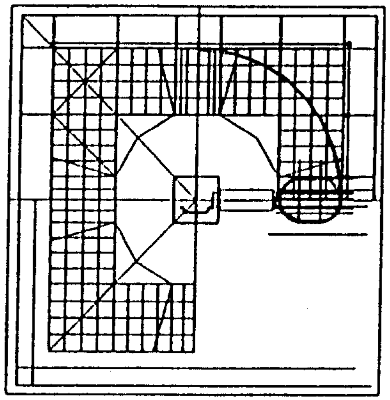

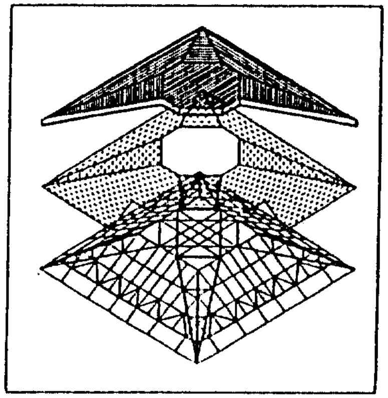

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January 1988

SPACE ARCHITECTURE: LUNAR BASE SCENARIOS

Edited by Edwin G. Cordes, Gary T. Moore and Stephen J. Frahm

A study of design alternatives for a lunar base settlement. The publication explores the lunar environment requirements, program development, goal identification and processes involved in the design solutions. The report is the result of a fall 1987 graduate design studio at the University of Wisconsin - Milwaukee, School of Architecture and Urban Planning. Graphic presentations involved the use of computer design techniques (CAD). Reproductions of each student's work is included. Highly illustrated.

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Preface and Acknowledgements

This report is based on the results of a 4-1/2 month graduate design studio in the School of Architecture and Urban Planning at the University of Wisconsin - Milwaukee. The studio was under the direction of Associate Professor Anthony J. Schnarsky, with the contributors to this report being the students. Other authors were visiting design critics Thomas M. Crabb and Mark K. Jacobs of Astronautics Corporation of America, Madison, Wisconsin (head office in Milwaukee, Wisconsin). Other design critics included Claudio Veliz of Claudio Veliz Architect, New York and Larry Bell of Bell and Trotti Inc. and the Sasakawa International Center for Space Architecture at the University of Houston, Houston, Texas.

All graphic material presented in this report was produced using AutoCAD version 2.62 computer design program on IBM PC\AT computer systems. Editing and typesetting utilized Ventura professional desktop publishing software run on an IBM PC\AT system.

The editors would like to thank all those who expressed an interest in our project. We would especially like to thank the individuals from Astronautics Corporation of America, Claudio Veliz, John Clark and Larry Bell for their thoughtful insights into this unique design problem. We would also like to thank Tim Lovett, Bob Greenstreet, Mark Roth and Chris Burns for their help in compiling this publication.

Finally, we would like to express our graditude to Dean Carl Patton for his continuing interest, support and encouragement throughout the semester.

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DESIGN SCENARIOS

FOREWORD:

DESIGNING IN A VACUUM

Anthony J. Schnarsky
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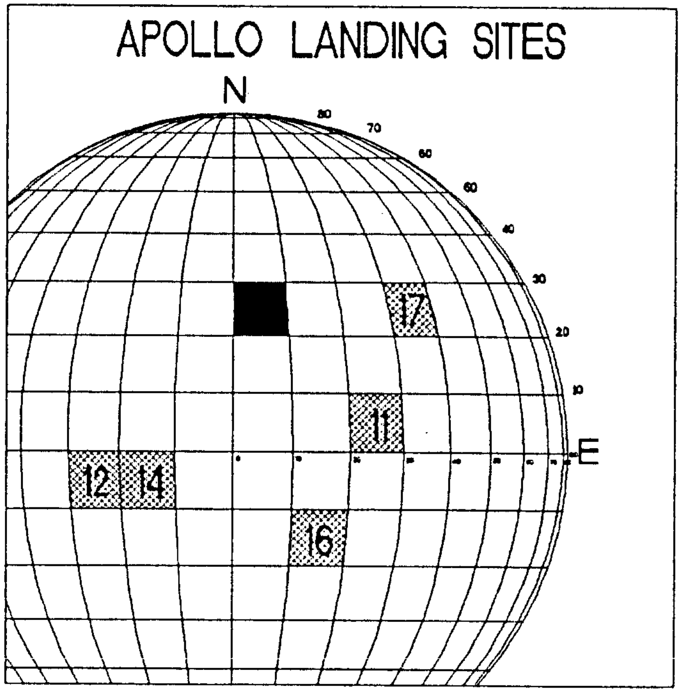
With great interest I attended a meeting hosted by the Dean of our School, Carl Patton, which introduced members of the faculty to an aero-space company, Astronautics Corporation of America, with corporate headquarters in our state. The managers and engineers that sat at the table with the academics had already put hardware into space, some of it even reaching the moon's surface. What could an architecture program add to the complex, highly technical methodology of building structures in the vastness of space?

At this first meeting, most of the attending faculty asked about human factors and environment-behavior topics of space. I soon realized there is a lot work to be done in this new environment. Vast amounts of data and literature already exist, but represent just a beginning for the enormous effort of inhabiting the moon's surface and the planets beyond. The managers described missions that would require structures for housing science, mining, and manufacturing for periods greater than one year and for groups up to 20 people on the lunar surface. According to the timetable - a seemingly remote 25 years from now, the first-phase landing parties will begin arriving on the lunar surface. As we sat there, no human had been in space quite as long as the proposed durations.

Finally, the discussion turned to computers and design. Engineers use computers. Architects view themselves as designers. Could this be an opening? At that point, I promised to run my very next computer studio with the topic being habitation on the lunar surface of the moon in the year 2025. It just shows how little I knew at the time.

That was in the spring of 1987. I began to kick myself daily for the remainder of the semester. What kind of students would be interested in space architecture? How many of them would meet the CAD prerequisite for the course? When I advertised the course referring to such literary giants as Ray Bradbury, Robert Heinlein, Isaac Asimov, Frederick Pohl, and Andre Norton, I wondered how many would recognize their books? I felt the big vacuum. Either today's students do not read science fiction, or worse, they want studios for corporate architecture only. Besides, earth has enough problems to challenge architects for years. What could I promise?

Luckily, a visitor named Larry Bell stopped by the school during the summer. He is a dedicated teacher at one of the strongest institutes for extra-terrestrial environments in the nation, the University of Houston. He had just arrived from a visit to Astronautics Corporation's Technology Center in Madison where they had told him of my foolish decision to offer a lunar studio.



Larry was a great source of knowledge and experience about the extraordinary design conditions of space architecture. He understood my ambivalence. After all, how many students will find work in this rarified kind of construction? He considered my uneasiness healthy. Larry enumerated the many indirect benefits emanating from space studies done by students and institutions of higher learning. We decided such a design problem is rich for future architects because of the following:

(1).It gives practice in working on huge projects involving many other disciplines.
(2).It gives practice in working with an enormous database including researched programmatic information.
(3).It gives experience with very technical construction and interior systems.

Larry pointed out the timeliness of getting involved with NASA's thinking during the lull following the Challenger accident. The main prediction he made was that the students would benefit most from the completely stark nature of the program and the relentless technical forces that bear upon space architecture. And, for a change, architects would not be considered the master builders. In fact, he predicted, we would experience a serious role reversal with our engineering colleagues. In short, we might feel that the aesthetic values of normal studio education, would be, for the most part, made irrelevant by the nature of the problem before us. The students would help plan and design the most technically understood objects on and off the earth, and they would come to know that they are not the lead discipline that they traditionally have assumed.

The reassurances helped me. The studio however, remained an idea. In fact, preregistration led to only one student. Thus the last hurdle remained -- the students needed to conduct the studio were missing; eight more were needed, to be exact.

Things worked out. Half the students in the class were from more than 120 degrees longitude from Wisconsin. And half were not CAD literate. But they were there opening the class. Men and women from Nigeria, Malaysia, France, Iowa, and Wisconsin. We all wondered what we would contribute. It was a very invigorating opening. And I must say that for the entire semester I'd never seen such design development and learning brought on by such a challenging condition.

Herein lies the major point of this foreword. Space architecture has such a strong and deterministic nature about it that one is constantly humbled by it as an individual. And properly understood, this has great virtue in developing general design skills appropriate to the studio format.

The second insight is that architects employ unique ways of approaching design problems -- ways not common in this engineering dominated realm. With due respect to my engineering colleagues, the architectural design process has important holistic value for the future of space environments.

I propose that there are three components in space design methodology:
(1) engineering and technology application
(2) science and physics,
(3) human/environmental planning.

I suggest that because of the nature of our times, each of these specialized components seem to have their own terms and methods for getting systems into place and assuring that the environment will function and that humans will survive and thrive. Architects are not regular participants in space, however, the lunar program statement now includes words that have been the domain of architects -- words such as habitation, master plan, construction sequence, modularity, and interiors. What I propose is that scientists use art, engineers design, and architects plan. For something as profound as the colonization of other planets, each field should combine their unique talents and abilities to arrive at the best solution possible. Later, in a section called "Lunar Base Studio Design Process," I will describe several distinct phases in this unique studio's life and will continue my argument for inclusion of the architect's approach to design in the total process of a lunar base development.

After months of struggling with the forces and issues in the studio process, one comes to places where no one has ever been before - design horizons where no one has time to think about the program, the forms, and the long amounts of time that future space personnel will experience. In our studio, this occurred in a remarkably short period of time with totally unprepared students and faculty. One of the reasons for this studio's success was the effective integration of computer-aided design (CAD); another is the balance of reading with design synthesis. Both are represented in later sections written by one of the students.

Despite the overwhelming number of pages of data and material available about space habitations and design requirements - to which we hope this report will make some small contribution -, we are all still on the edge of design that has little previous published precedence. We remain humbled by the vastness of the task of designing for space that lies before us.

LUNAR DESIGN INFORMATION

Edwin G. Cordes

In the development of a design program, the studio spent a period of time investigating the peculiarities of the lunar environment. The understanding of the problems and advantages afforded us by this foreign environment continued to evolve throughout the semester. Therefore, in order to completely understand the conceptual thinking behind the projects to be presented and their design evolutions, the reader must have a basic understanding of the lunar climatic conditions.

The studio approached the nuances of the site in a architectural manner. Engineering was used when it directly affected architectural expression. The students felt their role was to investigate overall design solutions rather than specific engineering problems. The information investigated by the students and presented below in a summary form may seem simplistic and generalized to someone familiar with the lunar environment, yet these engineering principles served as some of the most critical design forces for the projects.

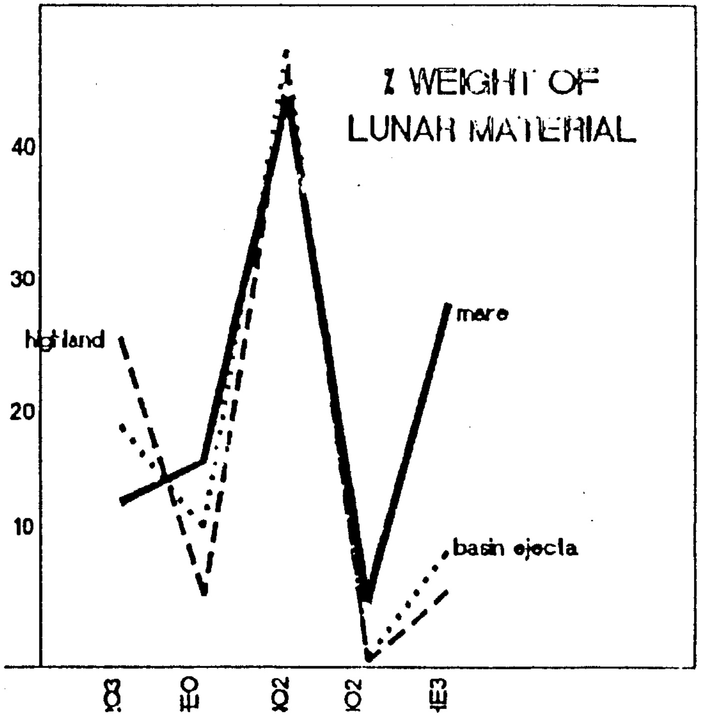
WHY?

The reasons for the eventual establishment of a lunar base are both varied and sometimes conflicting. In the most innate sense, we must go because it is there. The moon is the first stop in exploring and colonizing the space frontier. In more pragmatic reasoning, a lunar base would serve as an important nearby testing ground for technologies and methods needed for deeper solar system and hopefully galactic explorations.

The lunar base would also serve as a key ingredient in a near-space refueling station. The huge gravitational pull of the earth's atmosphere is one of the greatest limiting factors of present space exploration. By using the gravitational advantages of a low-lunar-orbiting space dock and lunar processed oxygen, the moon may provide the most economical solution to a space refueling port for missions exploring further reaches of the solar system.

While many believe that oxygen is the sole most important minable lunar resource, others feel that the lunar soil, or regolith, may hold other exploitable materials worth the investment. Examinations of lunar samples has shown they contain large amounts of potentially valuable metals. Concentrations of scarce or nonexistent earth substances like helium-3 which can serve as an energy source may also prove valuable for a resource depleted earth.

Finally, a lunar settlement will provide a key scientific outpost for further examination of deep space using large telescopes, the refinement of new substances and the study of plant and animal adaption and growth.



PRESSURE

The lack of any lunar atmosphere causes a number of interesting design problems. Besides the obvious issues involved in a closed architectural system like environmental control and the elimination of atmospheric leakage, larger issues such as pressure arise.

The design implications of an environment in which the lunar habitat exerts an outward pressure of over 2074 lbs\ft2 are quite strong. Pressures of this magnitude suggest habitats shaped to resist tension forces most economically. A perfect sphere is the most tension resisting shape. Therefore, designs which make use of tension resisting ideology would seem to be the most efficient and successful.

RADIATION

The lack of a lunar environment to act as a shielding device, presents additional problems for a successful design. Lunar bases must provide their own protection from intense solar radiation and occasional flares as well as harmful cosmic, gamma and X-rays. Without proper protection, the health of the base's inhabitants would be severely affected. Estimates show that protection equal to three meters of compacted lunar soil would be sufficient. The base should also provide protection from meteorite impacts. While not of the most vital of concerns, it is estimated that over 100 meteorites, weighing above 10 kg, strike the moon's surface each year.

TEMPERATURE

Without atmospheric regulation, lunar temperature fluctuations are great. The average daytime temperature is 134 C (270 F) and the average nighttime temperature reaches -170 C (-270 F). A more constant temperature range however, can be found just a few meters below the moon's surface where direct solar radiation does not have any effect. The severe temperature fluctuations necessitate designs which respond to thermal, insulating factors. One additional factor is that these daily temperature fluctuations occur over a period lasting 28 earth days.

The 14 earth day nights make it somewhat impractical to rely on solar radiation as a major energy source. The lack of an atmosphere also makes it difficult remove excess heat or cold from the closed base environment. Complex radiator and heat generating schemes will be needed to maintain the lunar colony at a temperature suitable for human habitation.

Related to the problems concerning temperature control, are those dealing with a closed life support system. Venting of toxic gases is very difficult. Maintaining a sanitory habitat as well as one that is properly supplied with life essentials such as food, water and air, is another difficult design problem.

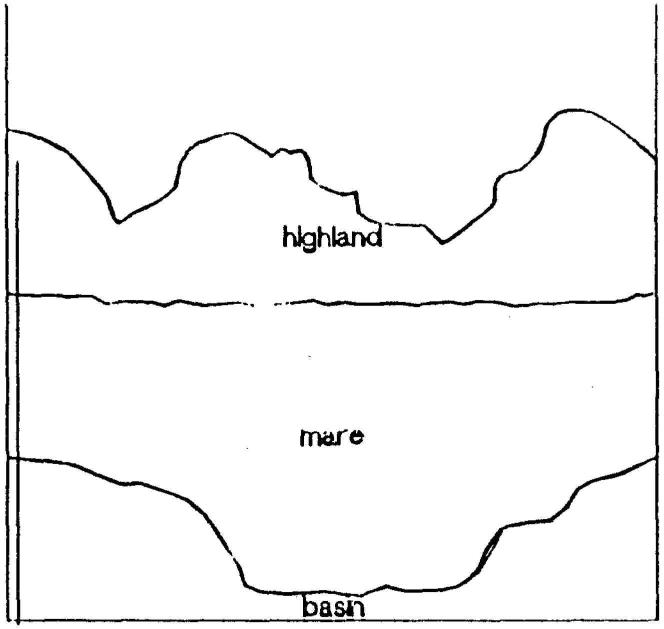
GRAVITY

The gravitational field of the moon is approximately 1/6 that of earth. The lessened gravity allows for a number of interesting architectural applications. Construction methods and materials that were unsatisfactory on earth may prove applicable on the moon. The design of interior systems may also change in response to the lower gravity. Since a human would weigh only 25-30 pounds on the moon, seating and work stations might also be redesigned. In an attempt to reduce the amount of materials sent to the moon from earth. Interior systems such as stairs and storage areas may be redesigned or eliminated.

REGOLITH

Regolith is generic term applied to all lunar surface soil types. The oxygen, metals and other elements found in the regolith will prove useful to a lunar colony. The regolith is similar to very fine grained sand and contains a large amount of silica. This substance can be used to produce lunar glass for such things as solar energy arrays. Regolith, in a compacted state would also serve as abundant radiation shield. The layer of regolith dust extends as much as 10 meters below the lunar surface.

The lunar landscape is further divided into three major categories, the mare, highlands and basin ejecta. The highlands represent the majority of the lunar terrain (83%) and are composed of the heavily cratered, hilly, rolling terrain with the common mineral feldspar being very abundant. The remaining 17% of the moon is composed of large basins up to 150 km across containing numerous smaller craters. The large plains in the basin areas are called mare regions. Mare comes from the Latin root for "oceans" and the oxygen and mineral rich regolith in these areas provide the most promising site for future lunar bases.



A SHORT HISTORY OF A LUNAR BASE DESIGN STUDIO

Anthony J. Schnarsky

The best way to describe the development of the Lunar Base Design Studio is a chronicle of visitors and the presentations we gave them. Without the support and pressures implicit in any of these visits, the studio would have failed.

ARTIST AS DESIGNER: INITIAL DESIGN EXPLORATION

John Clark, Jr., a gifted aero-space artist was our first visitor. His work and experience with military aircraft paintings inspired us in the first week of the project as we looked forward to rendering exotic structures on alien landscapes. He has published paintings of the solar system planets and planetoids. Most exciting, however, was his method of slicing aircraft structures at one foot increments and projecting these slices in perspective.

OUR FIRST SPACE ENGINEER: CONSTRAINTS AND DESIGN CHALLENGES

Our first weeks were spent in elementary literature search and reading. Class discussions primarily revolved around space publications. An early design pin-up was required, without a program and with little published research precedent. We were aware that a program was necessary, and we anticipated our first visit with our "client" representatives from Astronautics Corporation, both engineers.

Often architects, in school, do not understand engineers; they have many negative preconceptions. What a surprise when Mark Jacobs of Astronautics Corporation presented a highly graphic, informative, and compelling afternoon discussion of the complete spectrum of issues and scenarios for 25 years of development on the moon's surface. He was articulate and exacting.

Most of the students were now very troubled. What could they do to add to the kind of grasp of lunar base design that such professionals already have? Should they assume the historic role as an artist articulating NASA's ideas? Thanks to the input from Mark Jacobs and Tom Crabb of Astronautics, the students wanted to contribute more.

INTERSTITIAL TIME: EXPLORATION OF DESIGN ISSUES

After the first four weeks of the semester, the design critique and review process became stale. A gap developed between the massive amount of reading and research available for our study and my insistence upon applied designs without yet having a clear program. I pursued conceptual development, a difficult task in a vacuum. A few of the students staged a rebellion. They refused to pin-up their sketch designs! I conferred with them alone in the hallway.

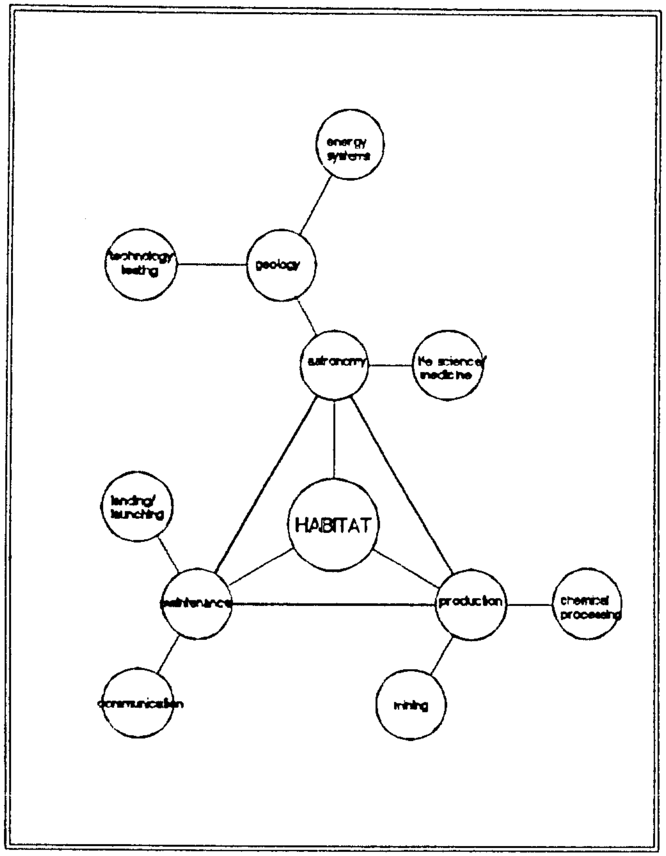
Slowly, however, certain issues began to emerge which would eventually form the basis for the studio design goals and program. Three of these issues were (see the following section on "Goals and Design Principles" for the others):

1.Cost-Efficient Least-Weight Design. Although we understood the need for cost efficient design, and therefore for least-weight design, due to the extreme expense of space ventures, application of this idea was not realized until late in the semester.

2. Radiation. Realization of the hazards due to radiation became apparent early in the process. The long-term astronaut will receive dangerously high levels of solar radiation without proper protection. Shelter from additional danger such as cosmic radiation and meteorites is also a concern. The design scenarios presented later were based on habitation durations of greater than one year. The studio refused, however, to accept the notion that their designs must be buried beneath the lunar soil.

3. Boredom and Confinement. Despite all the danger and glory associated with being an astronaut, analogous research shows that boredom encountered in closed environments can be life threatening (National Aeronautics and Space Ad-

ministration, n.d.). Submarines, polar continent exploration, and science missions have indicated the rigors of confinement and cramped quarters.



Schematic "bubble" diagram for a base design

ARE WE DESIGNING YET?

Ready or not, our first major design presentation approached. We presented to a group of four engineers and human factors experts from Astronautics Corporation. Included was Thomas Crabb, the Manager of the Space Station Section of Astronautics Technology Center, the person in charge of the company's lunar base investigations.

In preparation for this presentation, the students began to express some key design concepts. Included were biological analogies such as a sea creature carrying its own shell, and more pragmatic thinking like the utilization of the lunar site conditions and materials to reduce the dependency on earth-manufactured modules. Such thinking was well received by the Astronautics staff. The students awareness and understanding of radiation dangers had also become stronger. While many of the instincts against burying a lunar base persisted, most schemes addressed the issue of site utilization in an effort to avoid direct solar radiation. Sites were chosen along craters and rock up-lifts for their shading abilities. Vertical integration concepts were also developed. Many schemes programmed space to allow activities where the most time would be spent residing in the lower portions of the base, with shorter duration activities occurring closer to the surface.

The students remained rather insecure about their work, nevertheless. Presentation to experts in the field was quite intimidating. The work did include good speculative thinking, however, and many of the students with CAD deficiencies were beginning to come up to speed.

The presentation to the Astronautics team was labeled a success. The student's rehearsed presentations were both relaxed and clear. Most of the students worked in teams and shared concepts and CAD elements. Discussion following the presentations explored further issues and new strategies were devised. The visit to the Astronautics Corporation office in Madison resulted in many new ideas and directions.

STAGE TWO: THE ARCHITECTURE OF SPACE INTERIORS

During the weeks prior to the second major design presentation, the studio was visited by an alumnus of the UWM School of Architecture and Urban Planning, Claudio Veliz, a practicing architect in New York City whose interests lie in the interiors of space and Manhattan habitats. His knowledge has been gained from work with NASA's Ames Research Center. He spent an afternoon sensitizing the students to the myriad of needs that a lunar base must supply the inhabitants. The studio, which to this point had been concerned only with external issues such as construction sequences, phasing, and radiation protection, was exposed to the an enormous list of very human and utterly critical requirements, and to the importance of well designed interiors. The added new stress of interior considerations again overwhelmed the studio.

This experience created the realization that no one student could possess the knowledge necessary to design a perfectly "correct" lunar base. Team effort became more important with the time constraints and the realization that perhaps the task was somewhat beyond what a four- to five-month studio could accomplish.

THE SECOND PRESENTATION: CRITICAL ANALYSIS

Another distinguished critic was invited to review the students work. Larry Bell, Director of the Sasakawa International Center for Space Architecture as well as the Center for Experimental Architecture at the University of Houston was known to the students through his publications in the field (see, for example, Bell, 1987, n.d.). By this point, each student had achieved a much clearer understanding of space architecture, yet Larry Bell represented an academic position. The students were unsure of the responses to the previous months' work, and the fear of a juried response loomed.

A full day was devoted to Larry Bell's visit and critique. The morning was used as an open presentation of his work and programs at the University of Houston focused around two lectures and a research seminar. In the afternoon, each student gave a 15 minute presentation consisting of color slides and/or large plots. The second presentation showed excellent process even though many problems were still not fully understood. The resulting discussions were quite pointed, controversial, and stimulating. The students had received the first severe analysis of their work and again new directions were established. Perhaps Larry Bell should have visited the class earlier in the semester; perhaps it is better that he came when he did.

The events that transpired that day provided an excellent process for engaging in ideas. I spoke individually to most students after the critique and found little resentment about what happened. In every case, it was clear that we were beginners with little knowledge of the tremendous sets of deterministic forces. And in every case, students developed valid ideas that were conceptual counterpoints to the rigors of the many severe forces.

FINAL PRESENTATIONS: REALIZATION OF DESIGN PRINCIPLES

Slightly more than a month remained in the semester. Armed with a better comprehension of the goals, the program, and the emerging design principles, the students began their final push. The engineers from Astronautics returned the following week to help the studio integrate the new issues and concerns. The usual lull after a big presentation did not occur.

The students realized that much of their former work was "incorrect," but each student had mastered CAD in some form. The students willingly abandoned former module designs based on terrestrial thinking. Realization that rectangular vessels containing one atmosphere of pressure (2074 psf) would "cost" significantly more in weight than "aluminum balloon" structures was a major step. Design also included a mature awareness of the inconsistencies of radiation. Soil shielding became the accepted norm. Interior spaces became double-functioning, even multifunctional, and therefore economical. Efficient construction sequences took on new importance; lunar construction is dangerous, one slip, cut or puncture could be fatal.

The last month was exhilarating. When students were polled about a current profound professional question like "can an architect really design using CAD?," they quickly excused themselves to get back to their design - on a computer.

Several large issues were clarified during this final phase, including lunar construction sequences, cross-over points where lunar materials are utilized in combination with earth-shipped materials, and adaptive, highly programmed interior spaces.

The final presentation utilized a direct computer presentation system. Each student presented the viewers with a highly orchestrated script explaining the design scenario. The presentations were designed to bring the viewer from earth into the realm of the lunar habitat. Each student presented approximately a 20 minute show that was well received by the jury. Unable to end with a wrap-up discussion, the studio decided to meet for the last time to celebrate the project's completion. Buried beneath a recent Wisconsin snowstorm, 1/2 meter compacted, we spooned ice cream and thanked each other for the wonderful help each gave.

ARCHITECT'S DESIGN PROCESS IN SPACE

Architects are funny people. They romantically recall themselves master builders. They hire engineers to make their designs work. In space ventures, they are known as general problem solvers and are valued for their organizational abilities. In the foreword, I referred to certain unique abilities that architects manifest. They practice a process which includes pragmatic thinking, technical know-how, and artistic expression. Architects, for better or worse, represent a culture's meaning. The role to date of architects in the space program has been minimal. The space program has been a highly technical, highly engineered, highly scientific endeavor (e.g., Seamans, 1987). Artists have been employed to feed the public's imagination and to raise iconic flags for the next round of governmental appropriations (e.g., Kilgore, 1987).

I suggest that architects be included in space development. The work of 10 international students, each striving to become an architect, indicates a vital combination of process that is unique to our field. Architects rationalize graphically. Architects using computers think graphically using the most sophisticated information technology available. While our studio lacked a full database and limited research activities, in 15 weeks the young architects probed and simulated environments that will not be realized for at least 25 more years. Their first designs were naive, their second presentations conceptually stimulating, but still not technically possible, but their final work begins to arrive at issues and approaches never before considered.

There is an important movement in architecture to measure the success of the designer in not only understanding the problem but also in programming the facility and evaluating how people behave and use the building after the architect and contractor have completed the process (see, for example, some of the latest work on programming and post-occupancy evaluation in Zube & Moore, in press). This method could prove very fruitful for space based design. The studio method is an evolutionary process. Architects synthesize and speculate with drawings. CAD allows architects to draw a space frame or a space movie. The architect's purpose is to think critically about how people live and function in an environment. Those who make decisions regarding space policy and design owe it to those who will ultimately inhabit their creations to include architects in the design process.

GOALS AND DESIGN PRINCIPLES

Edwin G. Cordes

In the development of the design program for lunar base habitats, the studio generated a comprehensive list of pertinent design criteria. This list, developed with input from Astronautics Corporation and other consultants, formed the basis for the studio's design scenarios. The 32 design solution characteristics that were developed were further grouped into five basic areas of concern. These five areas will be discussed in more detail. The studio decided that the success of each individual's or group's design would be based upon its adherence to these design criteria and the further exploration of an area or areas of particular interest to the designer.

As a result of the design enterprise, four major design principles emerged, together with a number of other design ideas. These four design principles will also be discussed below.

SAFETY

Of utmost importance to the survivability of a lunar colony is safety, necessitating an emphasis on safety throughout all aspects of design. Safety consciousness can range from the design of "soft" furnishings and equipment to avoid possible bodily injury, to base-wide concerns like power and environmental supply redundancy, fire and contamination protection systems, and "safe havens" or contained environmental systems for sustaining life in emergencies.

HUMAN FACTORS/ENVIRONMENT-BEHAVIOR DESIGN

The psychological and physiological well being of the inhabitants of a colony in a habitat as foreign as the moon was one of the primary goals of the design investigation. The severity of the lunar environment necessitates a closed base design with limited exposure to the surface. These restraints can result in a number of psychological problems including boredom, wayfinding difficulty, and the feeling of isolation (National Aeronautics and Space Administration, n.d.).

Economic and resource constraints dictate spaces which serve multiple functions. Multi-use programming could result in some loss of privacy and socialization, increasing tension among workers, and causing other secondary and tertiary problems, including loss of productivity. Maintaining a highly productive and interactive team is one of the most important concerns in both a safety and economic sense.

The maintenance of the health of the astronauts is also of vital concern. The moon's 1/6 earth gravity will, over time, weaken muscle tissue and bone structure. To combat the possible loss of strength, a vigorous exercise program is needed. Successful design solutions should allow space for exercise equipment and rigorous human workouts.

Finally, the design of spaces for basic health care must also be considered. The ability to perform emergency first aid, dental hygiene, and health maintenance will be required.

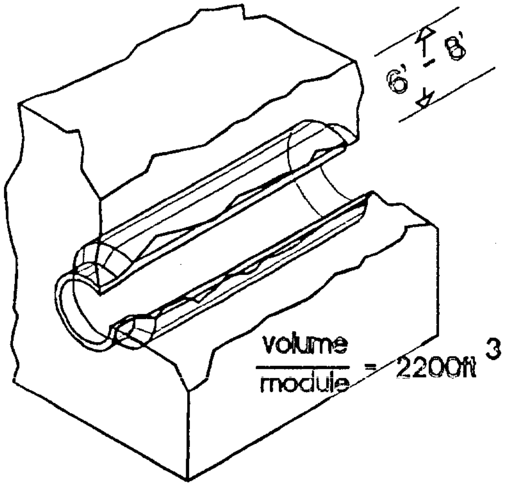
BASE PLANNING

The program developed for the design scenarios called for between four and six phases of construction taking up to 20 years to be completed. During this time, the base's primary role would evolve from simply a "safe haven" to an exploratory base camp, a scientific research center, and finally a lunar materials processing center. Base design and planning should address the evolving nature of the structure in allowing spaces to adapt easily to new functions. Early phase structures must integrate well with later phase construction to make the base economically feasable and safe. This will require long range planning and visionary designs early in the base's evolution.

ENVIRONMENTALLY RESPONSIVE DESIGN

The extreme conditions of the lunar surface necessitate the development of a number of different environmental strategies. One of the most serious problems facing a lunar colony is protection from radiation. The lack of an atmospheric protective shield necessitates more complex radiation protection designs, including those which utilize the lunar surface's natural resources.

Another significant problem is the maintenance of a closed living environment. Designs must eliminate virtually all atmospheric leakage while still maintaining effective ventilation and filtering, sanitary upkeep and a constant supply of vital resources. Thermal control also poses a unique problem. Both heat retention and elimination in an environment lacking any atmosphere and having daily temperature swings from 134C (270 F) to -170 C (-270 F) require careful design consideration.



Economic, modular design strategy

DESIGN ECONOMY

The extreme cost and risk of delivering payloads to the moon's surface necessitates the exploration of economically feasible construction methods and materials. Design strategies developed in this study included tension structures, inflatable membranes, pressure vessel units, and the use of the lunar regolith for shielding and construction.

Also inherent in the development of economic design strategies was the investigation of labor efficient construction sequences and unit designs. Design strategies included the study of symmetrical units, repetition, and multiple building blocks. The use of robotic construction machinery, even in prehabitation phases, figured prominently in many of the solutions. It was the opinion that these machines could complete difficult, dangerous or mundane tasks without endangering the astronauts lives.

Details on these design principles and a number of other design criteria are given in the accompanying matrix. The circles represent those design principles and criteria that figured importantly in each of the student design scenarios.

TABLE OF SOLUTION CHARACTERISTICS BY DESIGNER

types of concepts

	● Ahmad Hamzah	● Ed Cordes	● Hairuddin Munip	● Michael Bahr	● Nnamdi Elleh	● Norshamsiah Abdhamid	● Steve Frahm	● Tim Luettgen
BIOLOGICAL ANALOGY					O			O
LUNAR (LAND) SCAPE UTILIZATION			O	O			O	
HIGH EARLY CROSS OVER TECHNOLOGY	O	O		O		O	O	
THE MOST EXPENSIVE CAMPING TRIP IN THE WORLD		O		O			O	

particular response to deterministic force system

	● Ahmad Hamzah	● Ed Cordes	● Hairuddin Munip	● Michael Bahr	● Nnamdi Elleh	● Norshamsiah Abdhamid	● Steve Frahm	● Tim Luettgen
RADIATION	O	O	O	O	O	O	O	O
LEAST WEIGHT DESIGN	O	O		O		O	O	O
VISUAL ACCESS TO LUNAR SURFACE			O	O	O		O	O
ADAPTABLE STRUCTURE	O					O		O
MODULAR CONSTRUCTION	O	O	O	O		O	O	
PACKAGING FOR TRANSPORT FROM EARTH		O		O			O	O
ROBOTIC CONSTRUCTION	O	O		O			O	
ACCESS AND REPLACEABILITY	O					O	O	
CONSTRUCTION SEQUENCE		O		O			O	O
INTERIOR SYSTEMS			O	O	O	O		O
INTERIOR DURATION STRESS (BOREDOM)				O	O	O		
SAFETY AND REDUNDANCY		O	O			O	O	
CIRCULATION LOGIC	O		O			O		
VERTICAL GRADIATION OF ACTIVITIES			O	O	O	O	O	
UTILIZATION OF EARLY EARTH BUILT MODULES AS BACK-UPS	O	O	O	O	O	O	O	
EARLIER STRUCTURES BECOME PART OF CROSS-OVER HYBRID		O	O	O	O	O	O	

kinds of construction strategies used

	● Ahmad Hamzah	● Ed Cordes	● Hairuddin Munip	● Michael Bahr	● Nnamdi Elleh	● Norshamsiah Abdhamid	● Steve Frahm	● Tim Luettgen
ALUMINUM BALOON	O	O	O	O	O	O	O	O
CABLE STRUCTURE			O					O
NET STRUCTURE			O					O
LUNAR CONCRETE	O			O	O			
SPACE FRAME	O	O	O			O	O	
ISOLATION OF REGOLITH STRUCTURE FROM ATOMOSPHERIC	O	O	O	O			O	
BAGGED REGOLITH PROTECTION							O	
MELTED REGOLITH GLASS PROTECTION				O				
LUNAR MATERIALS IN COMPRESSION		O		O	O			
BERM CONSTRUCTION	O			O		O	O	O
FLAT MARE CONSTRUCTION	O	O	O	O		O	O	
HARD ROCK OR CRATER CONSTRUCTION					O			O
HABITATION THAT CAN MOVE TO ANOTHER SITE	O				O			

THE UNIQUE CONTRIBUTION OF CAD TO DESIGN

Anthony J. Schnarsky

In architectural circles, there is a strenuous debate about the impact of CAD on the profession. The big question is "can one design using CAD?" Most architects think no. At best for them, CAD means computer-aided drafting.

One of the educational components of the Lunar Base Studio was to dispel this common thinking, or at least to give the students an intense experience with the tool for them to reach their own conclusions.

Not ignoring that the accurate expansion of the acronym CAD is computer-aided design, one must be very careful to define design. The designer is the person. The CAD system is the graphic processor that allows sets of physical information to be stored, edited, and combined. CAD does nothing more.

For the lunar base, there are particular CAD capabilities that are important:

1. High resolution precision is possible.
2. Information can readily be layered.
3. Modular coordination is facilitated.
4. Three-dimensional studies are possible.
5. Information can be shared by teams.
6. Color aids presentation.
7. Scale can be communicated readily.

8. Zoom allows working at a wide range of scales.

9. Every entity has a numeric database.

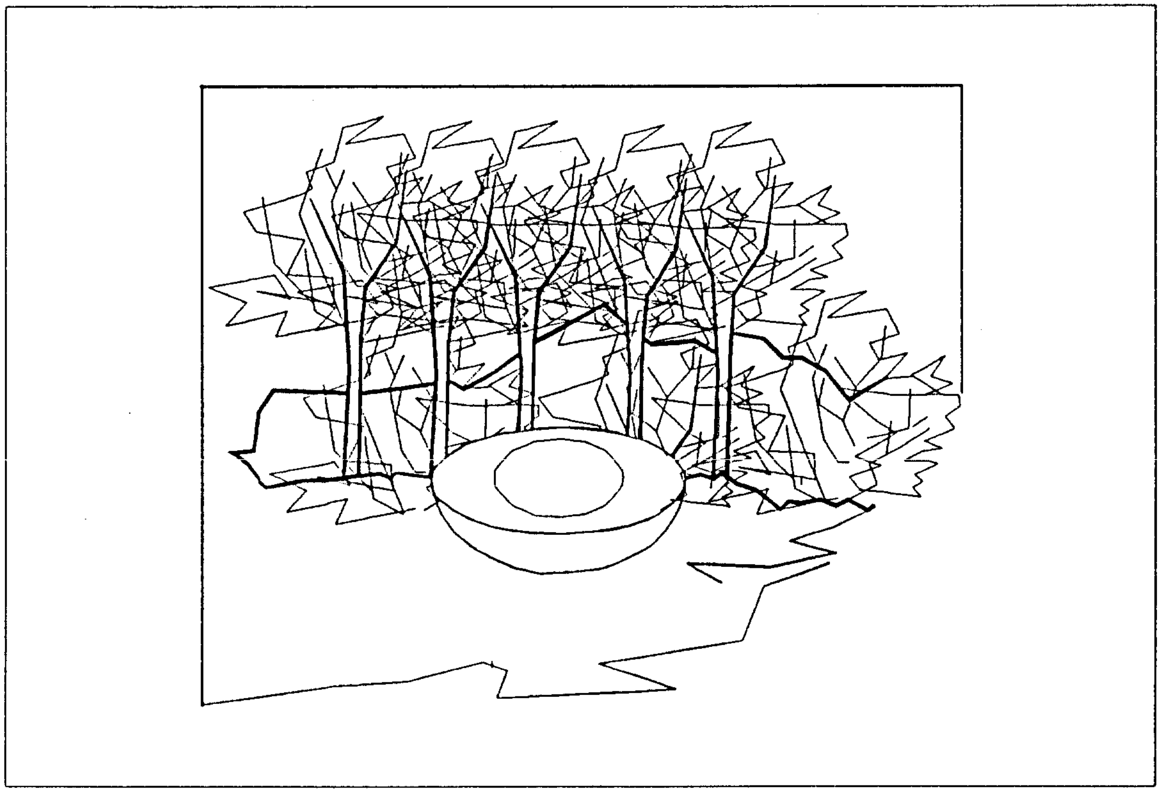
As you look at the graphic presentations in the design scenario section, you might wonder if there is any difference between the CAD process and hand-drawn design processes. Realize that each graphic image is a separate nameable file that has other sub-sets nested within it, and that all of these have been merged into a homogeneous master file complete with narration. While each student, in private and in small social groups, grumbled about the rigor and lack of speed of the CAD systems and procedure, the cumulative effect is quite different than most traditional architectural design scenarios.

Two qualities are apparent. One, the scenarios developed as a result of cooperative attitudes rather than competitive, and this is very appropriate for such a large project. Two, during the final month of the studio, the students became quite unaware of the fact that they were radically redesigning solely on CAD. This is facilitated because of CAD technology and is fundamental in any description of the design process. Good design requires redesign and convergence on what becomes a final design. Compared to any hand-drawn studio process, the volume of work and these essential qualities could not be achieved in any other way.

Any person in the area of the development of space knows that the computer is integral to existence off our planet. The unique series of lunar base designs that follows begins to suggest the same properties.

LUNARHOME

Nor Shamsiah Abd.Hamid

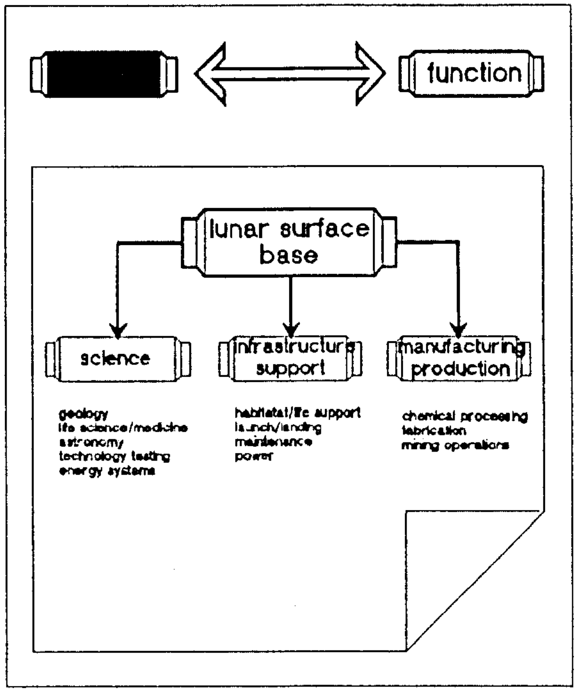


Of primary concern in this design scenario was the creation of a habitable human environment. In order to develop a sensitivity in the design to human factors a conceptual analogy to biological growth was employed. Like a seed, the hard outer shell of the base would provide protection from the environment. Like a seed, the base could also grow or multiply while still remaining self-sufficient.

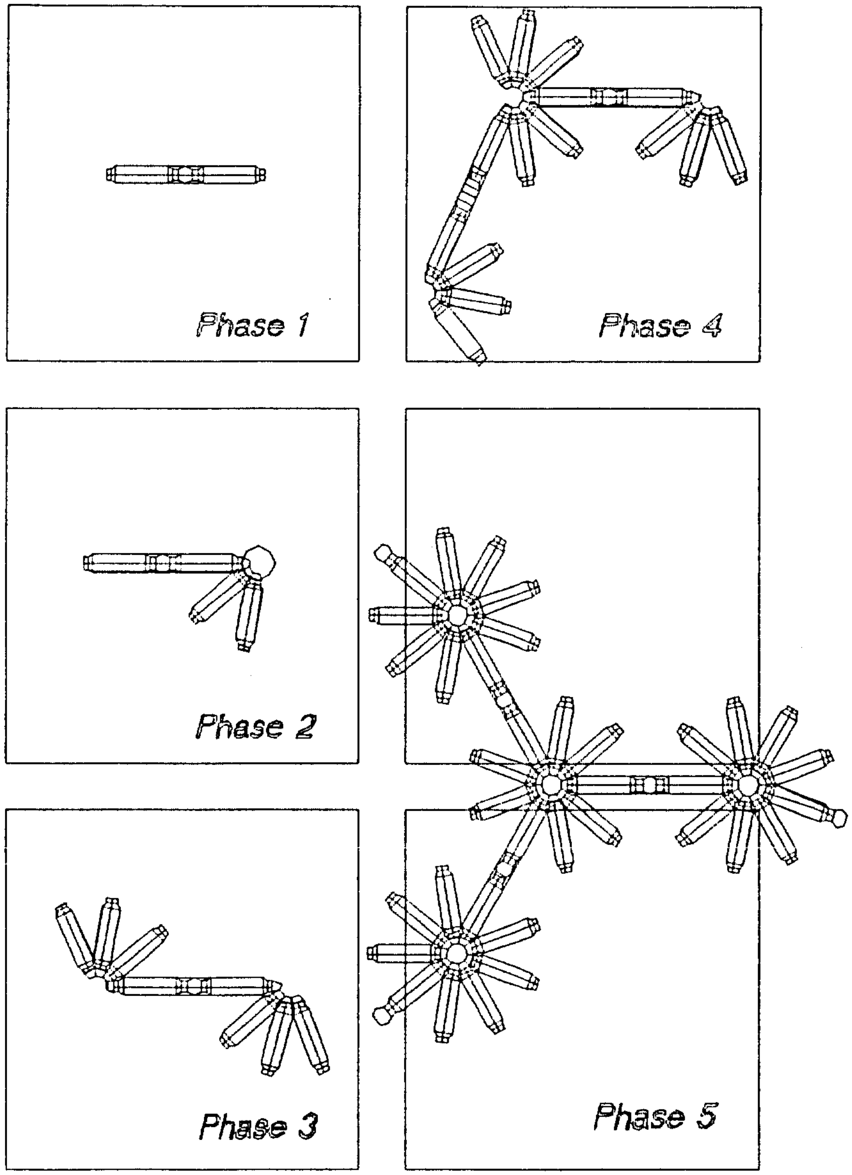
The pressurized enclosures would be protected from the environment by their placement six meters beneath the lunar surface. Limited surface contact would be achieved through the use of ingress and egress modules as well as vertical observation modules. The observation modules would allow the inhabitants limited opportunities for sight contact with the lunar surface and earth while remaining in a pressurized environment.

Prefabricated, modular interior systems of light weight materials, like fabric, would define various areas. All environmental controls and utilities would be supplied by a detached plant. Base sections would also contain emergency back-up systems. The use of elementary geometric shapes throughout the interior would allow familiarity and easier adaption to the surroundings by the astronauts. Other factors of consideration in the design were the use of colors, variation in room volumes and human interface with systems and equipment. Again, the primary concern was with the environmental needs of the inhabitants.

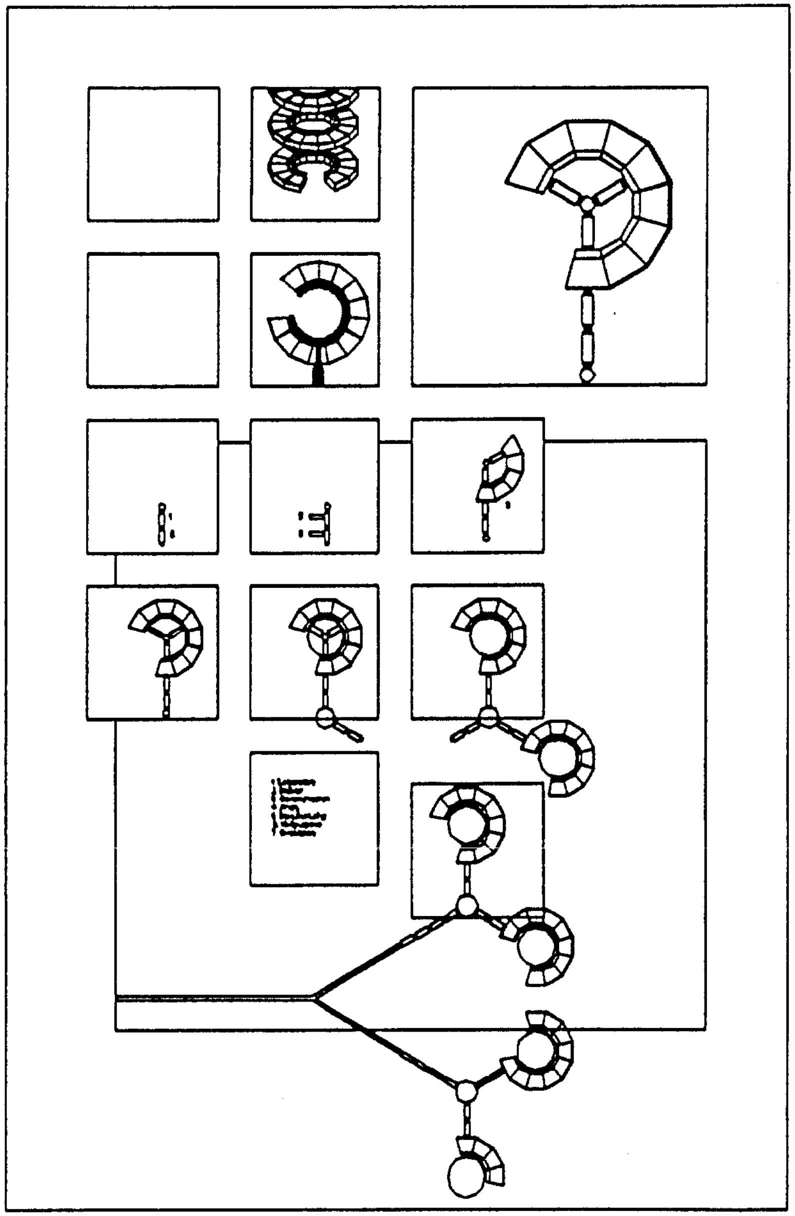
The first phase habitation modules would be earth constructed using aluminum balloon technology. Later phases would utilize lunar resources in the construction of tensioned concrete domes. These large lunar material domes would be initially supported with inflatable form-giving membranes. These membranes would then serve as hermetic seals under the porus lunar concrete. The larger interior spaces would also serve varying purposes, including processing plants, non-pressurized storage areas and recreation centers.



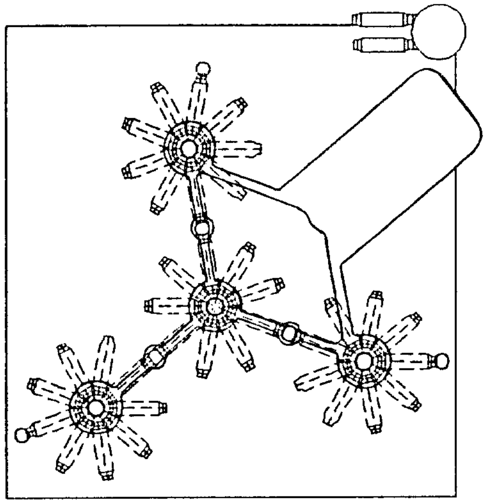
Lunar base functions and facilities integration.



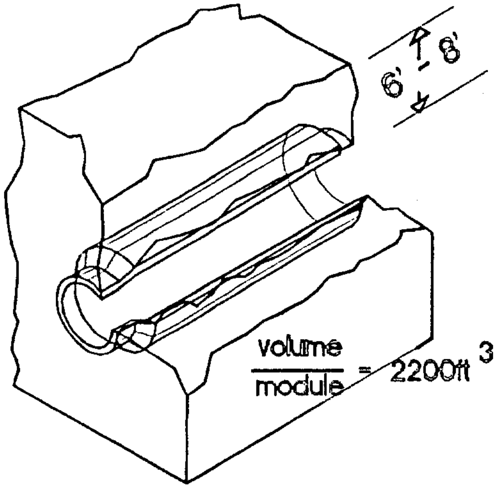
Final base growth/phasing scheme



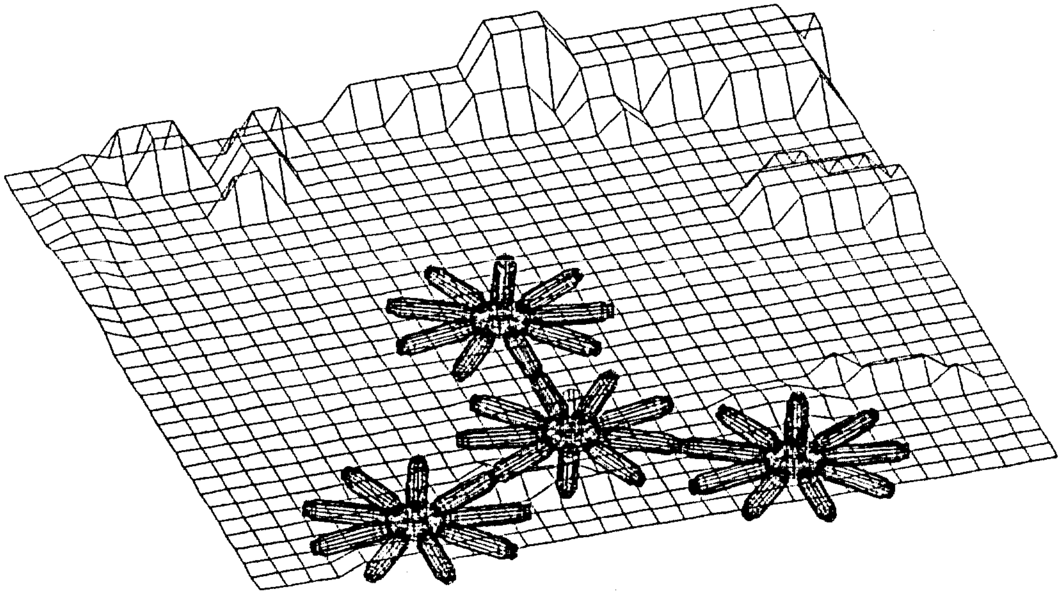
Preliminary base phasing scheme



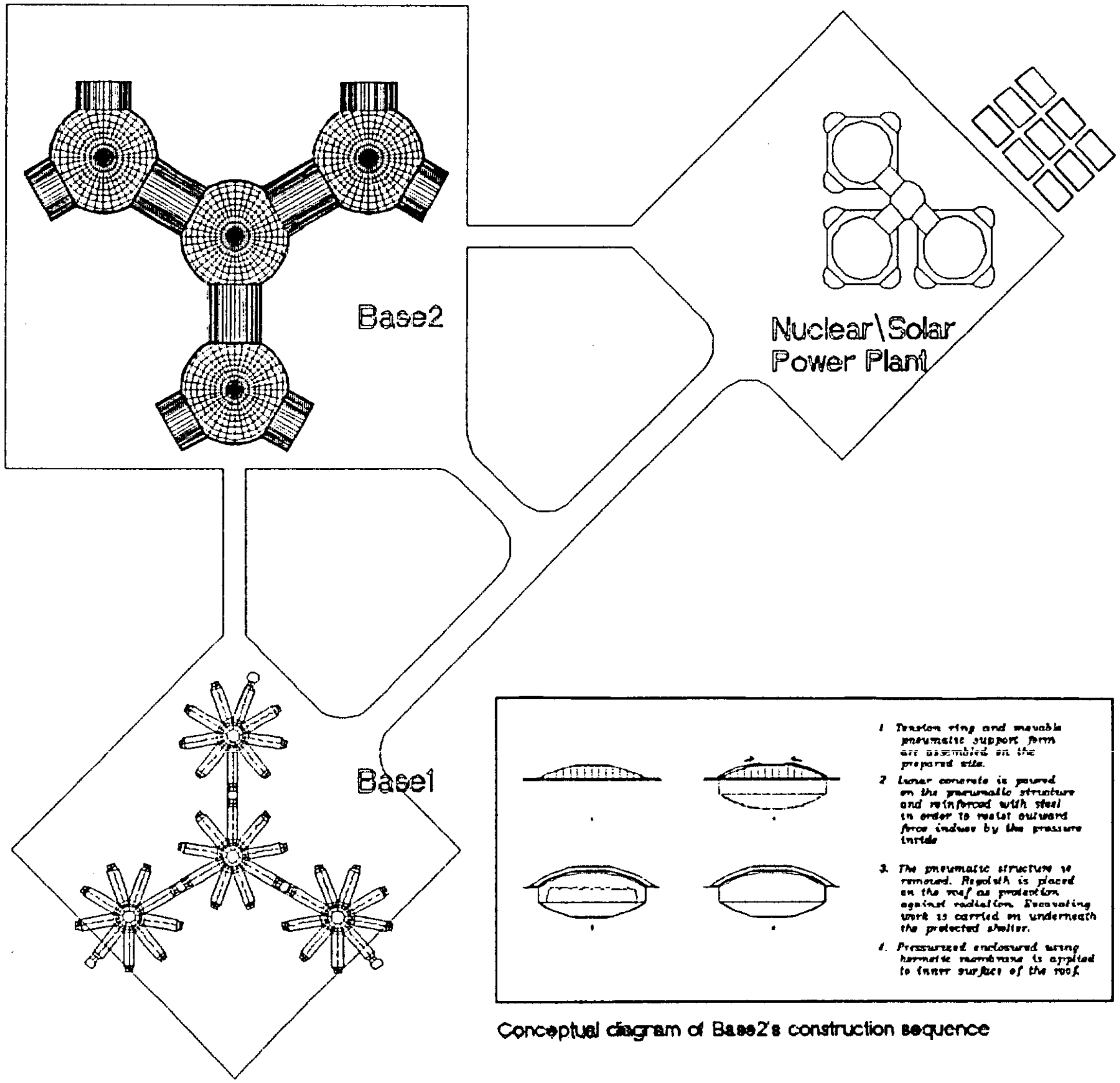
Site showing placement of cross-over point concrete dome structure.



Prototypical module volume



Site Isometric showing vertical modules



1 Tension ring and movable pneumatic support form are assembled on the prepared site.

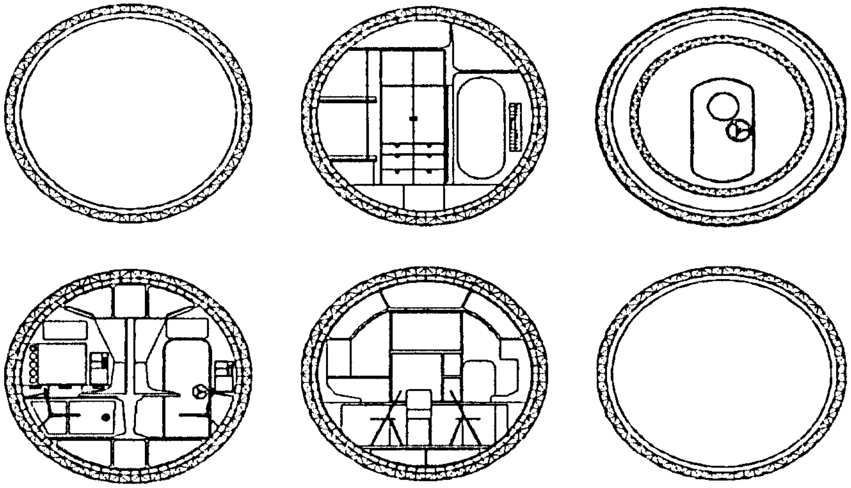
2 Lunar concrete is poured on the pneumatic structure and reinforced with steel in order to resist outward force induce by the pressure inside

3. The pneumatic structure is removed. Regolith is placed on the roof as protection against radiation. Excavating work is carried on underneath the protected shelter.

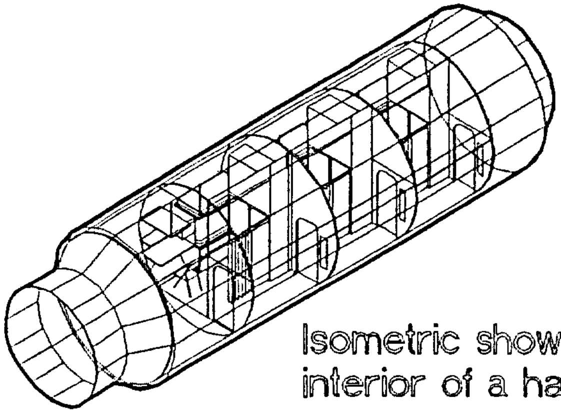
4. Pressurized enclosured using hermetic membrane is applied to inner surface of the roof.

Conceptual diagram of Base2's construction sequence

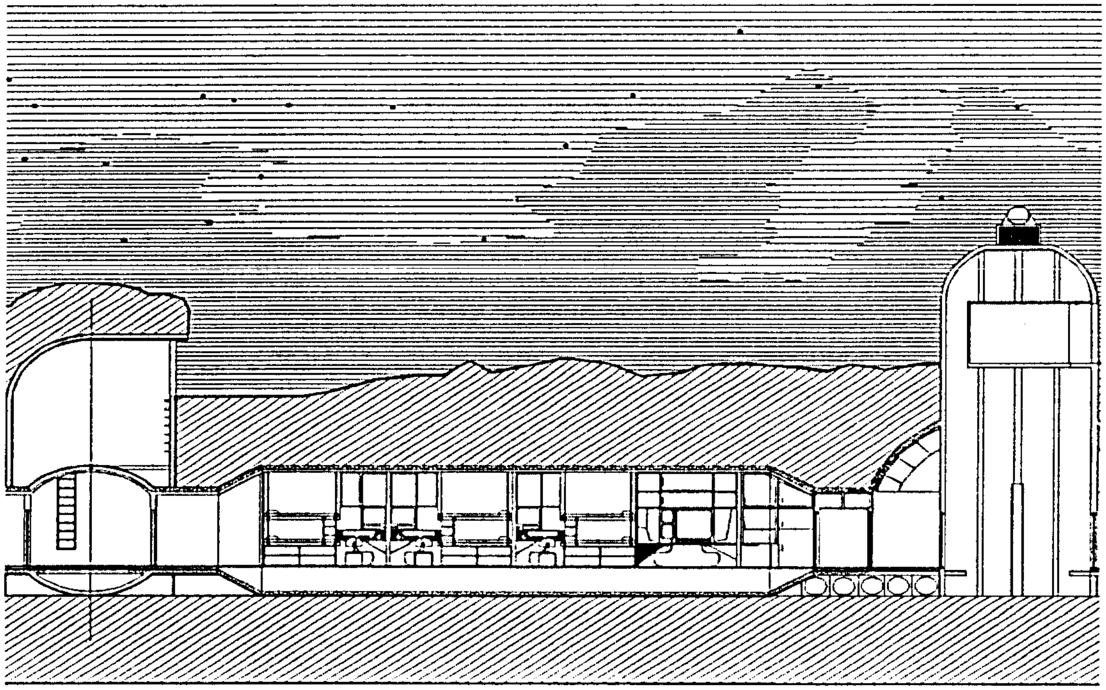
Base master plan



Module sections

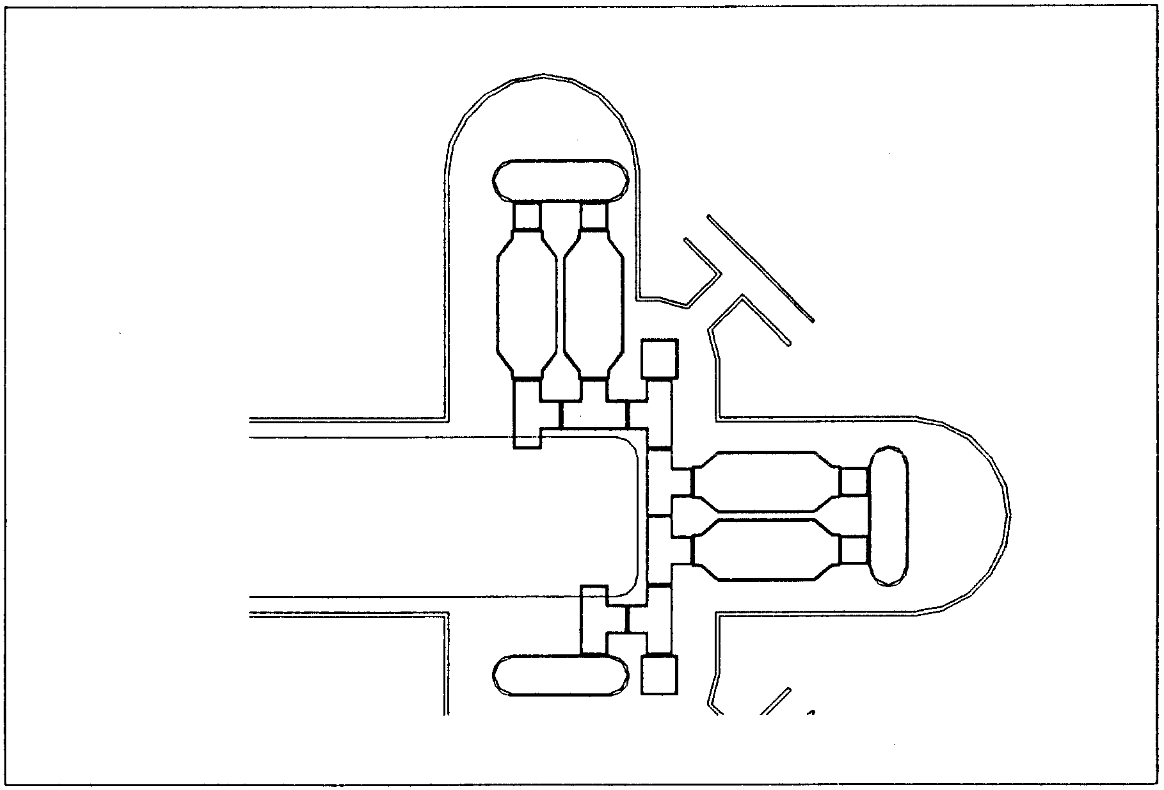


Isometric showing the interior of a habitat module



LUNAR TRANSFORMATION

Michael E. Bahr



An attempt to make as much use as possible of the lunar materials was the most important goal of this scenario. Limiting the amount of direct human involvement with the base construction was also an important issue in this solution. By utilizing robotics and abundant natural materials it is hoped that "cross-over" construction could occur within the first phase of the base's growth. A large economic savings would be realized by requiring only minimal earth payloads to reach a functioning level for the base. The use of robotic machinery would also greatly lessen the human risk factors.

As in many of the schemes, the radiation protection shield would function as its own entity. Derived from the lunar regolith and sintered (to weld with intense heat) into lunar glass blocks, the protective shield would be analogous to an igloo. As the blocks of molten regolith are created, the would be mechanically stacked to form the domed habitation areas.

The initial phases of development would rely on pressurized earth manufactured modules that would be inserted under the radiation protection shell. First phase development would include living/laboratory modules, airlocks, a power plant and a separate safe haven. The cylindrical first phase modules would include an articulated anchoring system to allow for various site conditions. They would also be easily removable for later expansion.

After a site has been prepared, robotic machinery would lay the regolith blocks, following steel frame guides in a cross pattern. Base equipment would then be inserted through one of the open ends. As more space is needed, long pneumatic structures would be inserted in other areas of the cross patterned shelter. The sintered block shelter would serve only as a radiation shield and because of its porus nature not a pressurized environment in itself.

Important qualities of this design scenario include the ability to create comparatively large pressurized spaces for uninhibited base growth. The mechanized construction sequence also lessens human risk and is very economical. Reaching a lunar resource cross over point early on would allow much quicker base growth.

Conceptual Analogy

When the Eskimos needed to shelter themselves from a harsh environment they built igloos with blocks formed from snow and ice found on the site. A small block, which is easy to handle, was used to build structures of a larger scale. All that was necessary to bring to the site was a small tool.
The lunar base can draw from the same technique.
A Robotic Construction Device can be sent to the moon before any humans. This RCD could form structures of regolith derived glass block.

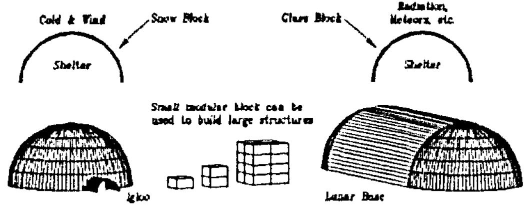


Plate 1

Michael Bahr

Growth - Phase 1

12 men on 1 month science missions using a minimum of modules.

2 housing/lab modules
3 'T' connection modules
2 straight connections
1 entry/airlock module
1 power/safe haven module.

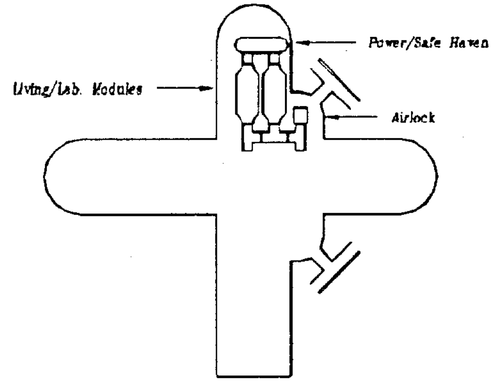


Plate XIV

Michael Bahr

Growth - Phase 2

24 men, 2 month science & experimental material processing missions. New modules:

2 housing/lab modules
3 'T' connection modules
2 straight connections
1 entry/airlock module
1 power/safe haven module.

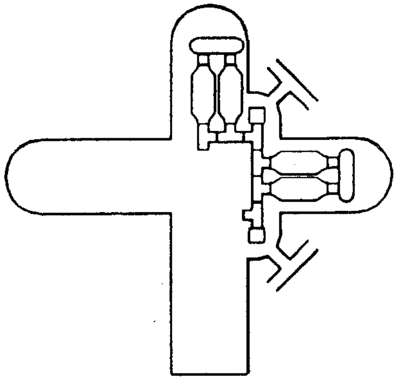


Plate XV

Michael Bahr

Growth - Phase 3

24 men, continuous duty science, mining, & material processing missions. New modules:

1 'T' connection module
1 power/safe haven
1 pneumatic module

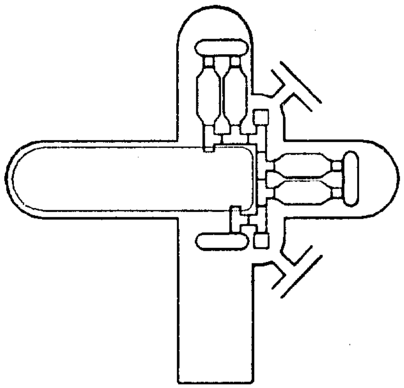


Plate XVI

Michael Bahr

Short Range Expansion - Phase 4

Short term expansion is provided by the allocation of space in the lower arm. The power/safe haven module located here can either supple systems to a small pneumatic structure or two more housing/lab modules.

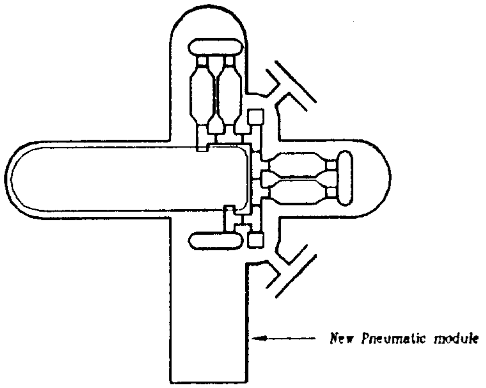


Plate XVIII

Michael Bahr

Construction

With the arches built, the rest of the structure may be completed. The terminating domes, entries, and inter-arch spaces may be built with glass block.
The path the robot follows as it lays the glass block course by course is linear and repetitive, reducing the chance for navigational errors.

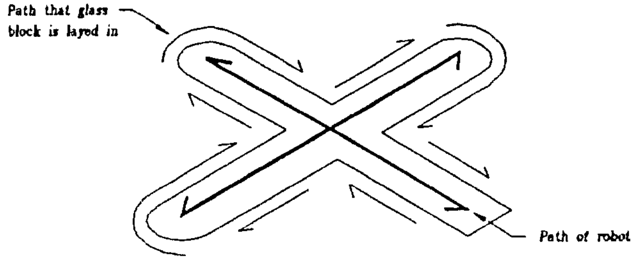


Plate XII

Michael Bahr

Block Formation

1 Collect Regolith
2 Melt & give form
3 Deliver
4 Fuse to neighbor

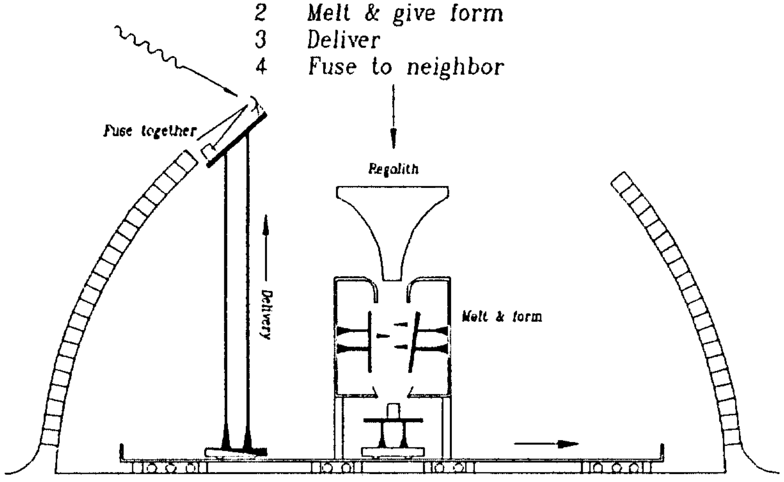


Plate II

Michael Bahr

Active Entry

A large triple-thick sliding glass block door is the moon bases active entry system. This door is used for moving the various modules and systems into and out of the base.

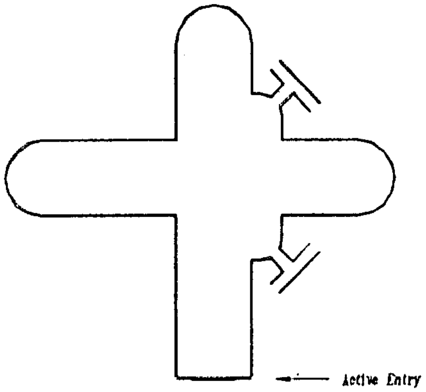


Plate XXIII

Michael Bahr

Passive Entry

The base uses two types of entry systems. The first is a passive system which uses simple techniques to reduce the amount of radiation entering the base. This type of entry is small scale and used mostly for entry by humans.

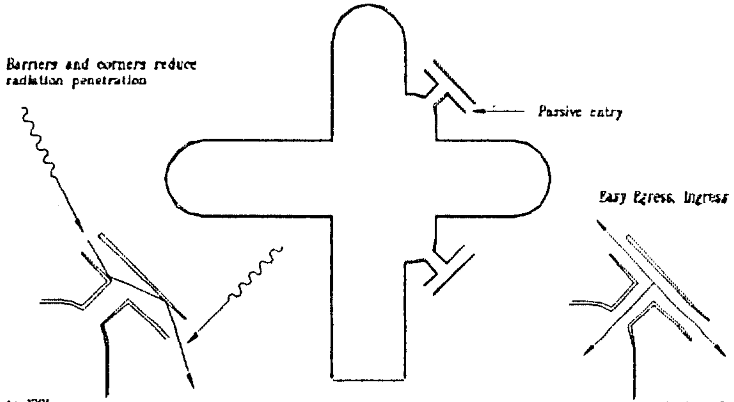
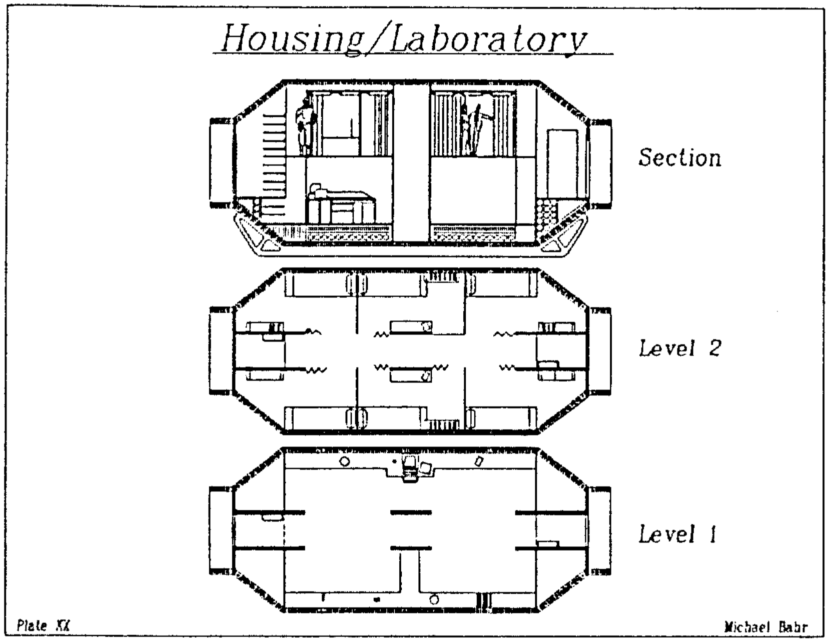
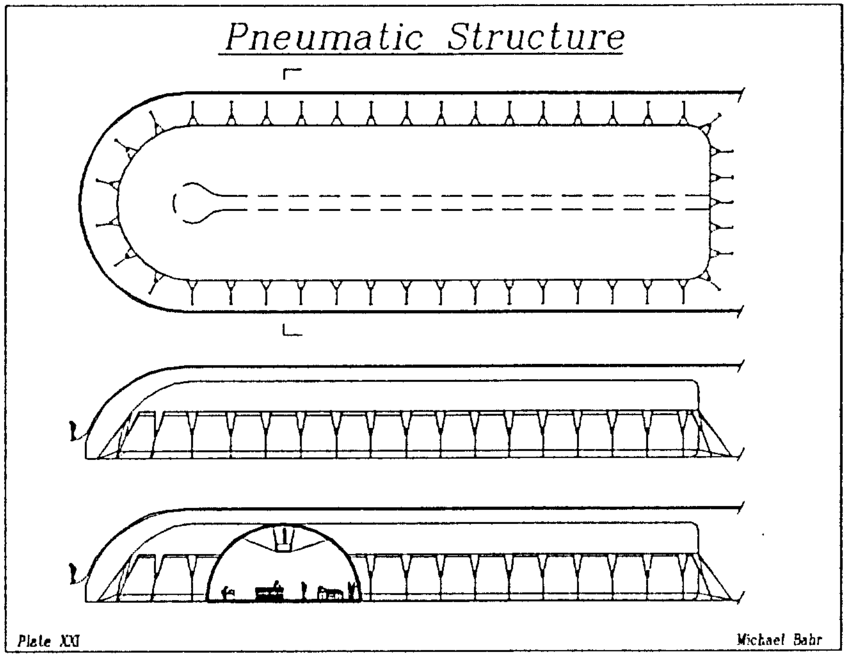


Plate XXII

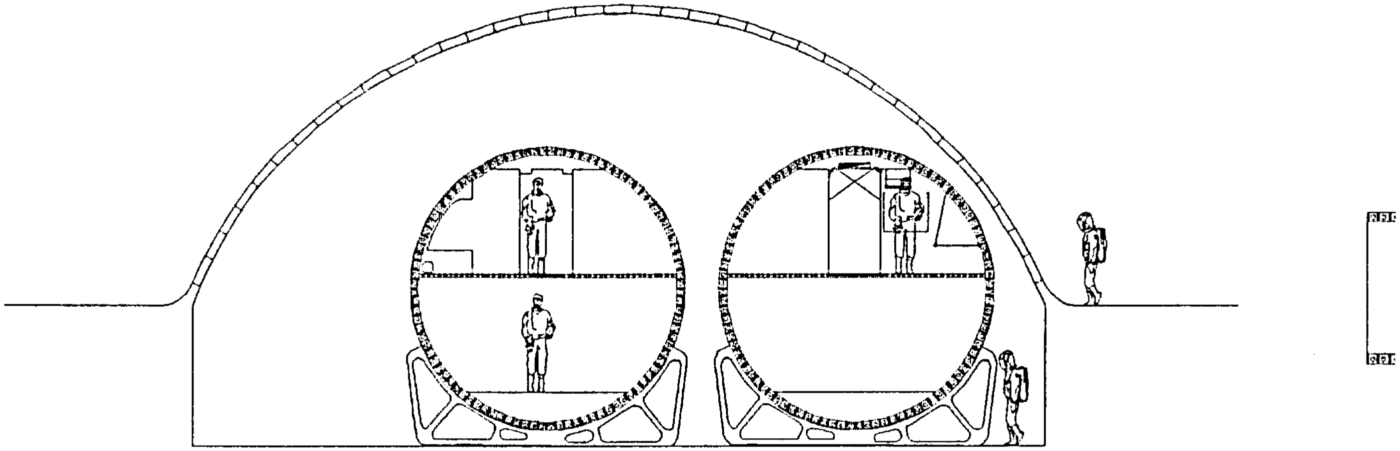
Michael Bahr



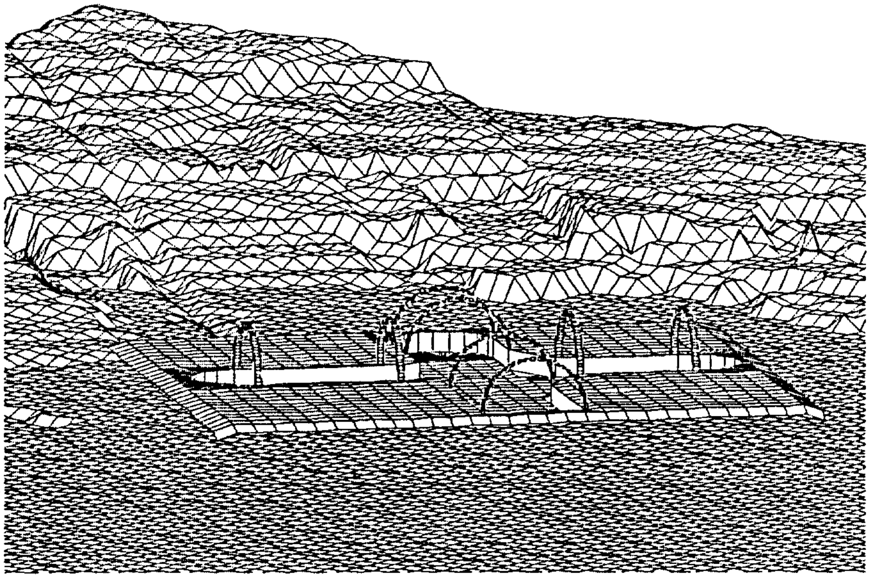
Habitation module plans and section



Cross-over technology inflatable structure.

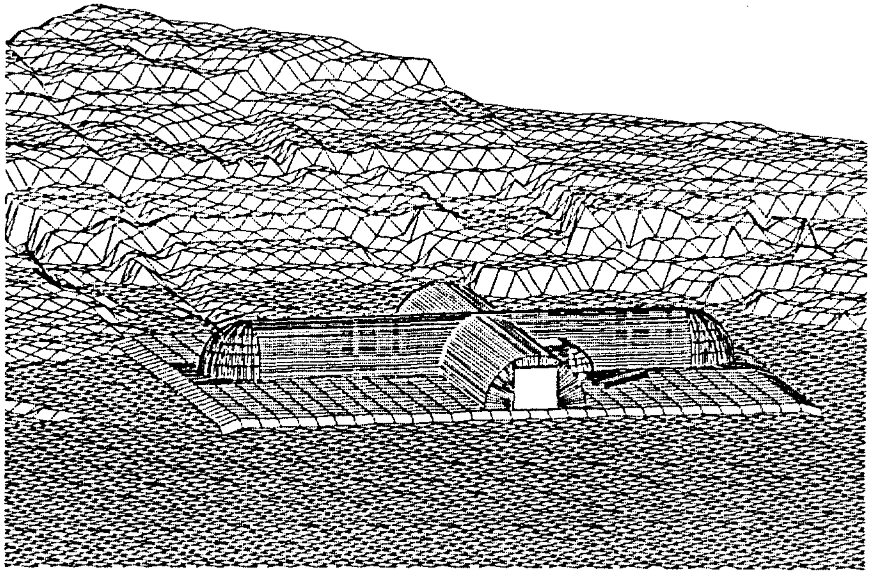


Base section showing relationship between habitation modules and protective shell.



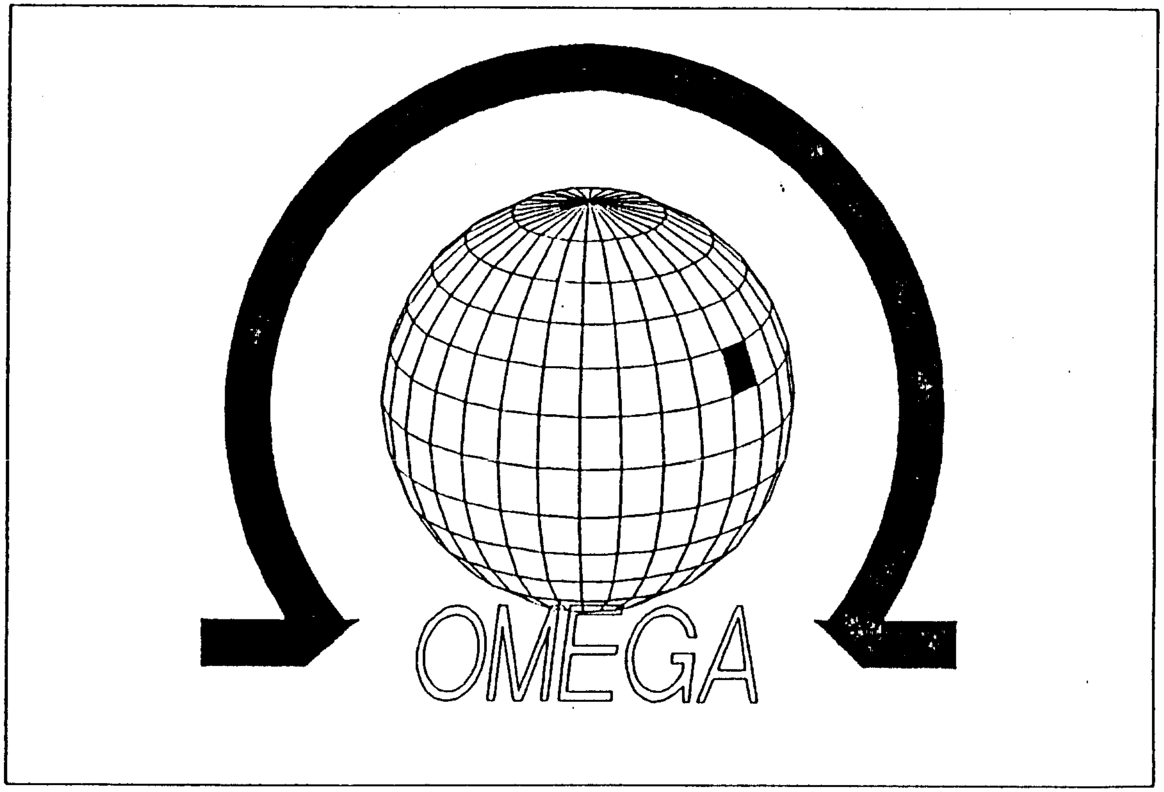
Isometric of base shell construction phase.

Isometric of completed shell



MOON BASE OMEGA

Edwin G.Cordes

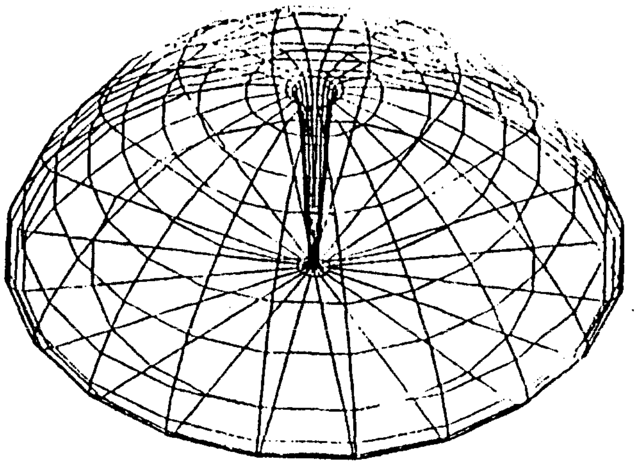


An exploration of the most cost and time efficient method of lunar construction was the primary goal of this project. Tension structures and inflatable habitats would be utilized for their least weight properties. An analogy of a camping trip with high technology gear served as the concept, A detailed construction sequence shows the ability to construct the base with very minimal human intervention.

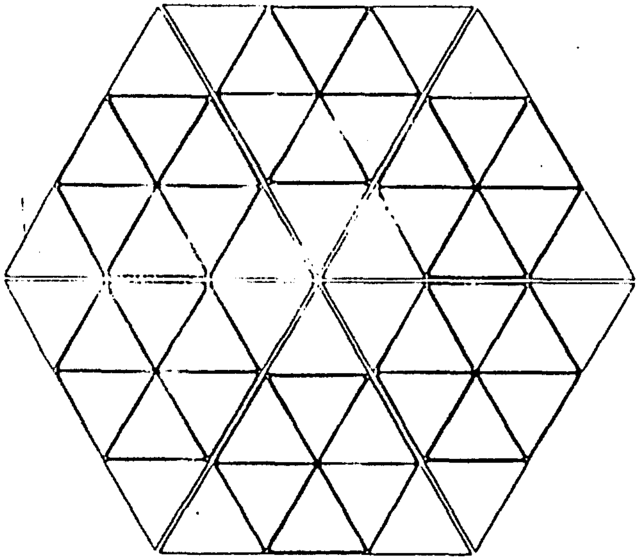
The base would be divided into two conceptual parts, the shielding net and the habitation domes. Each pressurized dome would be linked to other domes with a maximum of three "hard" tube circulation modules. These earth manufactured tubes would serve a multitude of purposes. Besides the obvious circulation link, they would be the primary points for ingress and egress from the base and would serve as self-contained safe havens in the event of a pressure loss in one of the inflatable domes. They would also function as cargo containers for the earth shipments of additional building materials.

After site selection, robotic regolith-moving machinery would create craters approximately 20 M (65 feet) across. Three evenly spaced support pylons would be created with a portion of the regolith around the depression's edge. Steel cables and netting would be placed in the crater and over the three support mounds. After 3 meters of regolth is replaced and compacted over the net, the cables would be pulled taut and a cave like shelter created. Additional net shelters could be linked in a triangulated fashion using common support points.

The inflatable domes would employ twin membrane construction for safety and insulating reasons. Insulation injected between the inner and outer domes after inflation would serve as the primary thermal regulating element. A containment structure of netting would allow the domes to retain their shape with the internal pressure. Environmental requirements would be supplied from a detached power station and enter each dome through a central core. The interiors would be easily adaptable for various needs by using hung fabric dividers. The upper floor of a dome would again uses tension technology and be hung from a central support column.

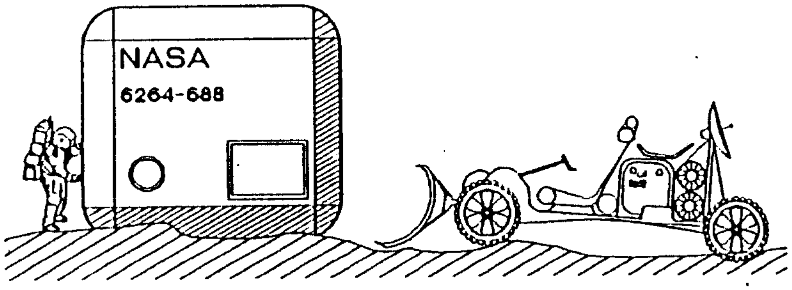


Isometric view of inflatable habitation pod with central supply core.

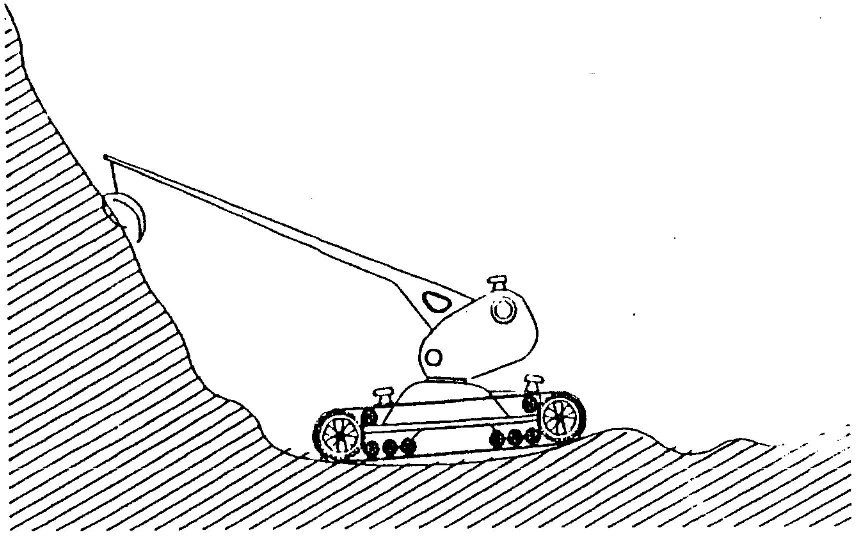


Possible configuration of regolith shielding nets. A circular configuration allows multiple use of support points and convenient access to all modules.

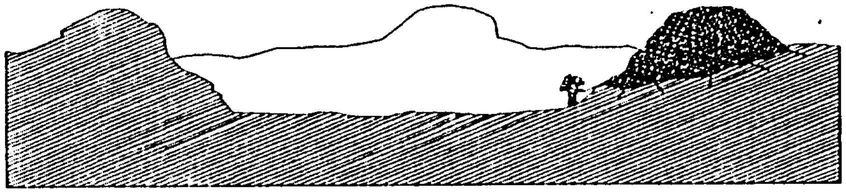
Key design issues of this scenario include tension structures to reduce shipping mass and weight, multi-use spaces and overall base growth and planning. Safety concerns and interior space adaptability are also significant issues.



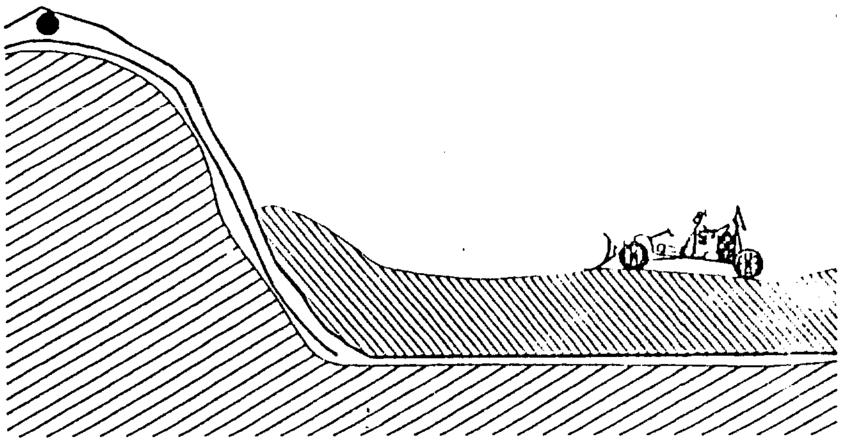
1. Materials are delivered to the site in reuseable containers.



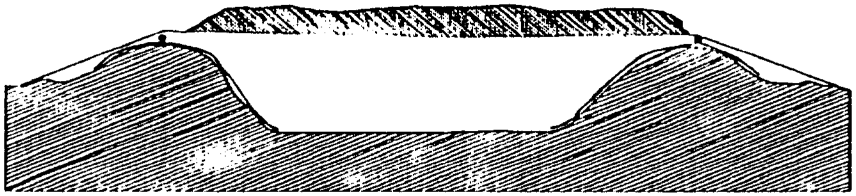
2. Excavation of site is begun using robotic machinery.



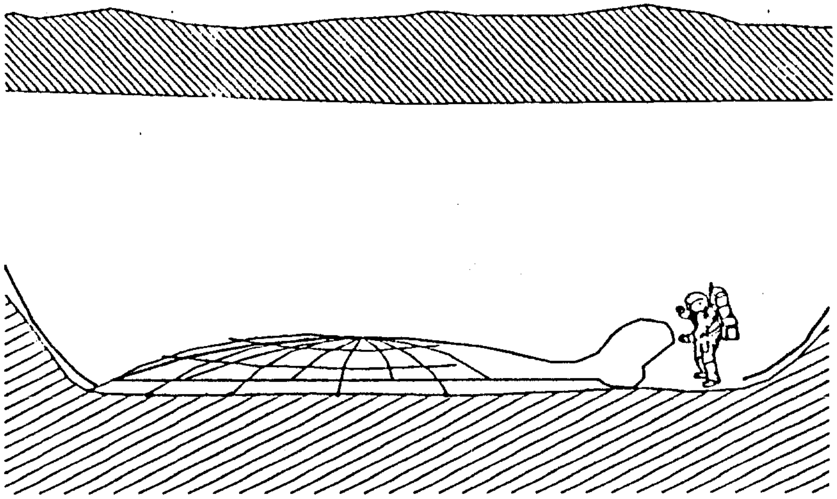
3. Netting is placed over the support mounds to added strength.



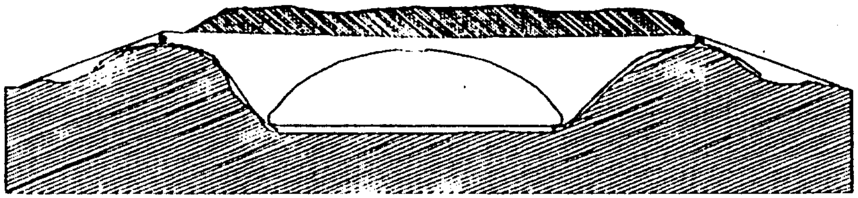
4. compacted regolith is placed over the cover net.



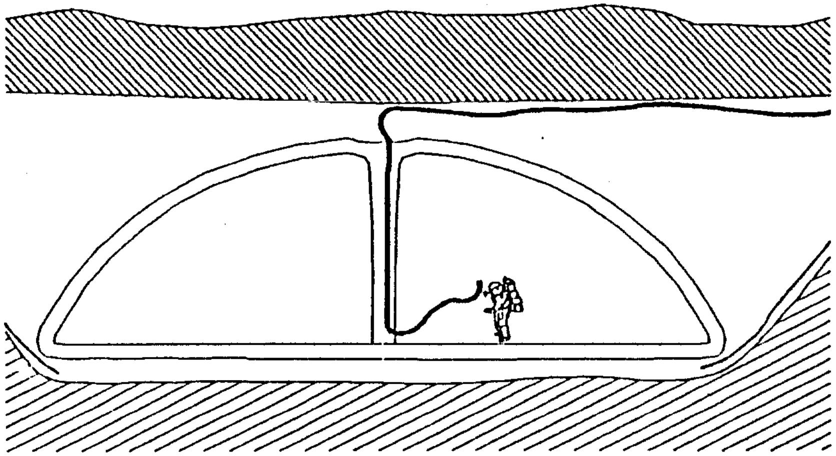
5. *The protective net is hoisted into place providing a radiation shield.*



6. *Inflatable domes are inserted in the cavity .*

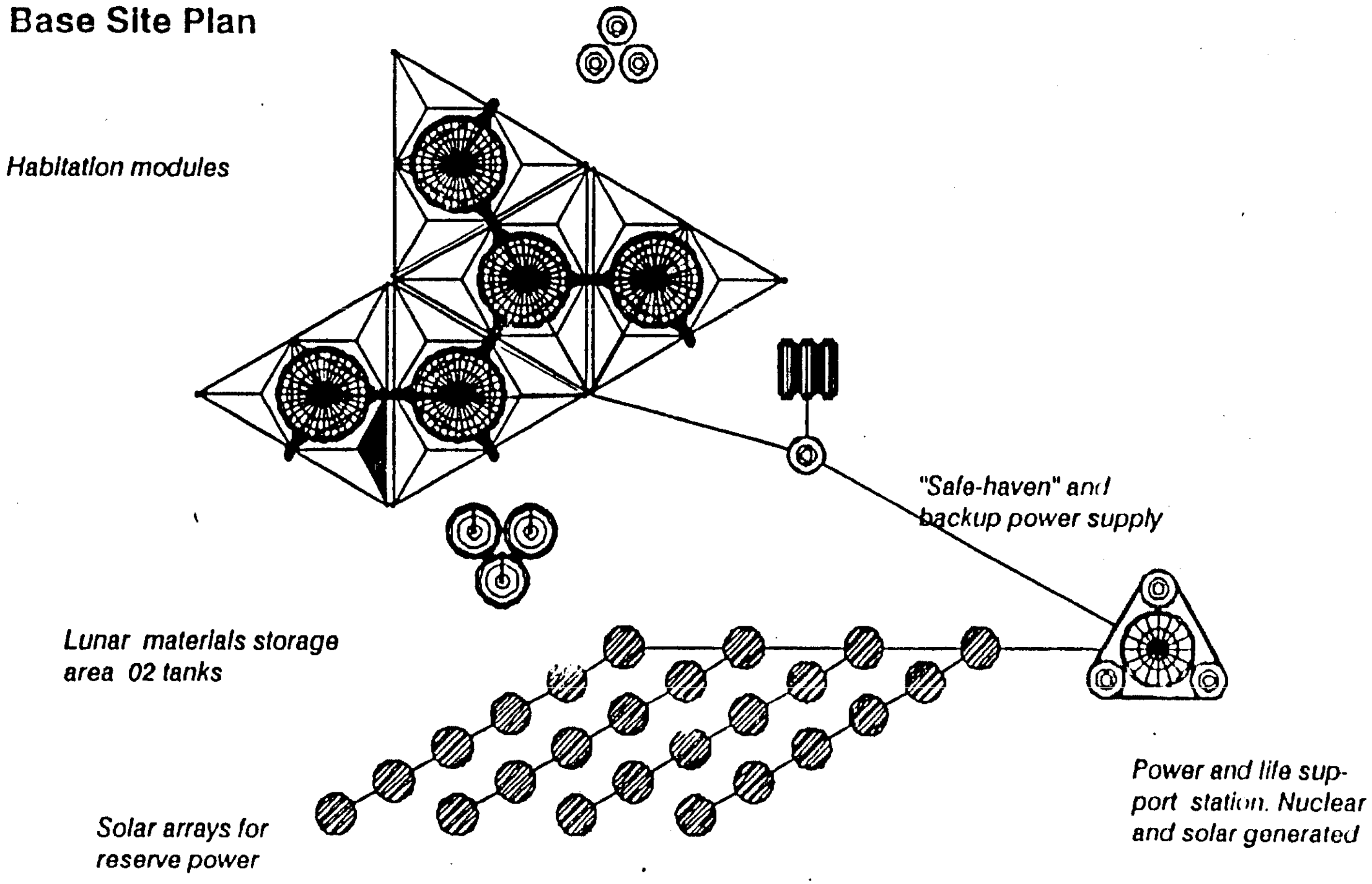


7. *The dome is inflated and passage ways are connected.*

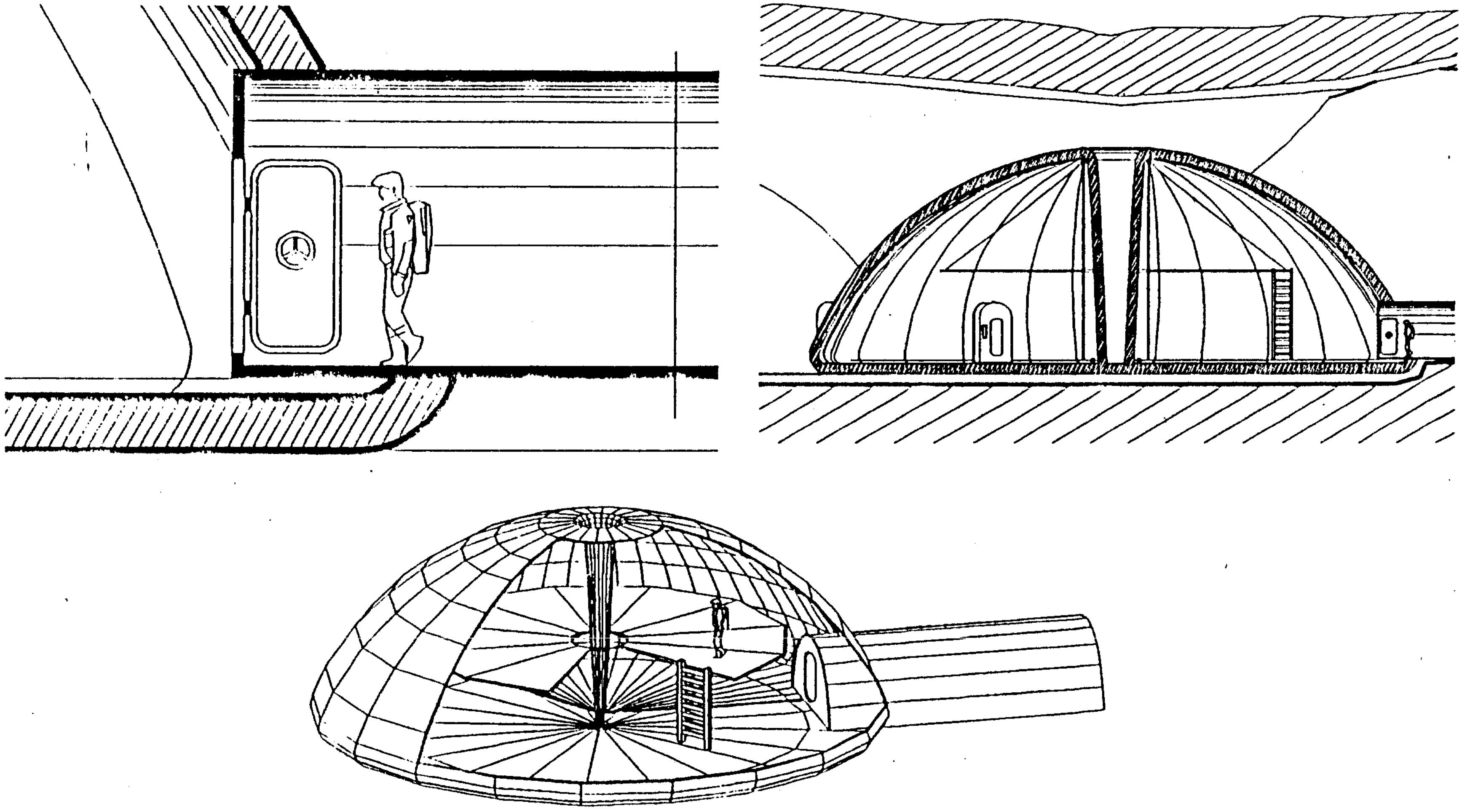


8. *After the inner dome is inserted, life support systems are connected.*

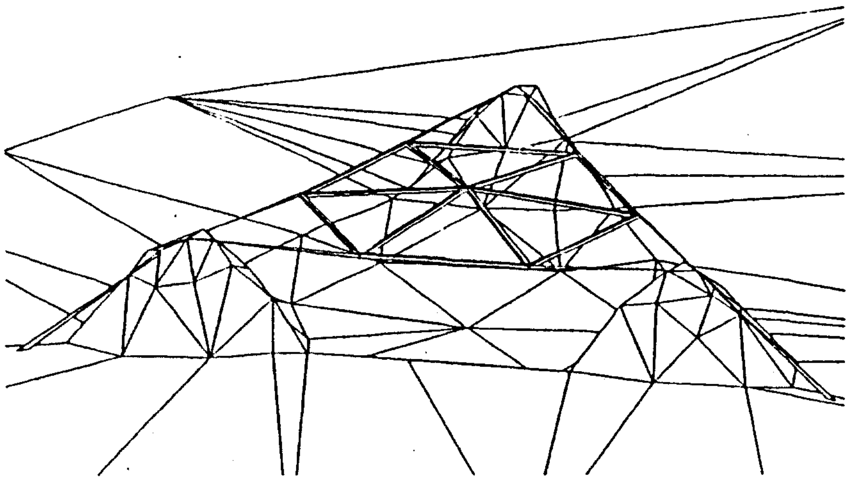
Base Site Plan



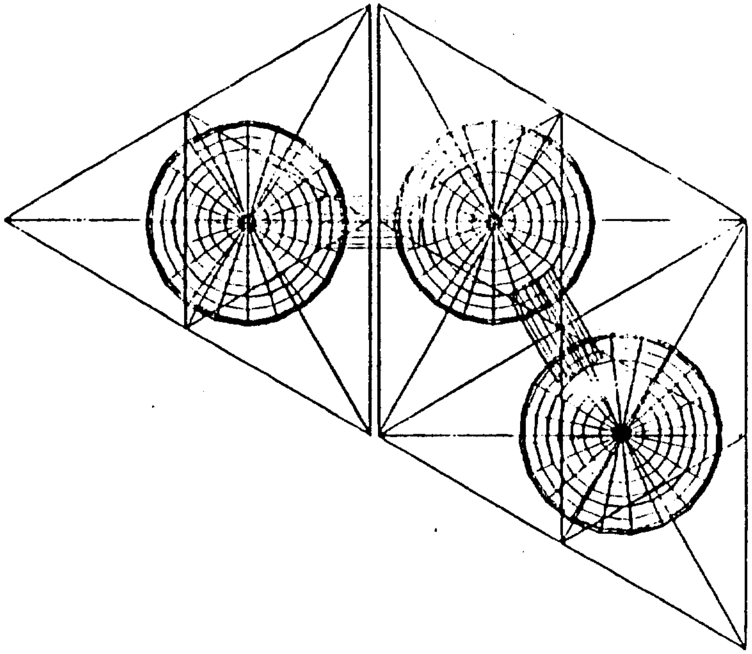
A site plan of later phase base developement showing five inflatable habitation modules and various support systems.



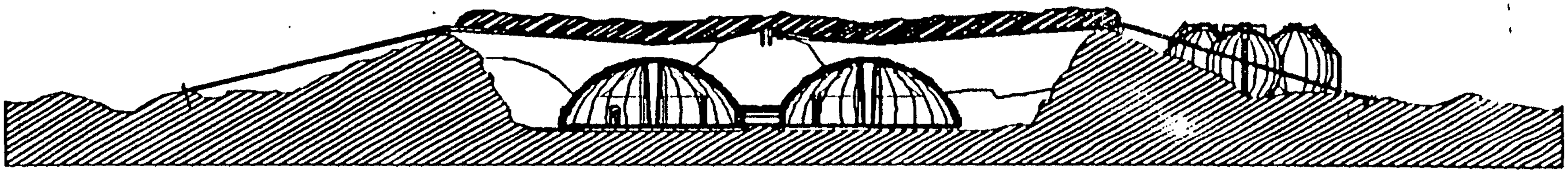
Section, detail and cutaway Isometric view of habitation domes, showing how interior systems integrate with double layered dome.



Perspective of regolith netting used to shield habitation domes



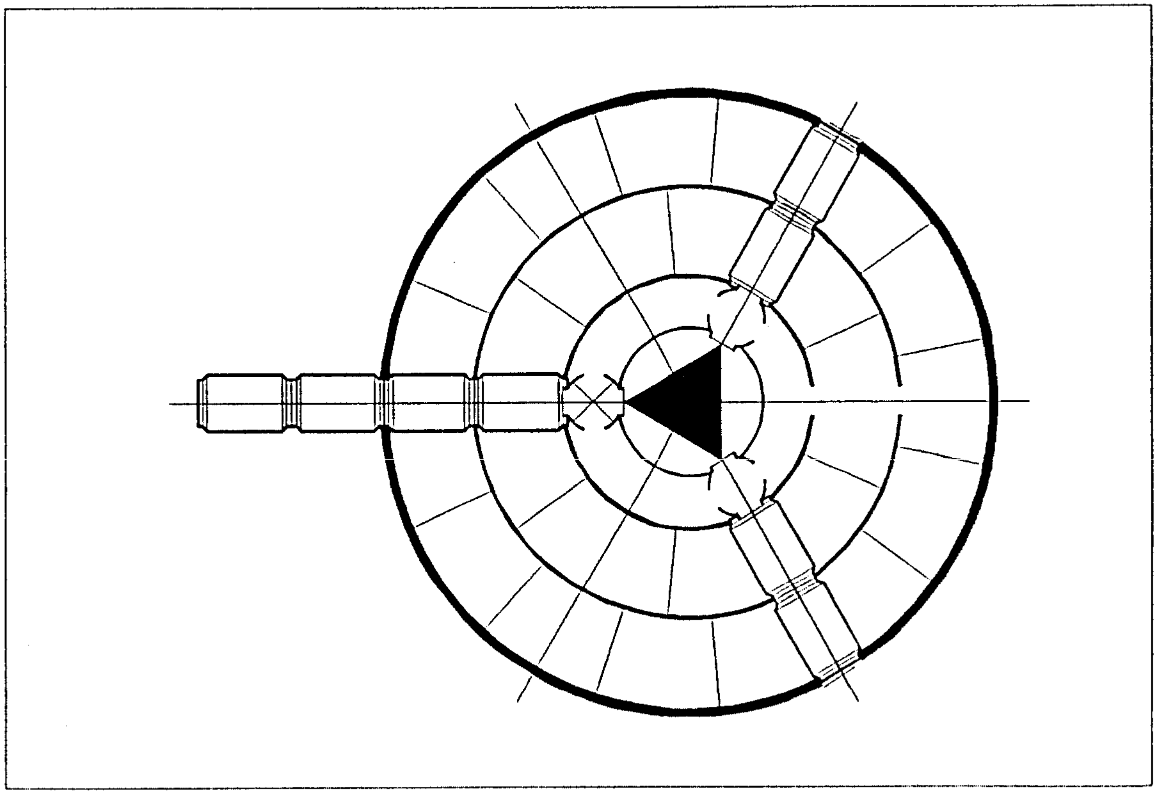
Plan view showing relationship between netting and dome structures.



Site perspective of base.

THE CRESCENT HABITAT

Nnamdi Elleh

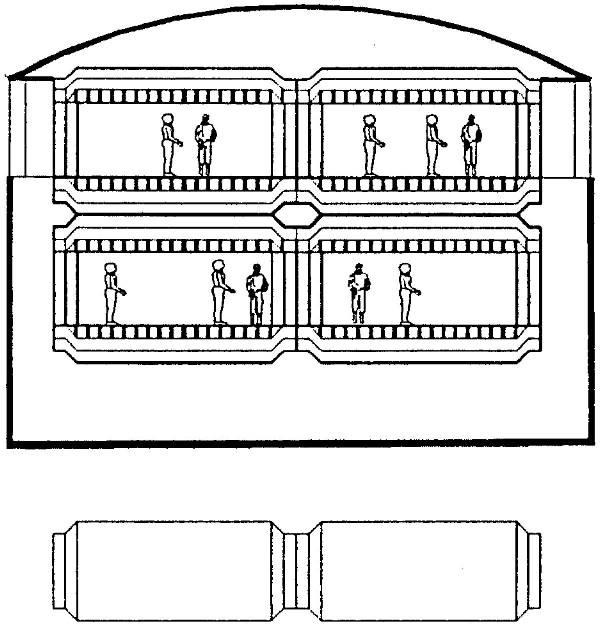


The major conceptual analogy of this design relates to the ability of certian animals to carry their environmental protection with them. The base is likened to a snail shell. Intial phases are composed of completely self contained modules. These modules serve as the basepoint for later expansion utilizing lunar materials in the construction process. The shape of the base modules are circular to best resist the atmospheric forces.

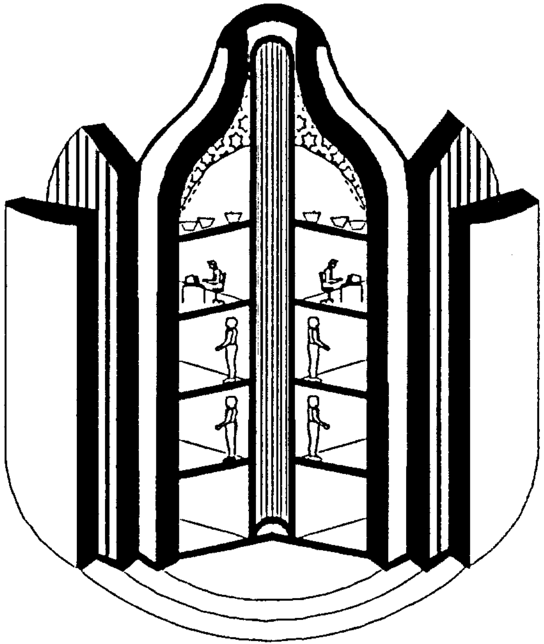
A tripartite zoning of the base separates the living quarters from the laboratory\processing centers and the food growth chambers. Complete self-sufficency of the base will be realized with the completion of the food growth chambers in phase two. Each zone contains its own life support system for added safety. Once the circular base layout has been completed, further growth is accomplished by replicating the entire base and connecting the two along any of the zone links.

While initial habitat modules are earth constructed of lightweight metalic elements, later stage developments are dependant on lunar fabricated materials. Silica derived from the regolith is melted to form glass fibers which are then woven together into three layer shells.

Phase three development involves the use of the glass fibers as well as lunar concrete in the construction of a large underground dome. The lunar concrete as well as the regolith covering it serves as adequate radiation protection for long term habitation. The interior utilizes easily moveable, hung panels which are both weight efficient and allow for easy modification of the environment. A great deal of concern towards reducing the problems associated with boredom and confinement was also expressed in this design scenario.



First phase base section showing stacked earth manufactured modules and regolith shielding.



Second phase lunar materials structure isometric showing three layers of shielding.

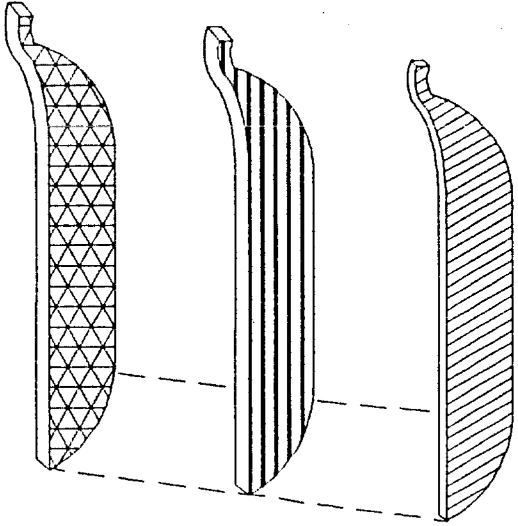
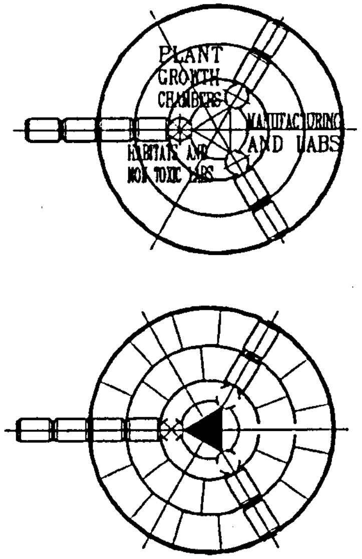
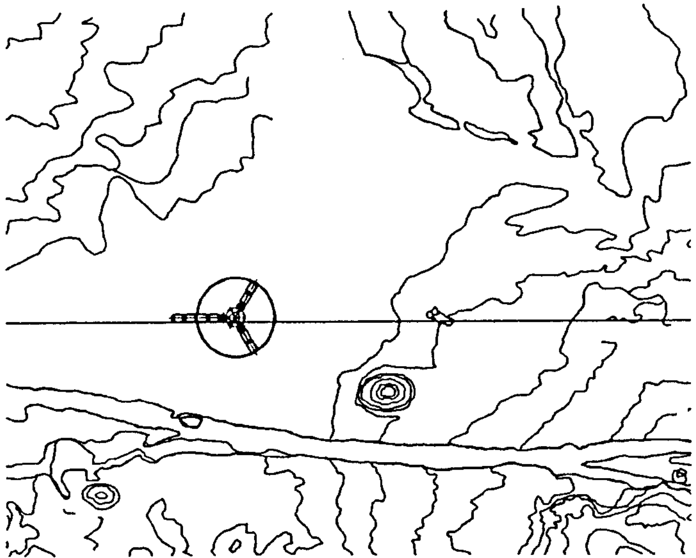


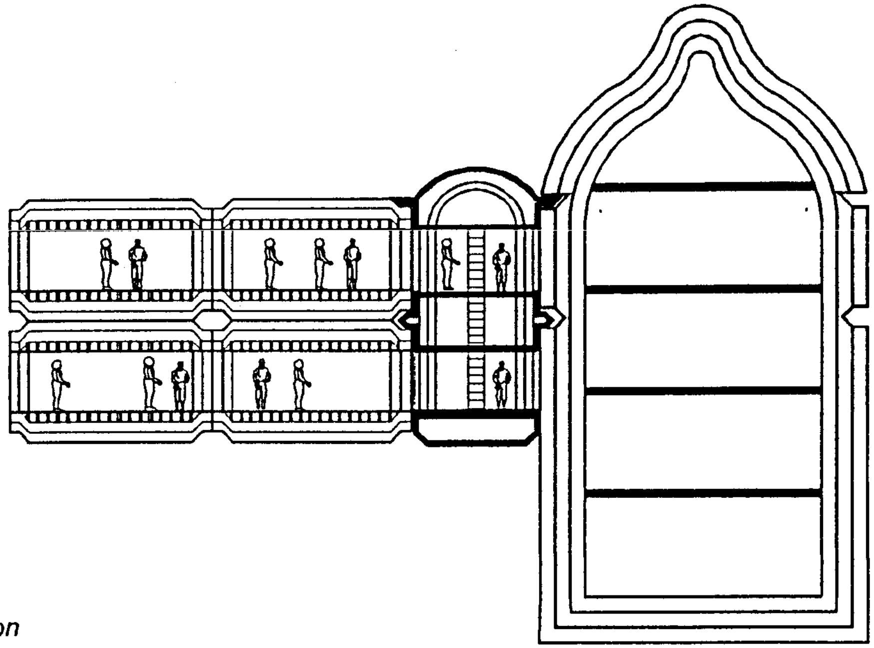
Diagram of three layered construction.



Base master plan showing tripartite division according to function.



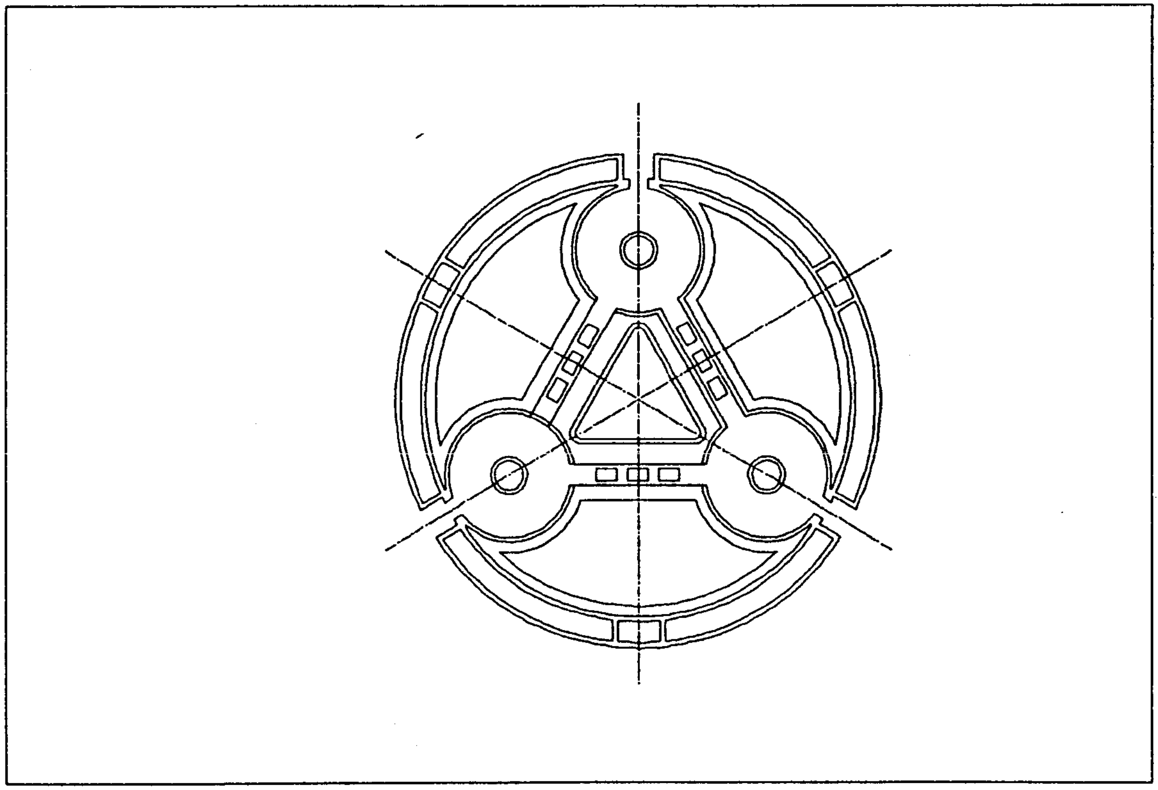
Site plan showing base in relation to surrounding topography.



Base section

LUNAR BASE GENESIS

Stephen J. Frahm



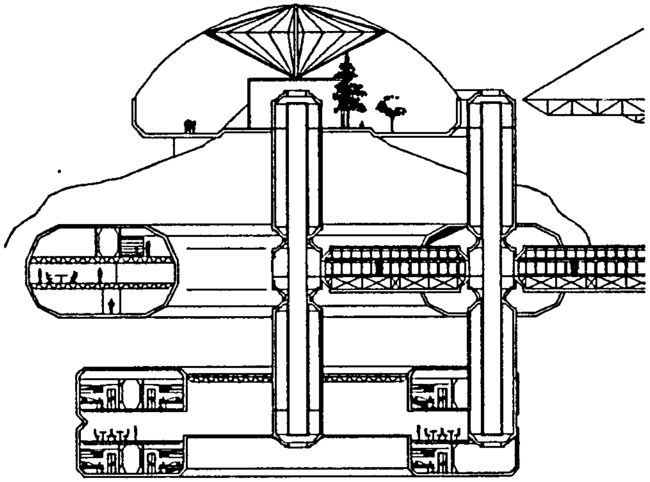
The following design scenario placed great emphasis on systematic phasing of the base's growth. The design was structured so that each phase of construction was linked to its particular function. The base is radially orientated. Areas became more specialized as the base grows in size. The overall amount of space per inhabitant also dramatically increases as the base grows. While early stages rely on earth manufactured structures, later base growth is dependant on the use of lunar materials.

The amount of radiation protection varies throughout the base. Generally, the amount of protection the structure offers increases as one descends to levels further underground. Areas in which a great deal of time is spent are therefore located on lower levels. Modules which are not buried beneath the lunar surface are protected by man-made radiation shields. these shields are constructed using space frame technology and are covered with bags of packed regolith. The shield's modular design permits rapid placement, accessability and expansion.

Life support and power supplies are located in the core of the structure and backup systems are located at various levels. The living quarters occur closest to the core area with science, manufacturing and ground support areas located in the large outer ring. Further base expansion can occur through links to this outer ring.

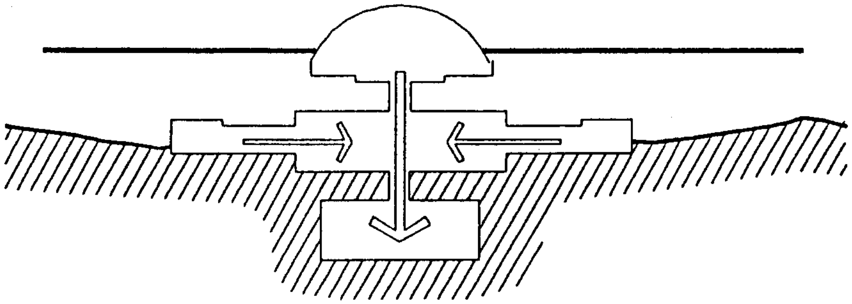
Early phase construction is of modular earth manufactured panels. Later construction schemes utilize lunar concrete to form radiating expansion areas. Later phases of base expansion involve the addition of plant growth areas. A large dome structure atop the base would serve various requirements. Besides supplying a portion of the base's food requirements, the dome would allow a large area for relaxation and recreation.

Interior spaces are organized according to activities and the amount of time they are used. Therefor, crew quarters are larger than laboratories and work stations, and allow for individualization.



Section through completed base showing stratification

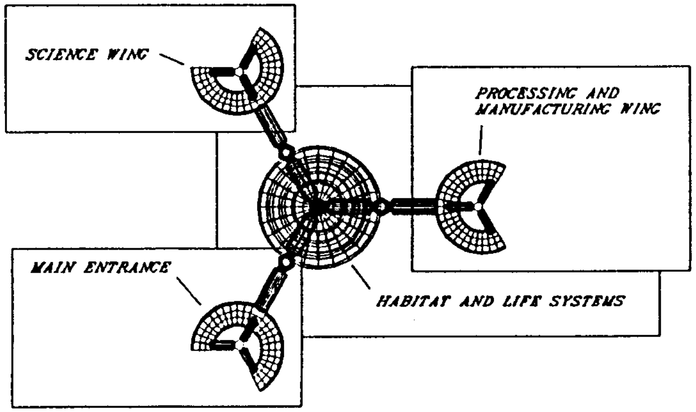
RADIATION PROTECTION



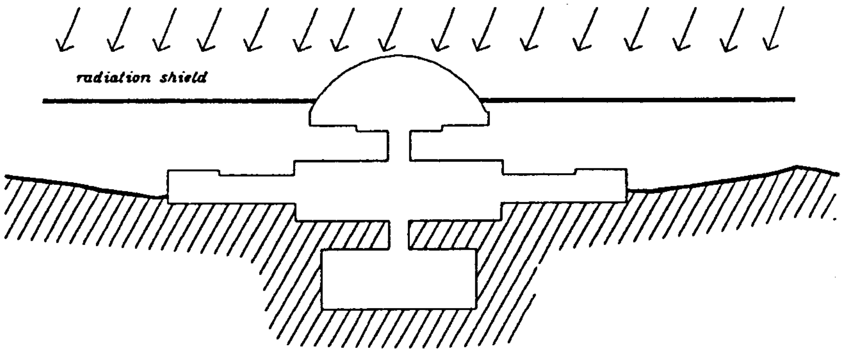
The deeper the penetration into the base, both in the vertical direction and in the horizontal direction, the greater the amount of radiation protection. The lowest point of the base thus has the greatest amount of radiation protection making it the safety shelter from the occasional solar flare thrown out by the sun. Storage of the vital elements such as food and water are stored within the inner core of the base.

BASE ORGANIZATION

The base is actually designed as for seperate bases. Each capable of supporting itself in case of crisis, having seperate entrances and access points in several key areas, and able to function as a whole.



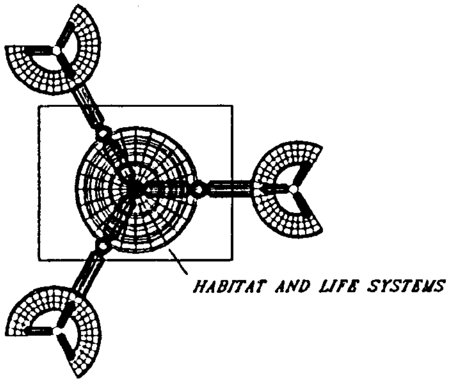
RADIATION PROTECTION



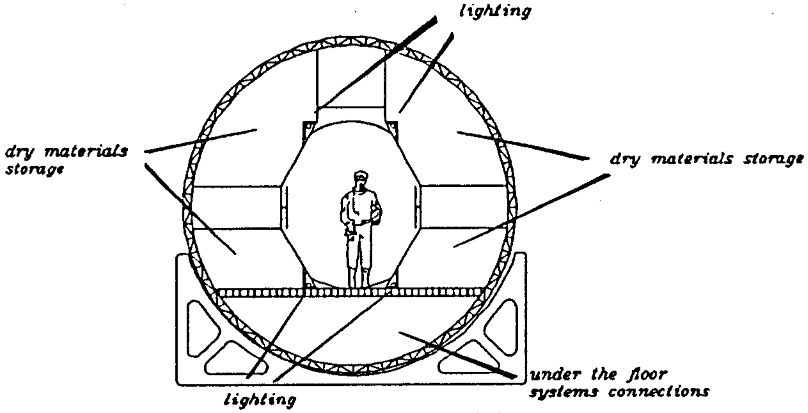
The seperate radiation shield over the base is covered with bags of packed ragolith. The external frame allows for the easy access to and expansion of the lunar base. Each 32x32 foot "pad" is constructed of lightwieght aluminum and is supported by cables from above. The easy of assamibly and time of erection are an added plus to the system. The modularity and lightness of the structure make it easy to move and easy to construct while still providing a strong support for the ragolith protection system.

THE HABITAT SYSTEM

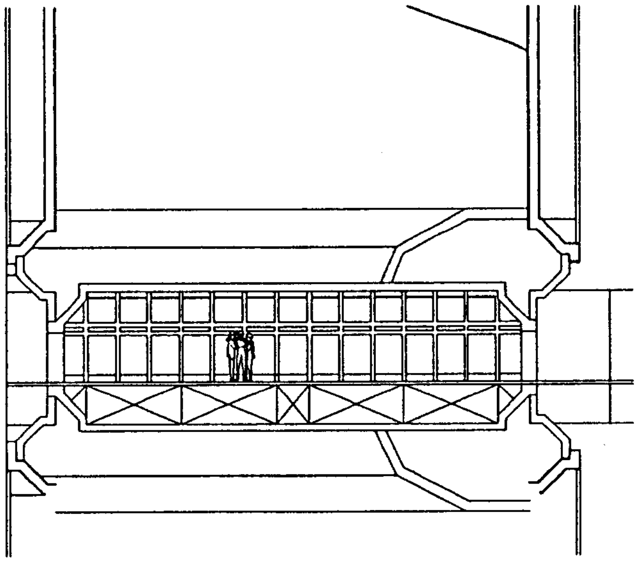
Located in the heart of the base is the life support systems. By locating the life support systems in the heart of the base, the system is assured the greatest amount of protection from the harmful radiation.



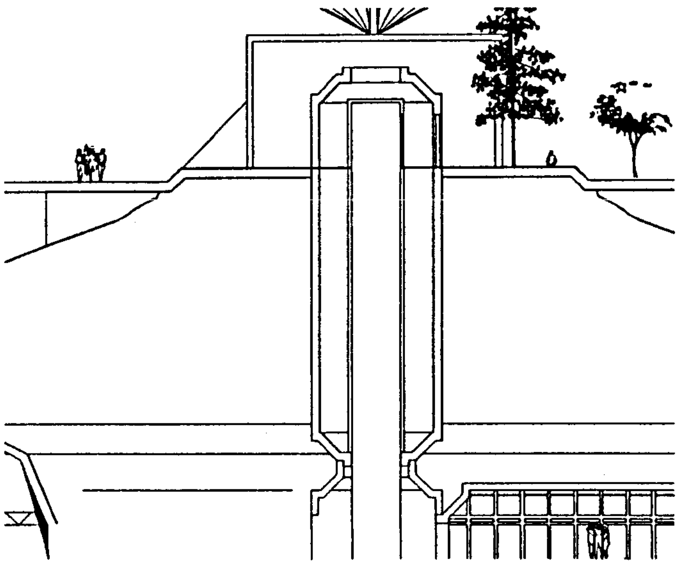
section through the circulation corridors



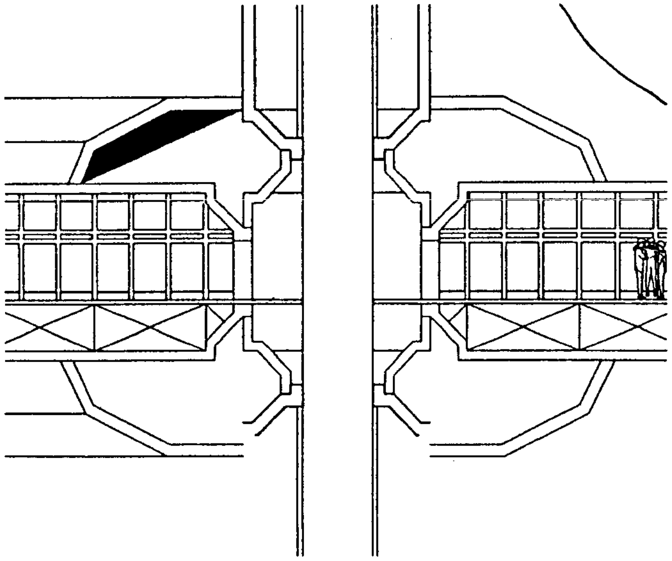
Detail of earth manufactured pathway modules



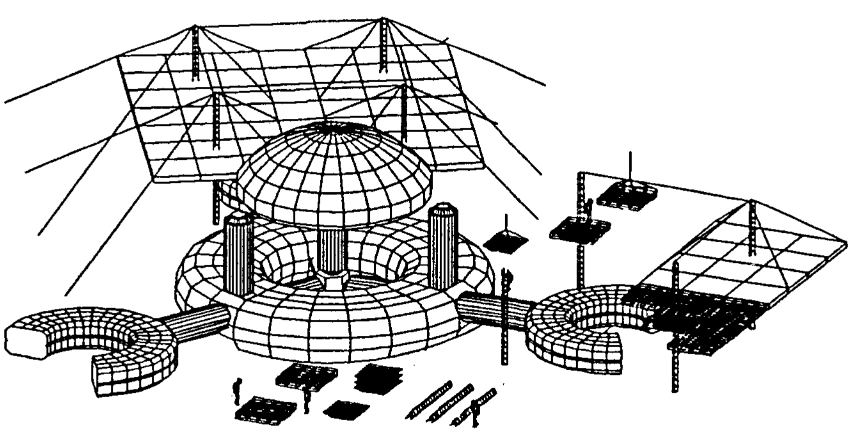
Horizontal circulation path



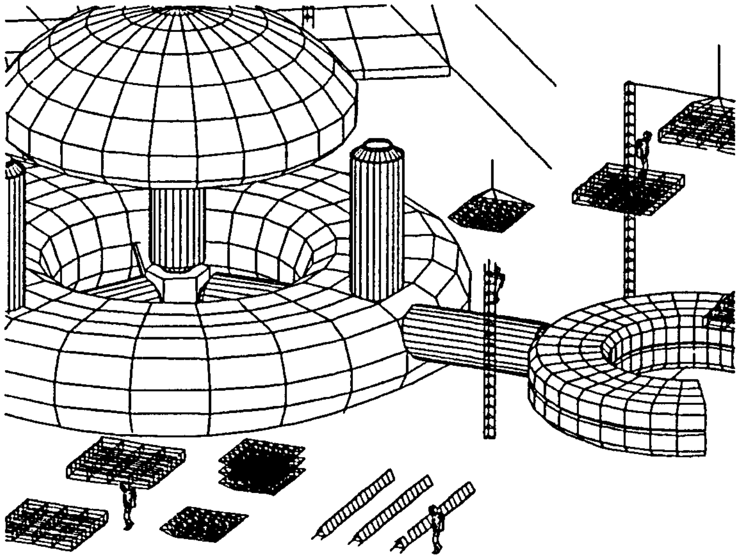
Vertical circulation path



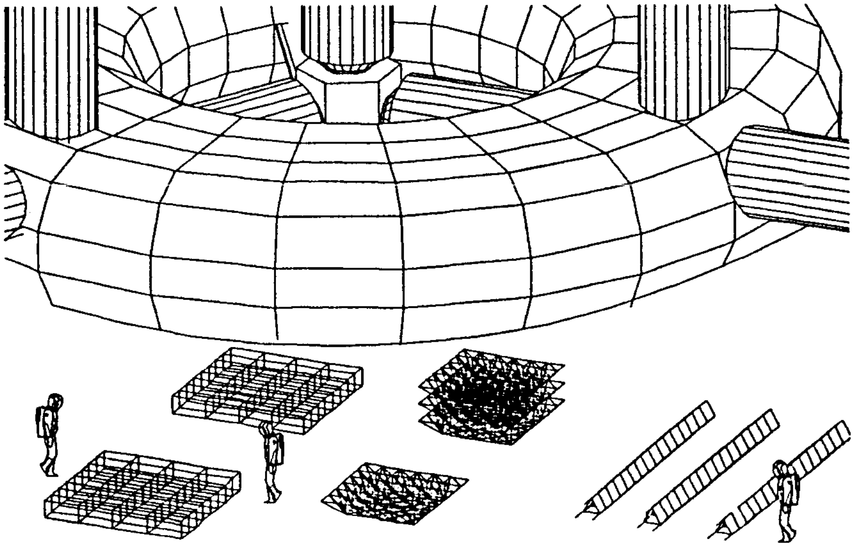
Intersection of vertical and horizontal pathways



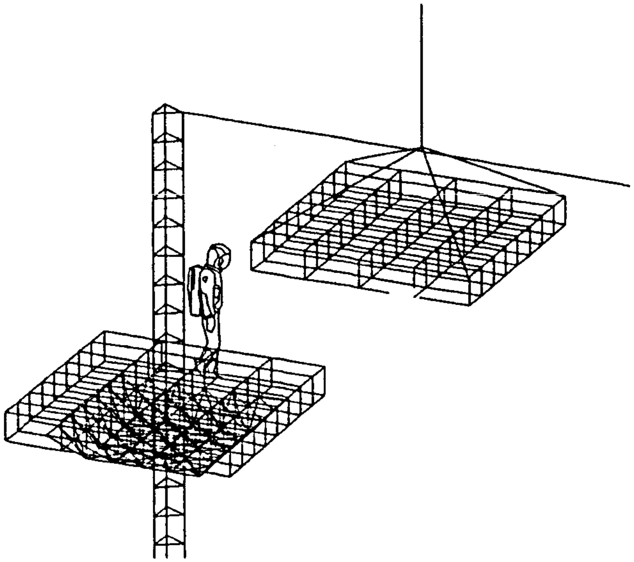
Base isometric



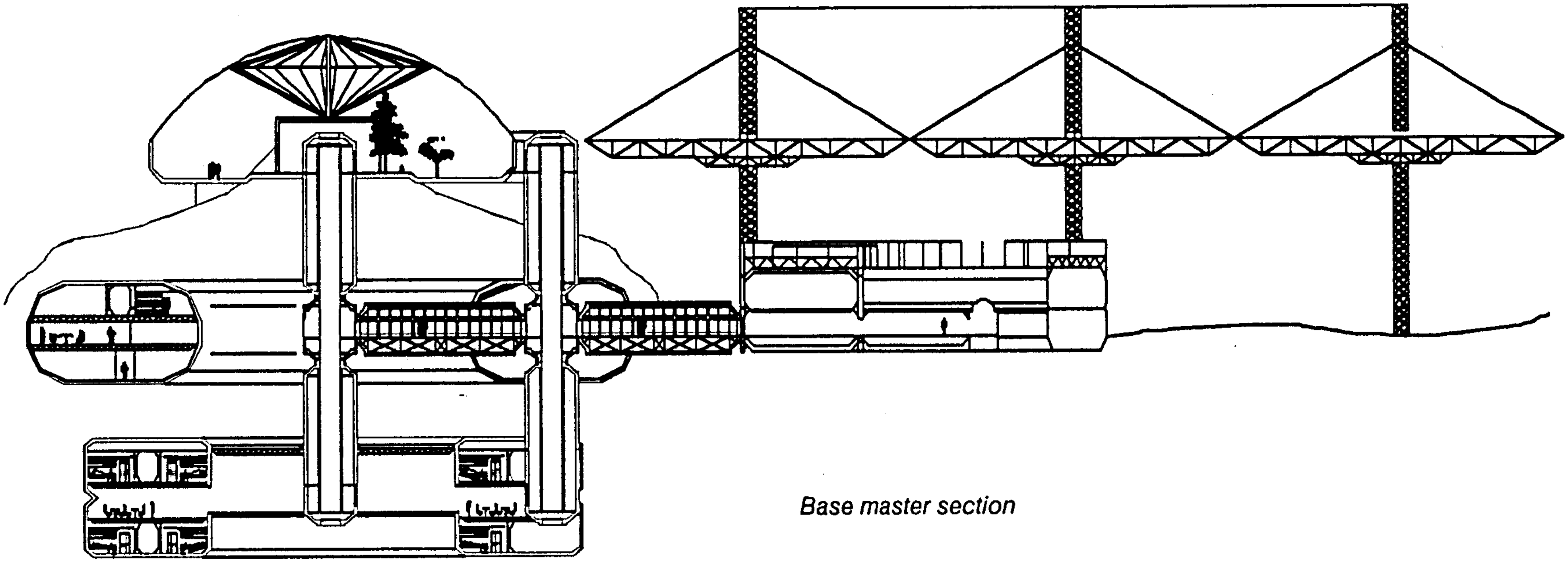
Base construction isometric



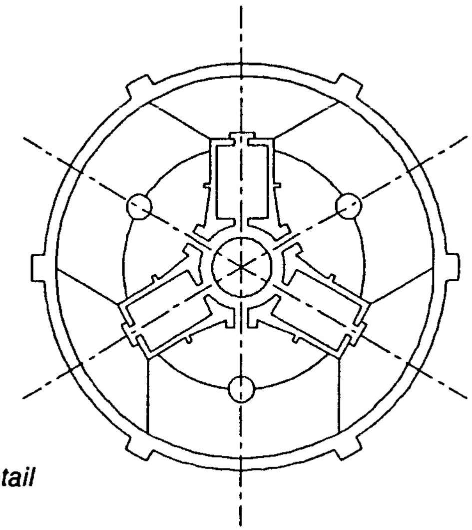
Base construction isometric



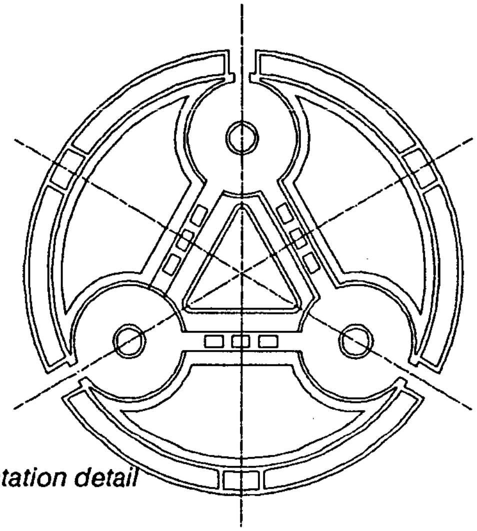
Construction detail = Spaceframe shielding



Base master section



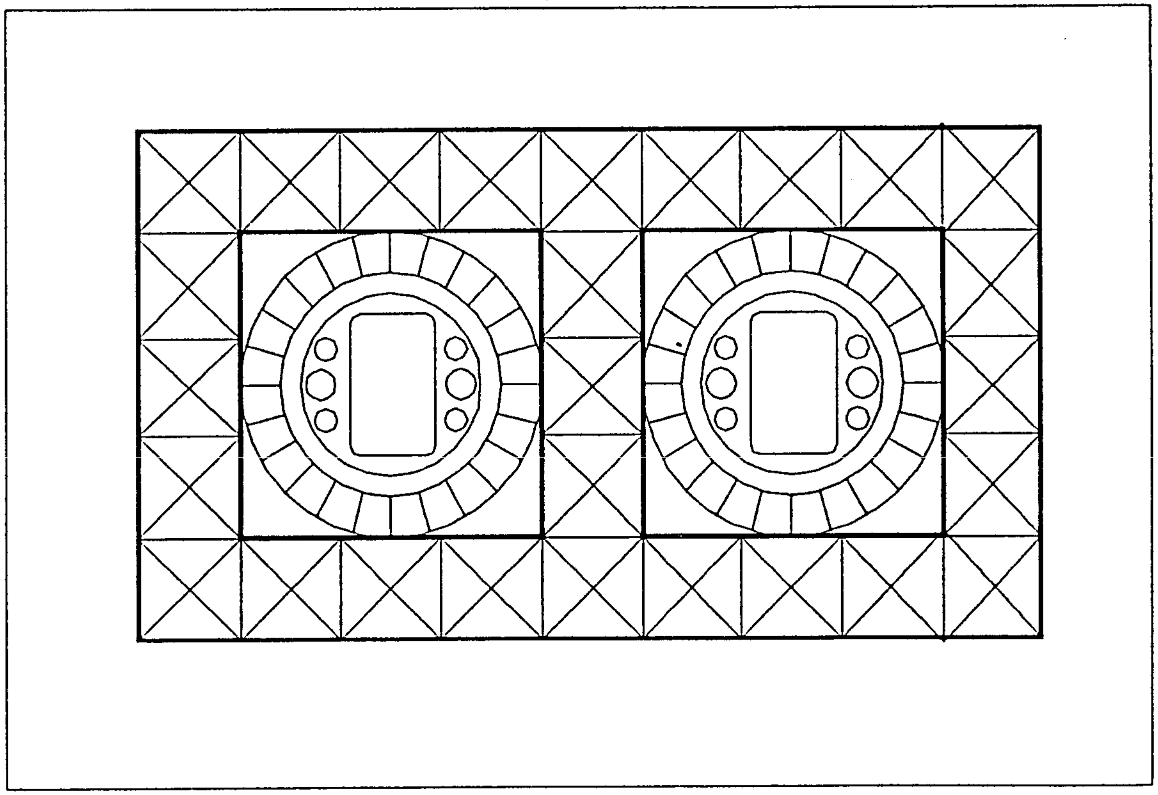
Launch pad detail



Power supply station detail

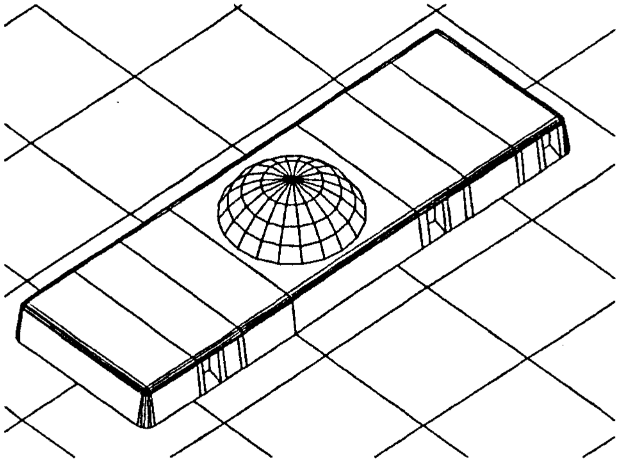
THE ADAPTABLE ENVIRONMENT

Ahmad S. Hamzah



The primary goal of the following project was to develop a simple yet systematic method of construction requiring the least amount of materials, time and labor. By utilizing the design concept of a wine rack, the base evolved into two separate systems. The rack would be analogous to the radiation shield and the bottle equated with the pressurized habitation modules. The individual "bottles" could be replaced if needed, and would form an easily expandable system. As a safety precaution, life support systems would be redundant in all modules.

Compacted lunar regolith would be utilized for radiation protection in the shelter, covering the exterior rack system. In order to reduce human involvement, robotic processing plants would gather, compact into blocks and place the regolith over the structure. Space frame construction would be utilized in the rack's construction.



Isometric view of exterior base shielding and dome structure.

Beneath the exterior shelter, cylindrical aluminum pressure vessels would contain the living quarters. All modules would have similar dimensions of 5 M (16.4 feet) diameter and 15 M (49.2 feet) length. There would be two primary uses for these modules. Circulation modules would create a central access spine and contain six airlock connections. Radiating from these central modules would be the multi-use modules whose functions would range from living quarters to laboratories. A third type of structure located beneath the shielding rack would be an inflatable dome signifying the "cross-over" technology point. This fabric and space frame dome would be utilized for operations requiring large open spaces such as lunar materials processing plants.

The Earth constructed habitation modules would have standardized shells and common utility distribution systems. Each interior would be customized on earth for its particular use in the lunar base. The modules' size is of human scale and would allow for privacy. By forming a long axis, the circulation spine could relieve the feeling of confinement.

Construction of the base would begin prior to human habitation. Robotics would prepare the lunar surface and begin production of the shielding regolith blocks. The initial phase would require 5 modules (3 multi-use, 1 circulation, 1 airlock and exterior link). After the modules are placed beneath the radiation shield, connec-

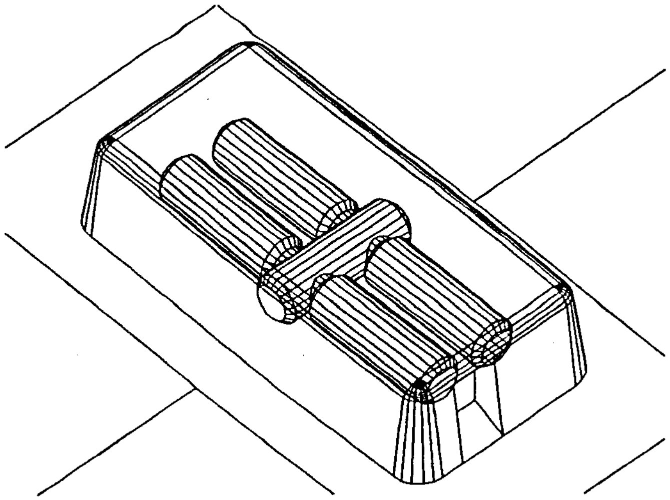
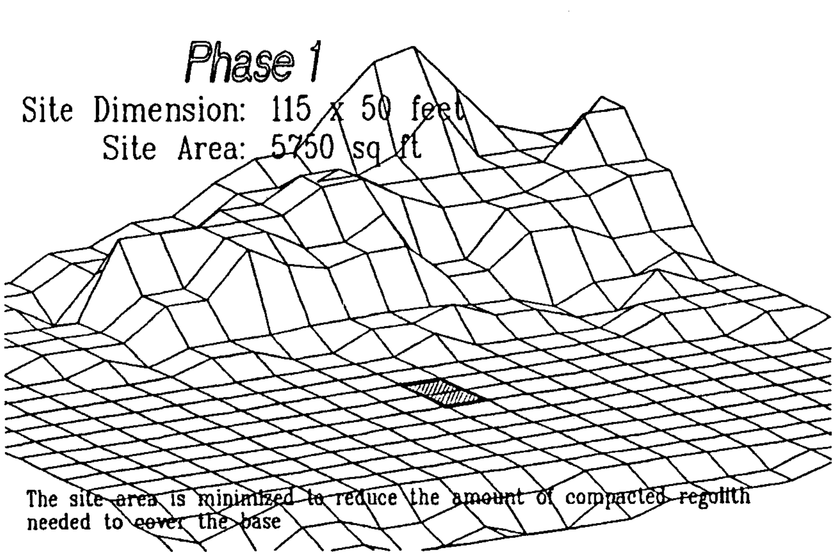


Diagram showing placement of modules beneath protective shield.

tions would be sealed and the remaining regolith blocks placed around the shelter. Additional modules could be added to the base as they are needed.

Phase 1

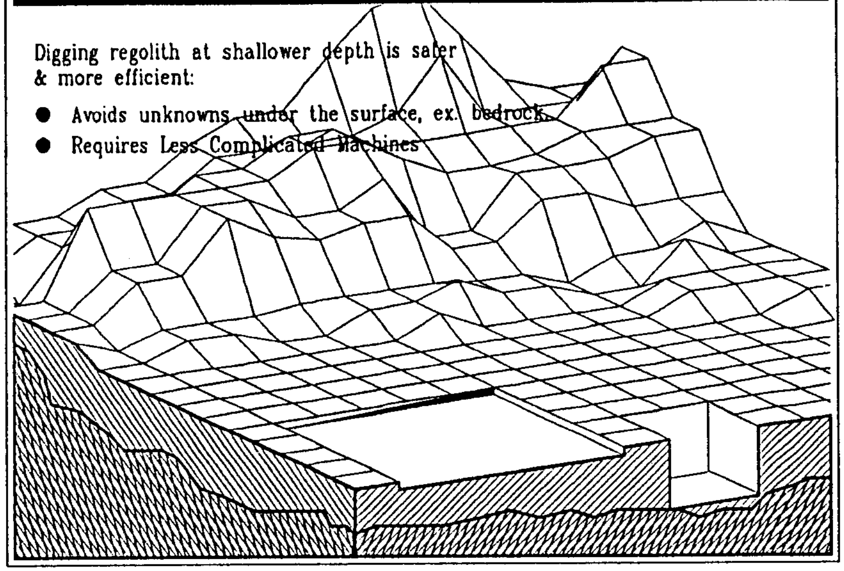
Site Dimension: 115 x 50 feet
Site Area: 5750 sq ft

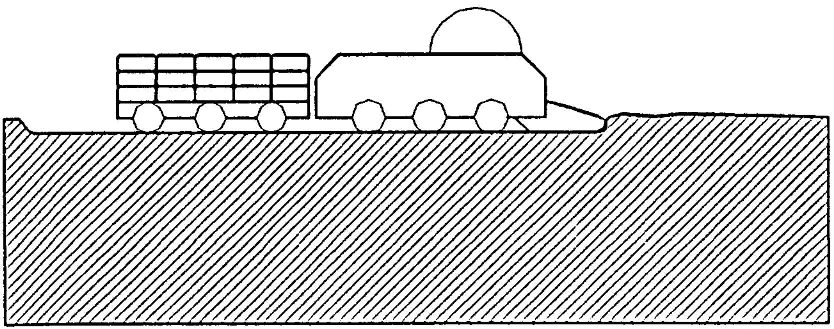


The site area is minimized to reduce the amount of compacted regolith needed to cover the base

Digging regolith at shallower depth is safer & more efficient:

- Avoids unknowns under the surface, ex. bedrock.
- Requires Less Complicated Machines





Compacted regolith is produced in the form of blocks.

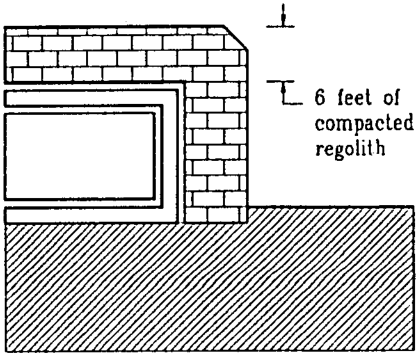
Compacting the regolith

Digging regolith

Protection from Radiations:

The base is protected from radiations by a layer of compacted regolith.

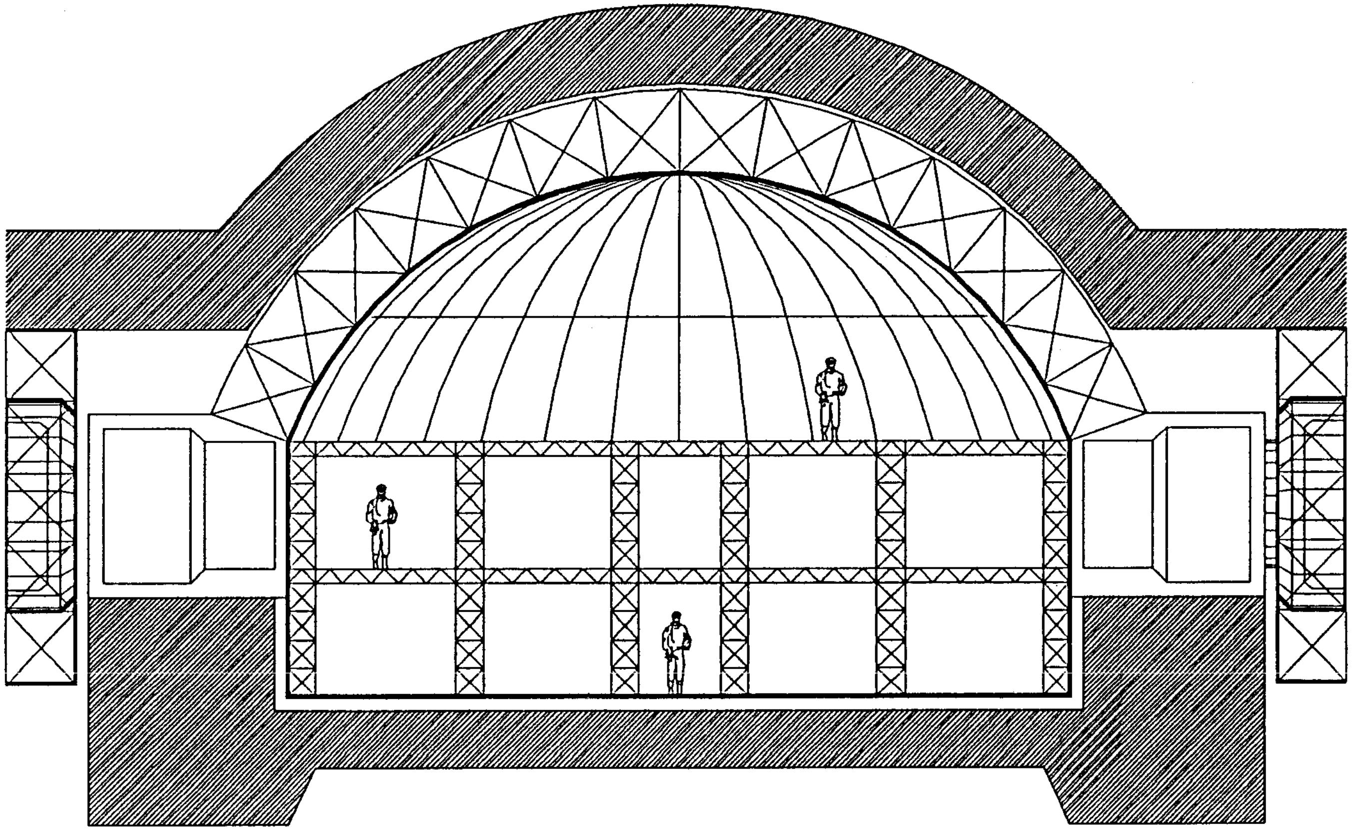
Covering an area of 5750 sq ft requires about 100,000 cubic ft of compacted regolith. Since the volume of unpacked regolith will be reduced to 1/3 when compacted, the amount of unpacked regolith needed is about 300,000 cubic ft.



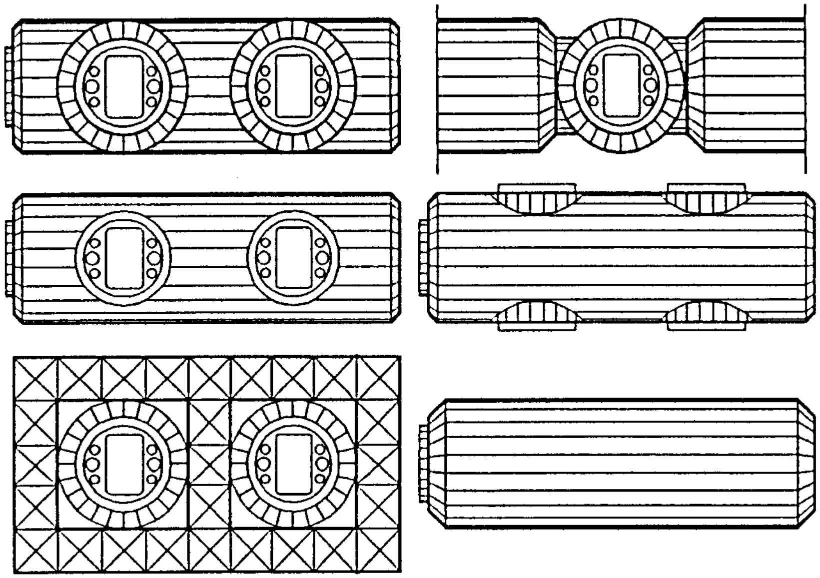
6 feet of compacted regolith

Area:	Depth:
Site 5750 sq ft	52 feet
Football Field	5 feet

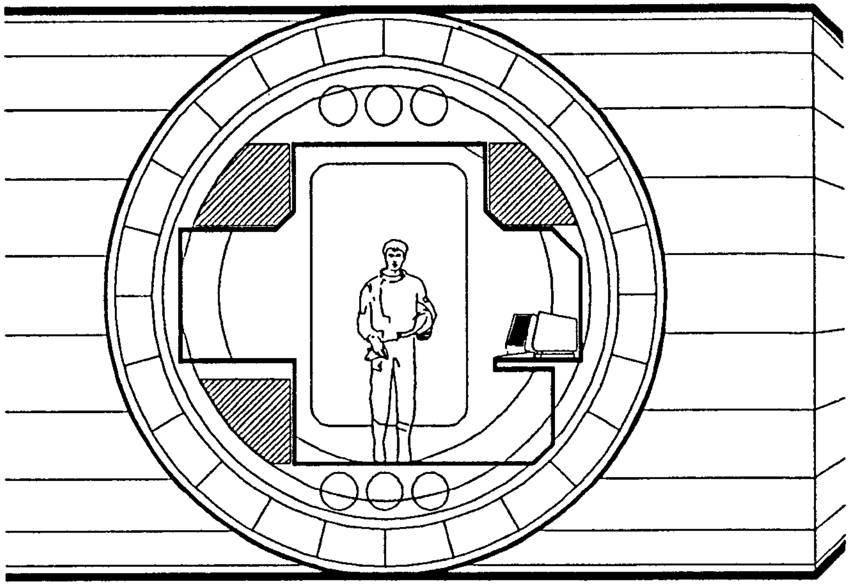
About 10 x Site



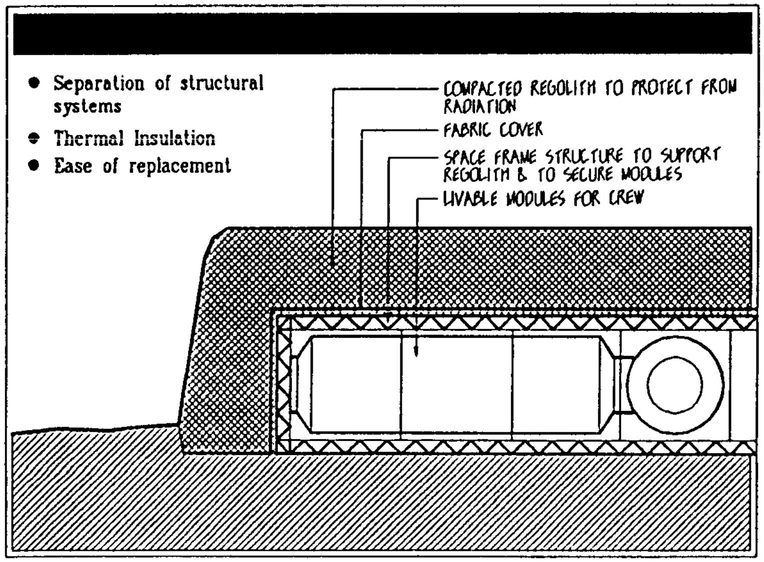
Section through large central dome area. The expanse is created using space frame construction and would be utilized for large scale operations such as lunar materials processing and storage.



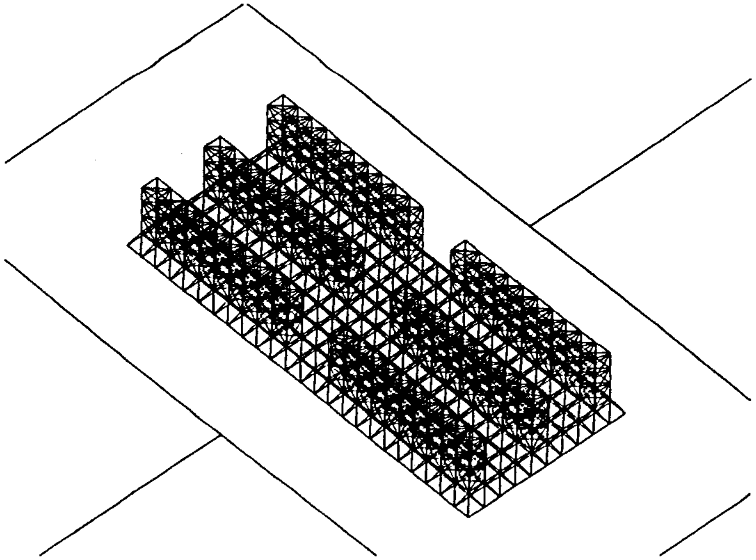
Habitat module elevations showing links. The diagram demonstrates how the modules are placed in the exterior shielding structure.



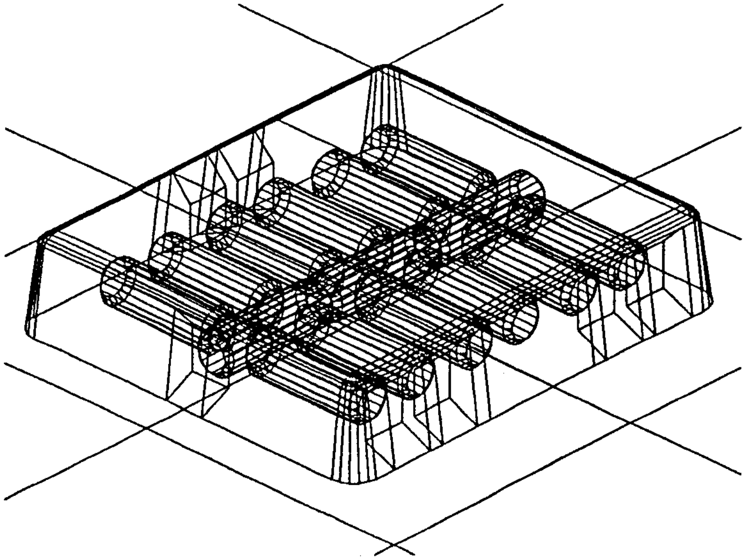
A Section through a module link. The section shows the relationship between the pathways and the communication/life support links.



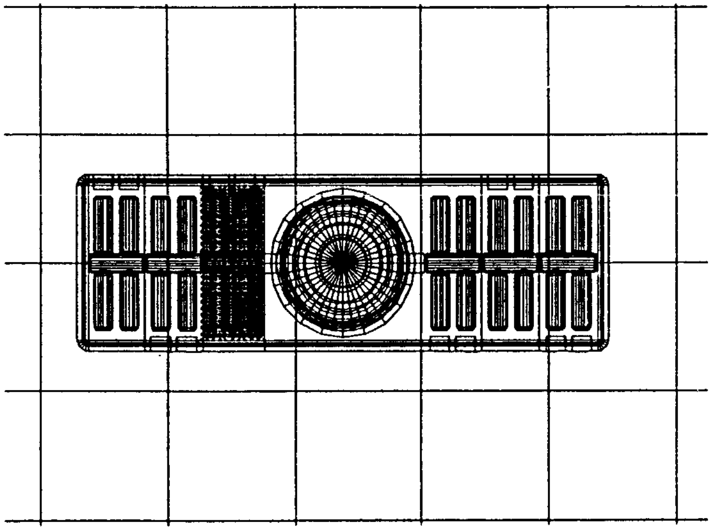
- Separation of structural systems
- Thermal Insulation
- Ease of replacement



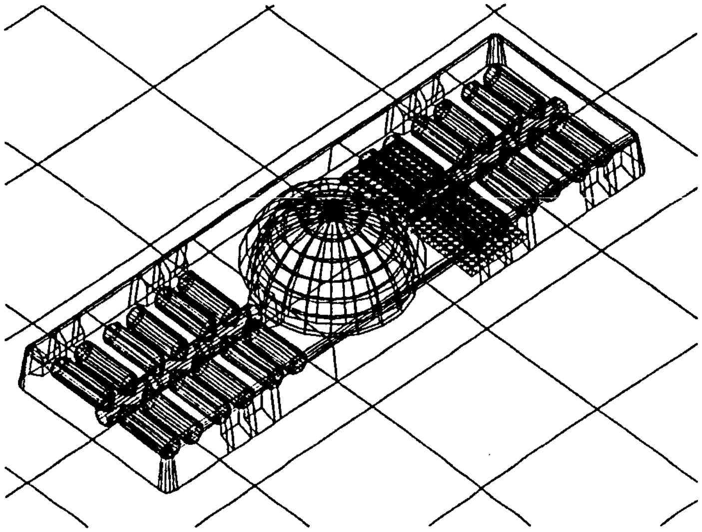
Isometric of shielding superstructure.



Isometric of module placement in phase 2 of development.



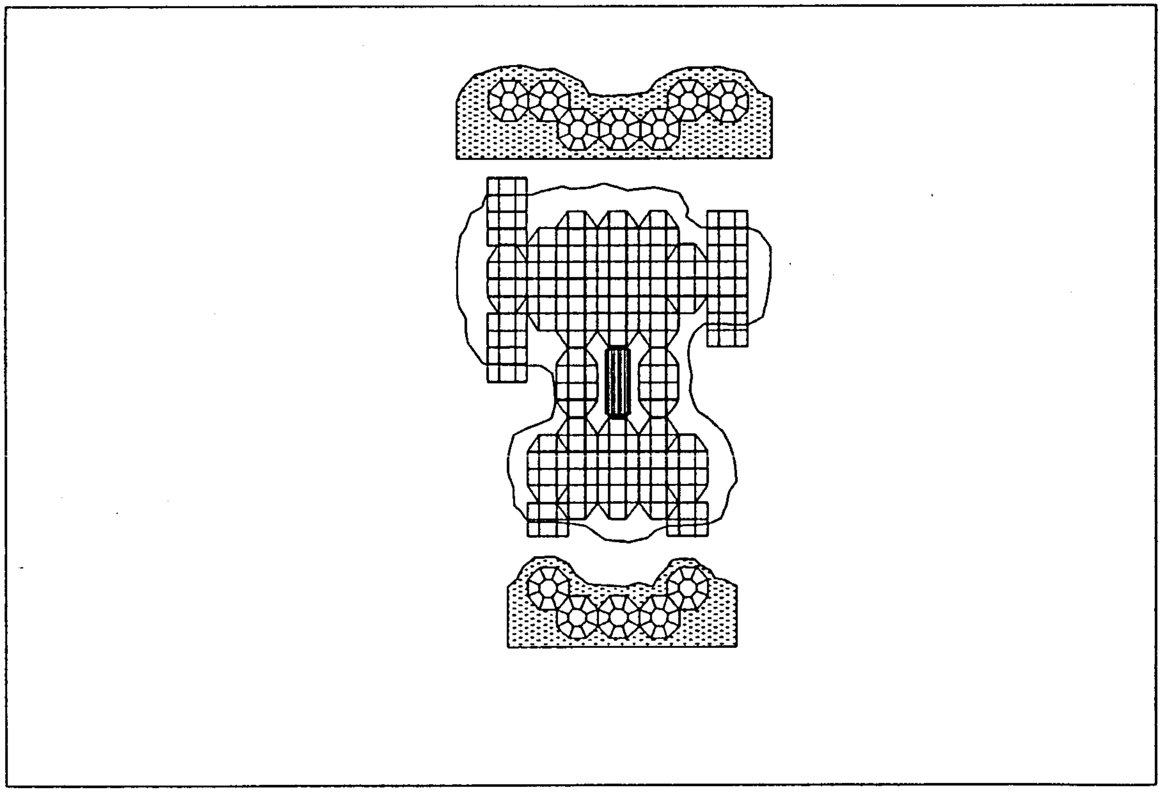
Plan view of fourth phase base design.



Isometric of base showing domed structure.

LUNAR STATION S-SPAN

Timothy K. Luettgen



The primary objectives of this project were three fold. Most important was the concern to create spaces which were larger than the primary habitation module. Secondly, to allow for expansion in a number of different directions and finally to permit easy access to damaged components from the interior of the station. The module shape is circular to resist atmospheric pressures, allow easy access and permit a range of site conditions.

The modules would be buried under the necessary depth of compacted regolith to provide adequate radiation and meteorite protection. Lunar surface interface modules have attached canopies extruding from the entrances also covered with a protective layer of compacted regolith.

The lunar constructed modules are 25 feet in diameter and ccomposed of a prefacbricated kit of parts. All environmental and energy supply systems are located along a central corridor which links to the entry hatch of the earth constructed first-phase modules. This core would then also serve as the primary circulation system for the base.

The interior structural systems employ a tension construction method and attach to the shell framework. Floor spans, walls, storage and eqiupment are hung from these tension members. All systems are serviced through the central core and can be completely isolated if required.

The construction sequence would first involve the completion of the core airlock and its attchment to the existing modules. From the central airlock, strut framework is extended outward to form a octagonal structure and insulated panels are attached to the framework. Additional habitation modules can be attached along any of the eight sides.

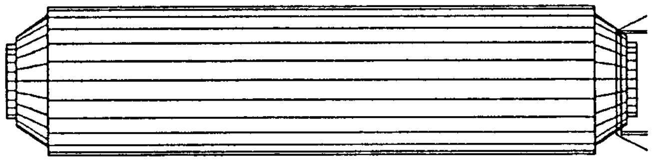
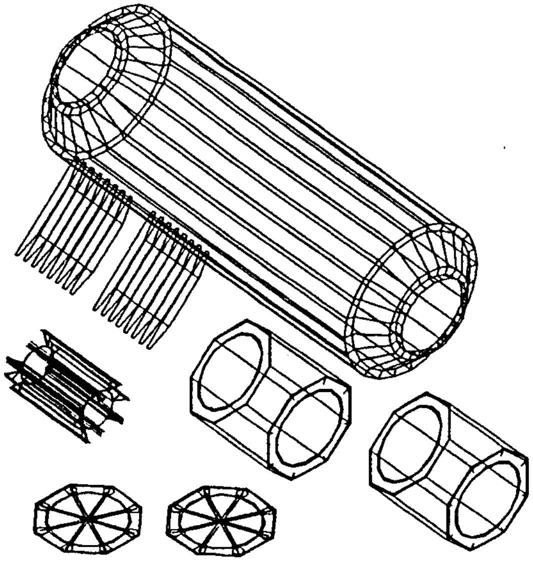
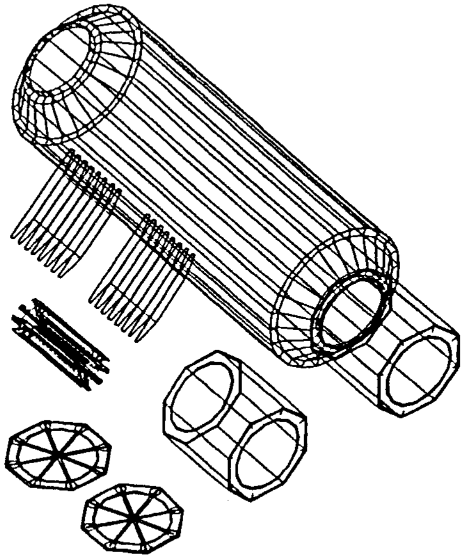


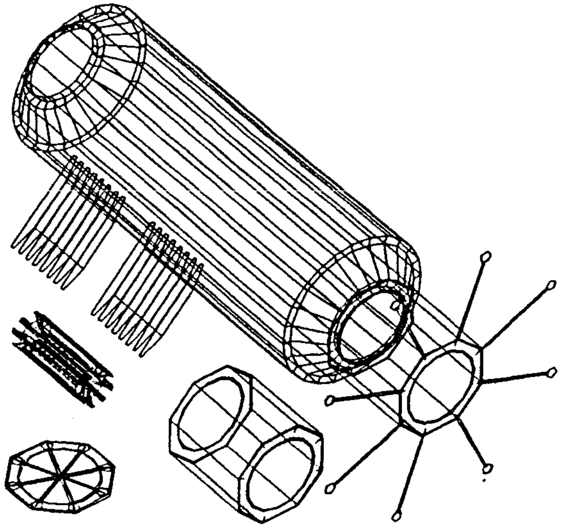
Diagram of earth manufactured exploratory module



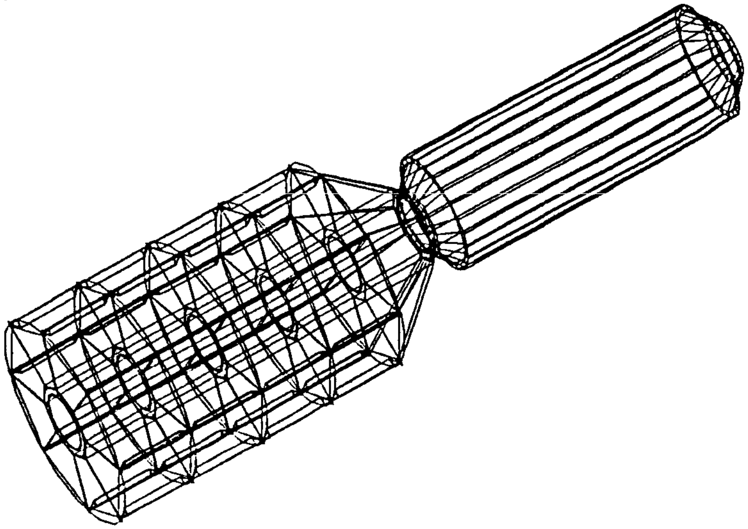
Parts required for lunar assembled modules



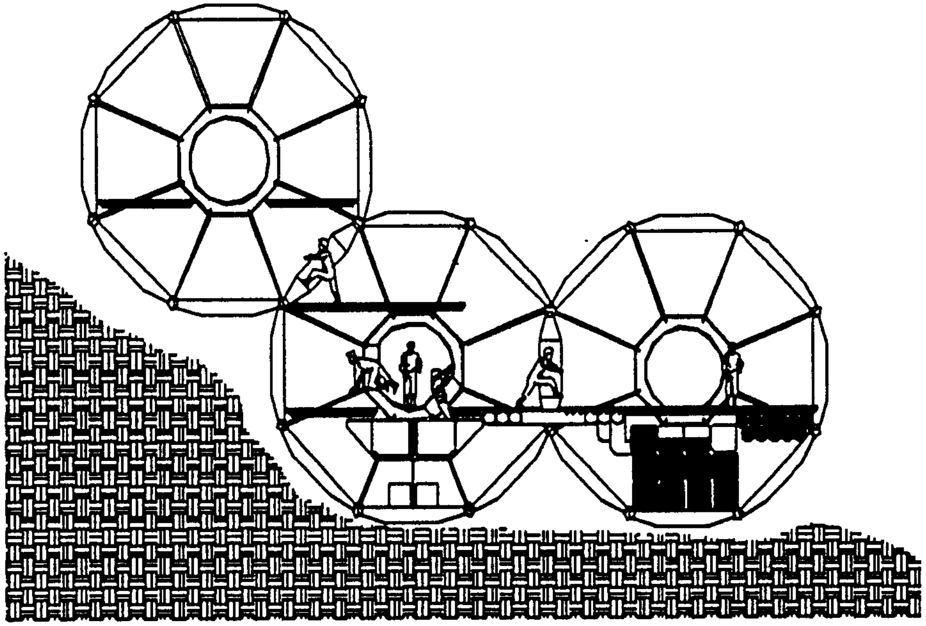
Construction of passageways is first step in units' assembly



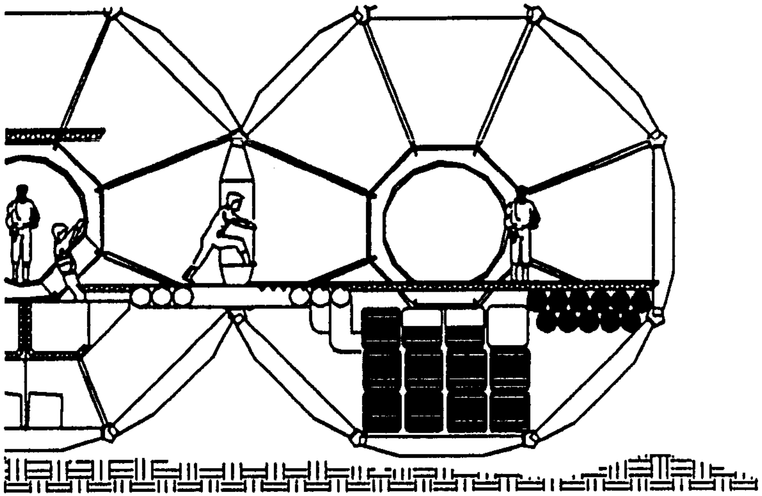
Assembly of radiating storage and living quarters.



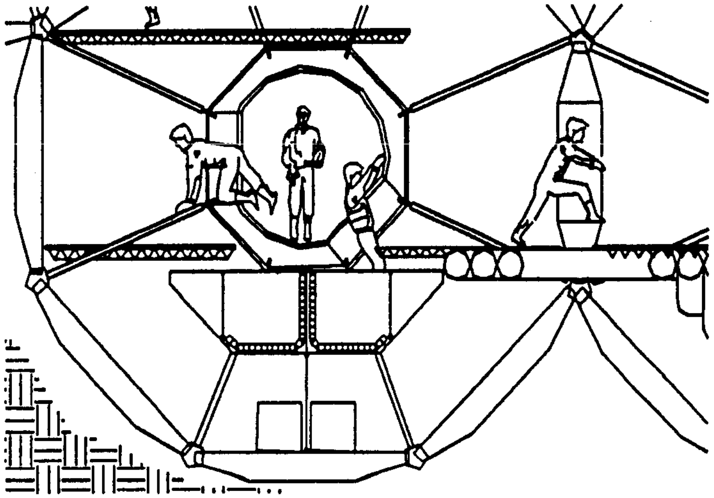
Completed expansion module linked with exploratory module.



Master base section through expansion modules

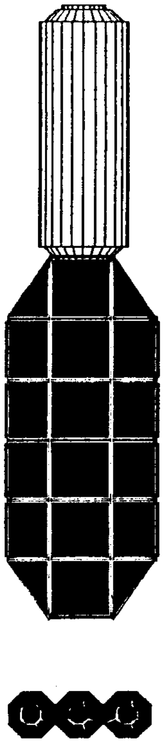


Detail of storage module and link to other modules

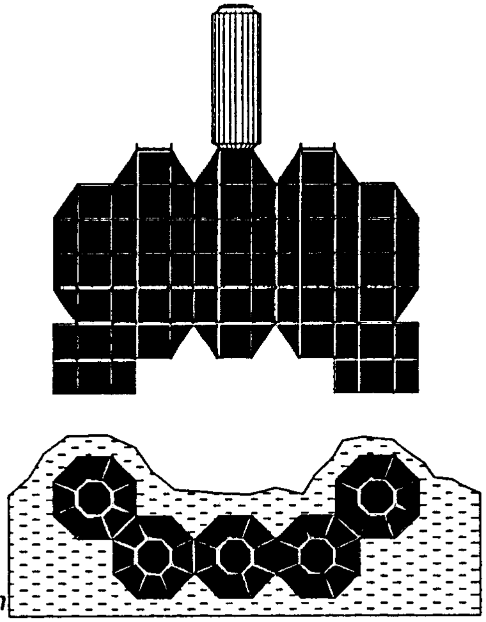


Detail of living quarters

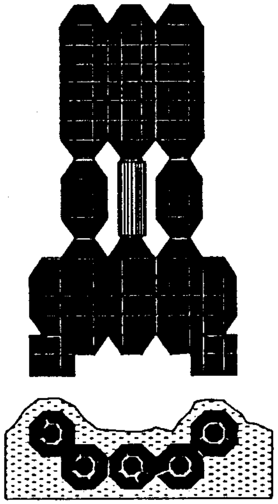
Phase 1 development



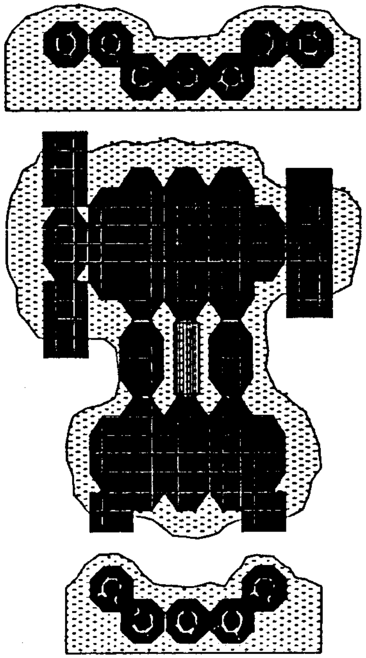
Phase 2 growth



Phase 3 growth

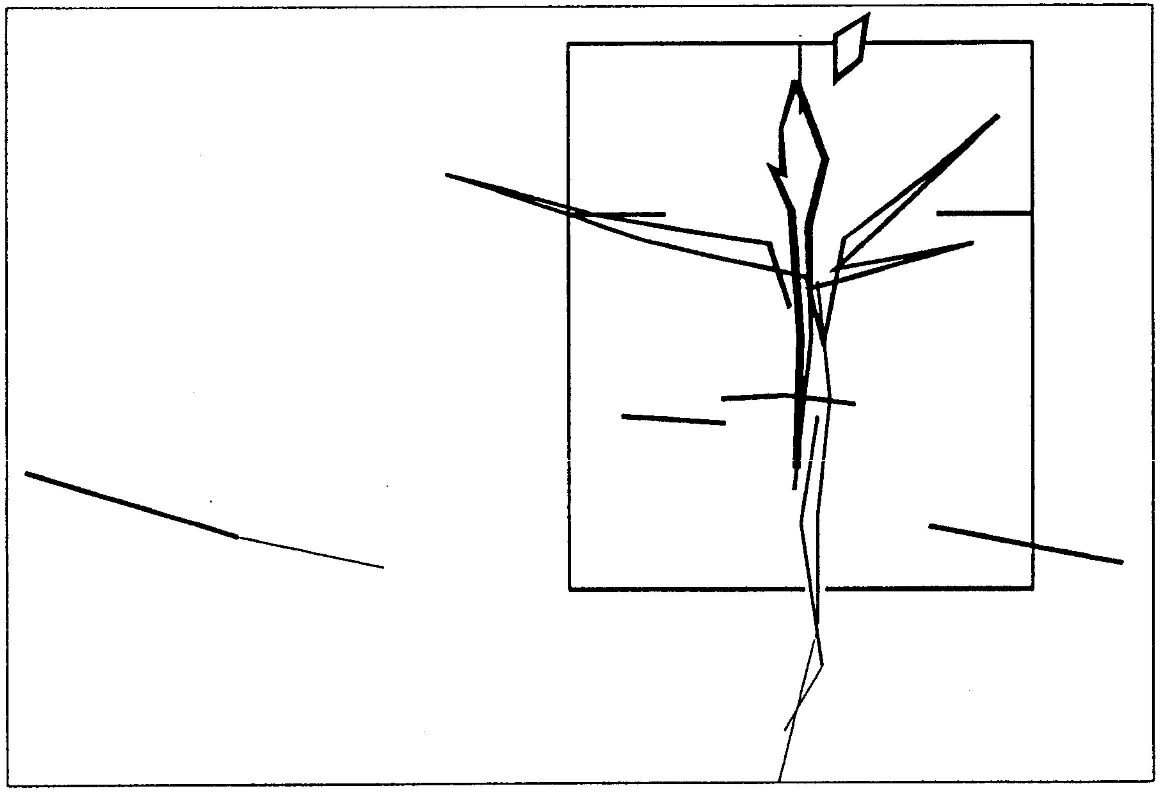


Phase 4 growth



MOON BASE ELANVITAL

Hairuddin Munip



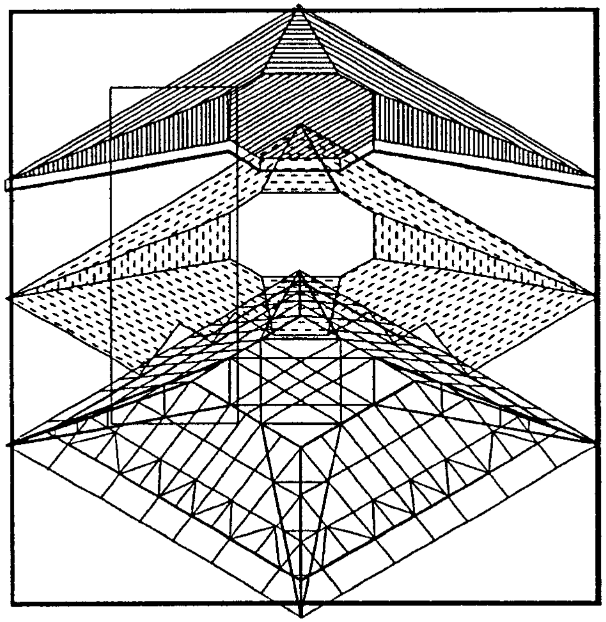
A study of the growth patterns of a lunar base was the primary objective of this solution. Conceptually, the base phasing is likened to the growth of a seed. As the base expands, parts will take on more specialized functions. All the construction components are utilized in the in the final base layout and many serve differing purposes throughout the construction process.

The expandable shielding protection is a separate entity from the habitation modules. Compacted regolith serves as the radiation protection material and is placed above the shield infrastructure. The infrastructure loads are distributed in a pyramidal fashion to the sides and corners.

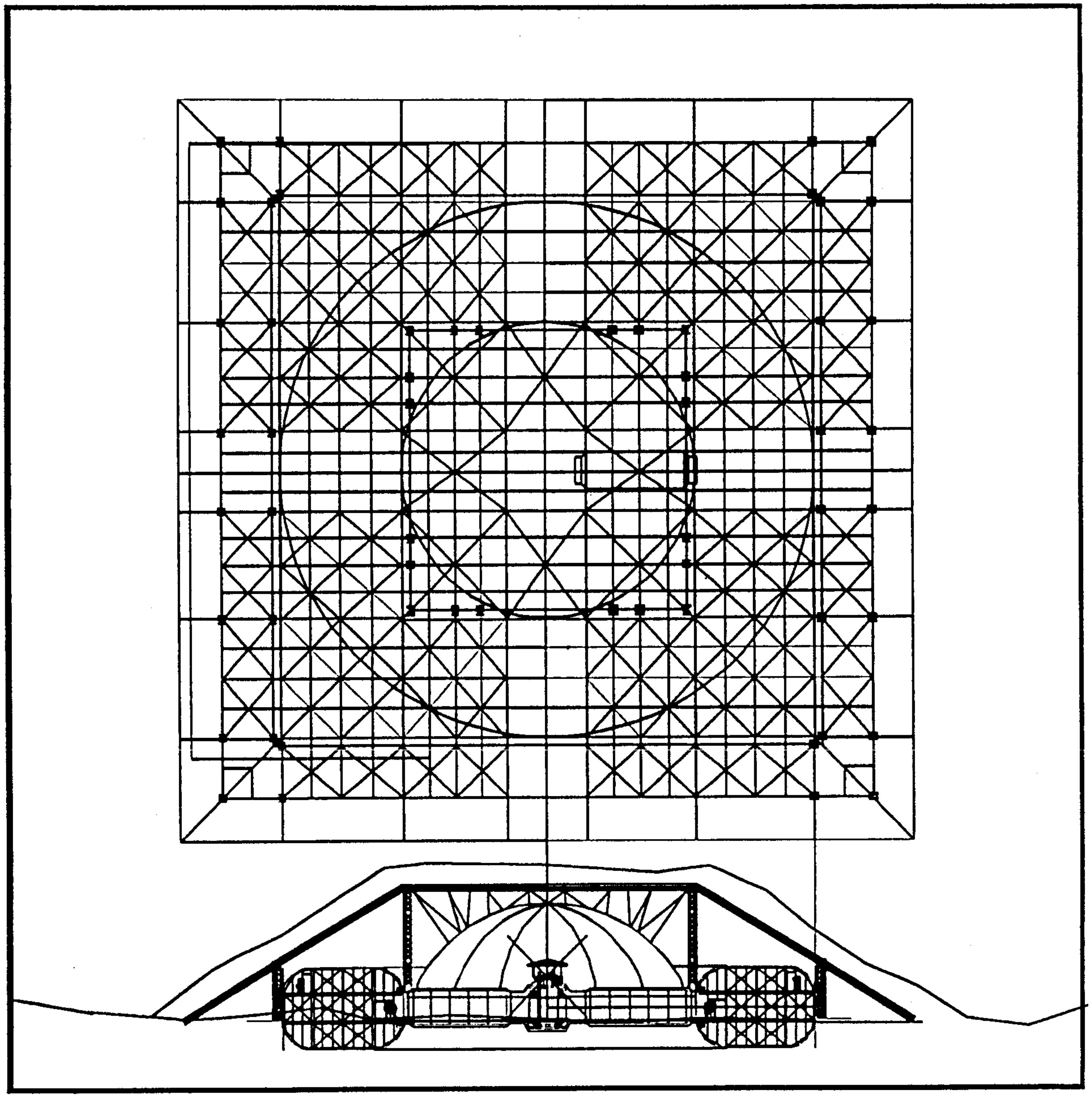
The habitation modules utilize an interior system based on tension elements. The large central membrane dome also operate under fabric tension technology. This dome is dependant on the interior pressure to maintain its shape. "Hard" habitation modules are constructed using a panel system and assembled in a circular fashion around the earlier earth manufactured modules. The information and supply system is linked with the major circulation paths along the perimeter of the base.

Interior systems are based on the open plan system and are easily adaptable for various sizes and needs. Space division is accomplished with hung fabric partitions. This system allows certain areas to become very personalized. The individual also has the ability to change their environment often if they wish to do so.

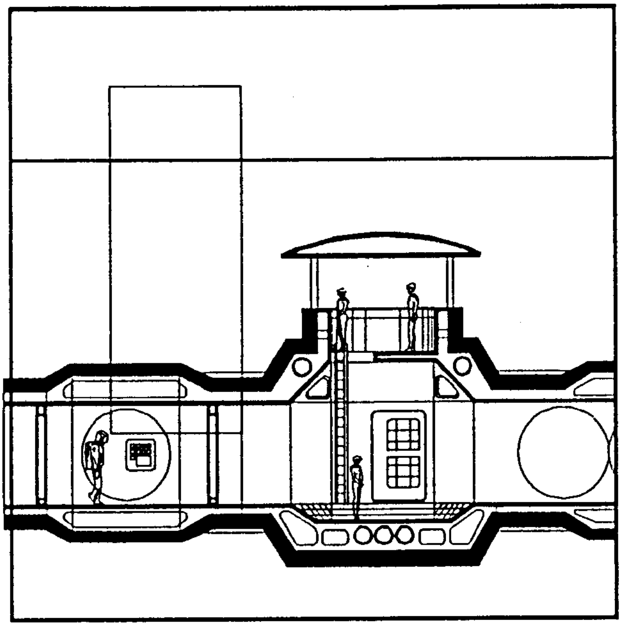
Construction of the base begins with the superstructure for the separate radiation shield since this construction is much faster than the habitat construction and the radiation shield is of such importance. Base design is analogous to a Bedouin lifestyle in which tent-like structures allow a quickly erected temporary shelter.

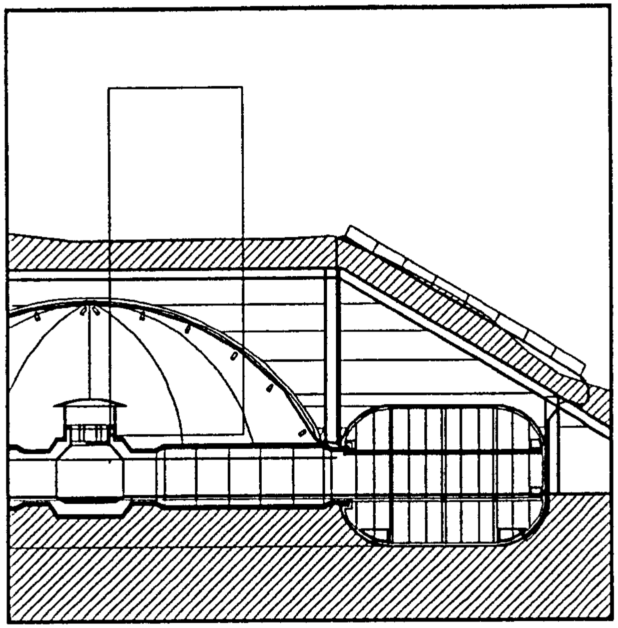


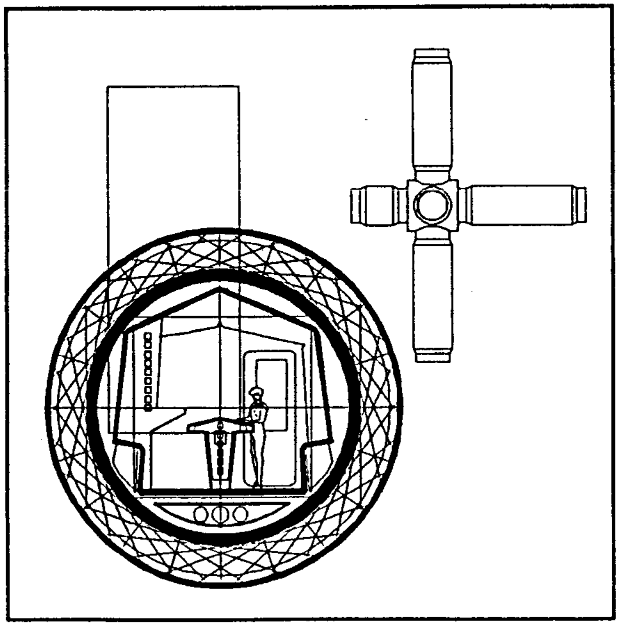
Radiation shield construction isometric.

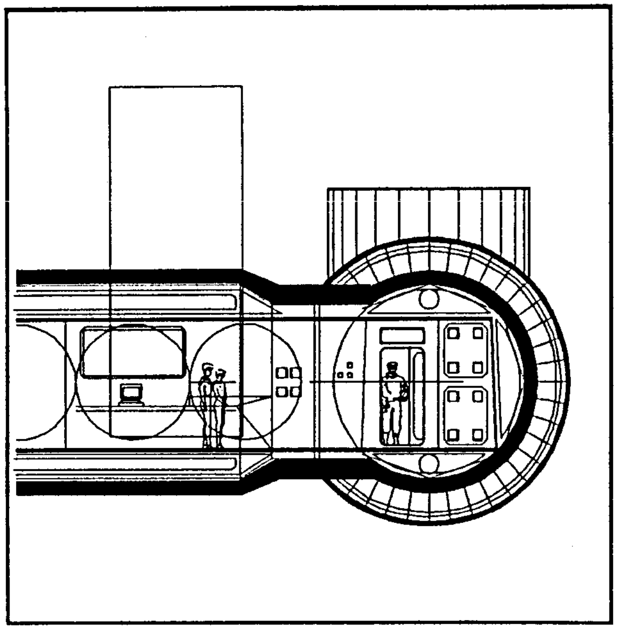


Base section and shield plan

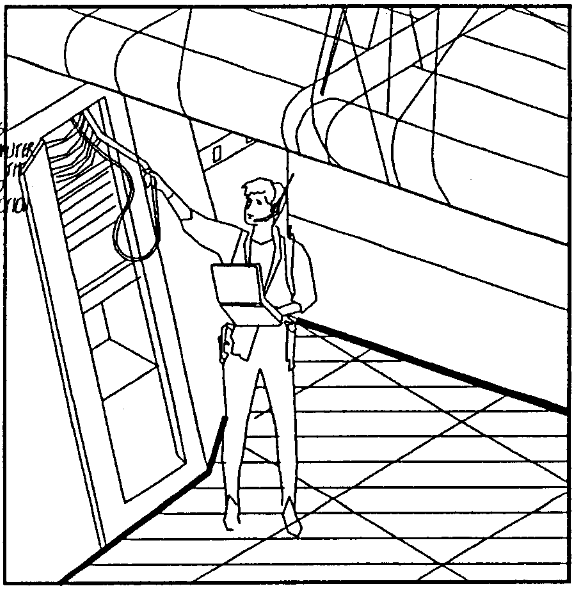






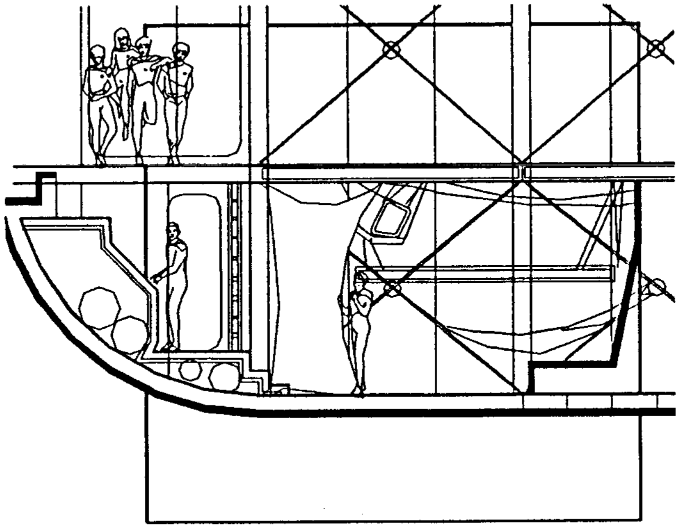


Accessing the communications/computer links.

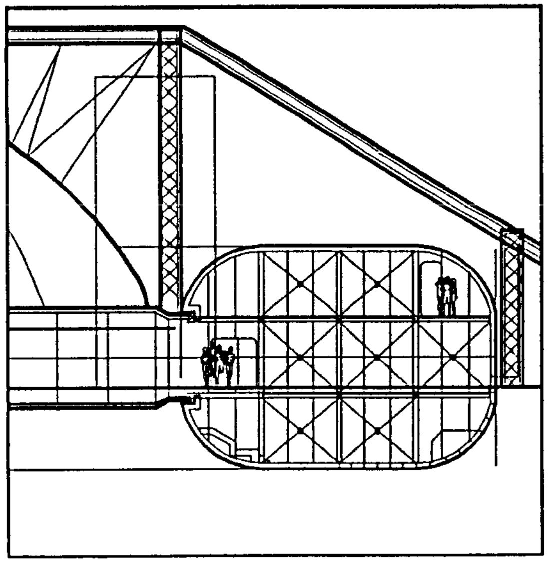


IF IN NEED OF
MINOR REPAIRS
THE MAIN COMPUTER
WILL ISOLATE THE
PROBLEMS AND
GIVES INSTRUCTION
TO THE
REPAIR CREW.

Systems repair/replacement



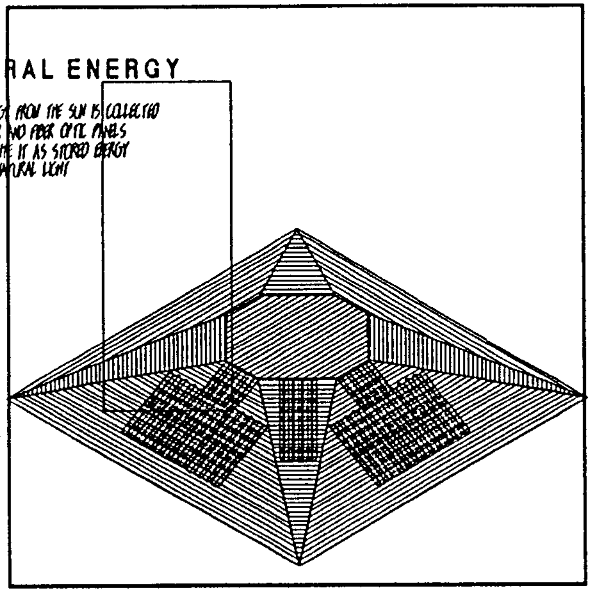
Living quarters detail

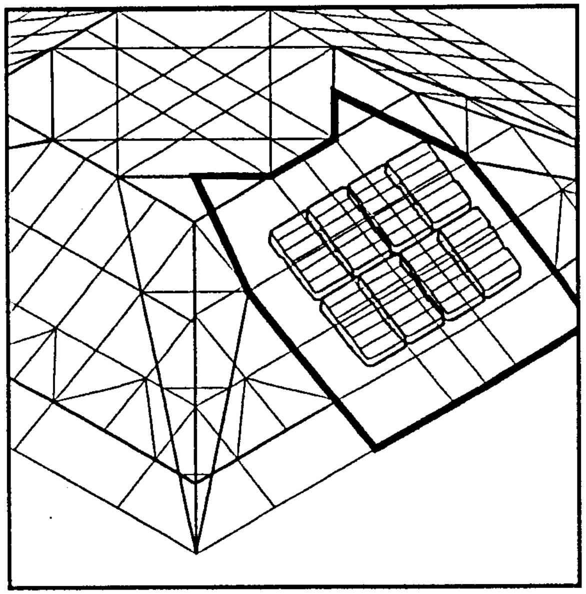


Expansion ring section

NATURAL ENERGY

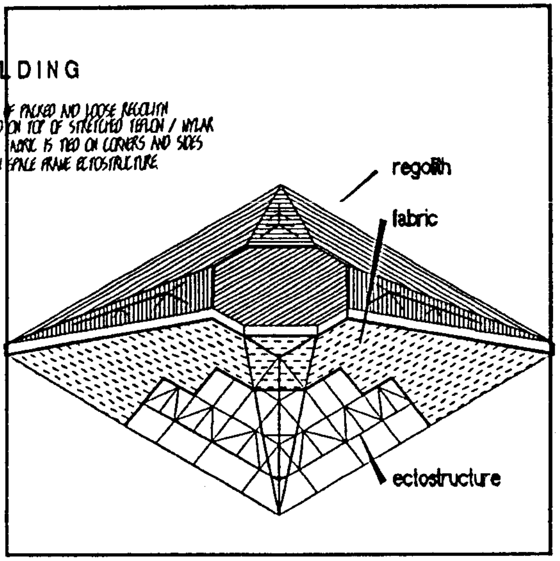
NATURAL ENERGY FROM THE SUN IS COLLECTED BY THE SOLAR AND FIBER OPTIC PANELS THAT DISTRIBUTE IT AS STORED ENERGY AND PURIFIED NATURAL LIGHT





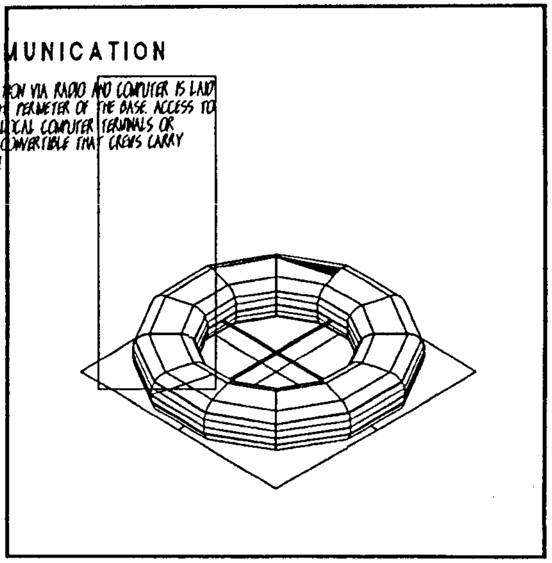
SHIELDING

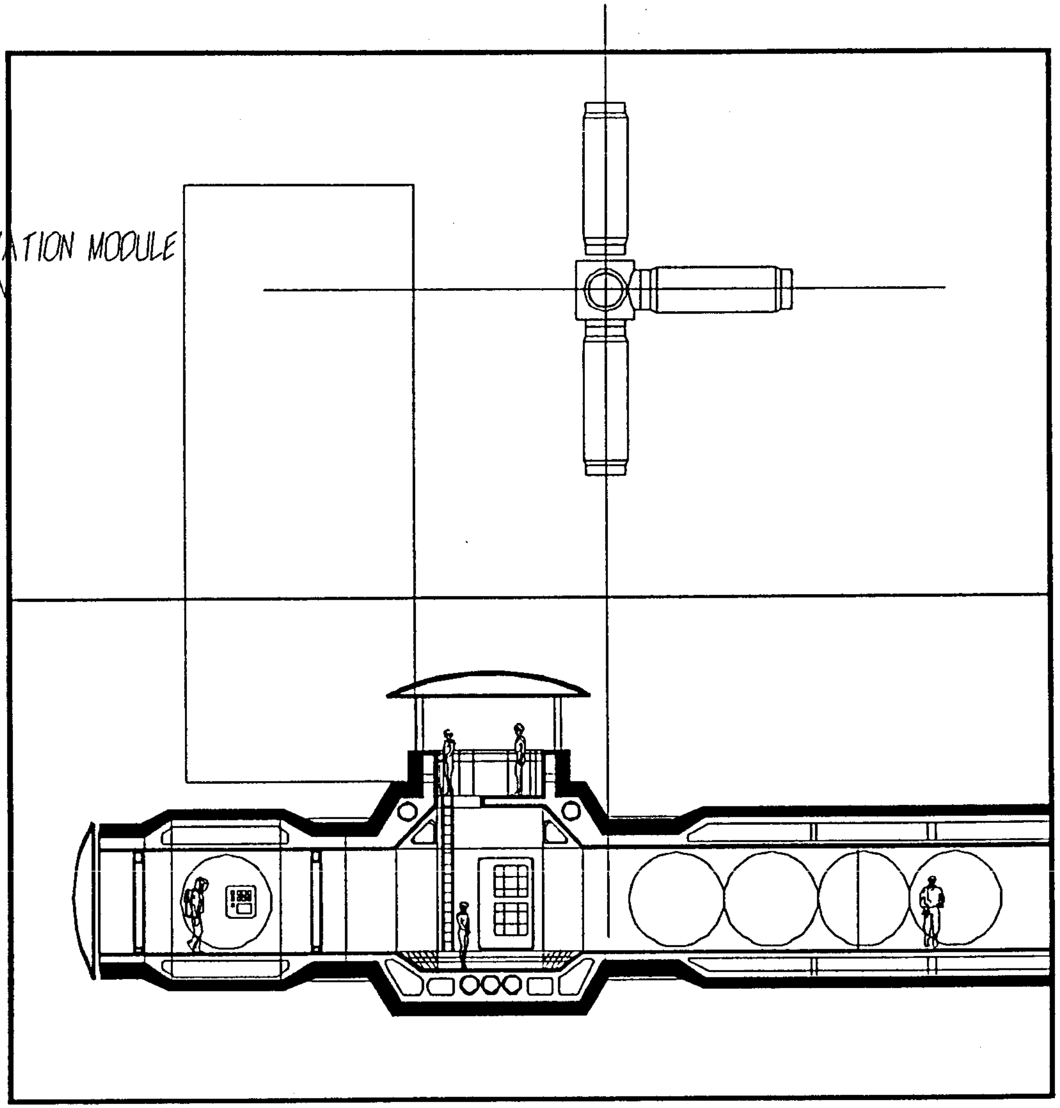
COMBINATION OF PACKED AND LOOSE REGOLITH ARE LAYERED ON TOP OF STRETCHED TEFLON / MYLAR FABRIC. THIS FABRIC IS TIED ON CORNERS AND SIDES TO THE MAIN SPACE FRAME ECTOSTRUCTURE.



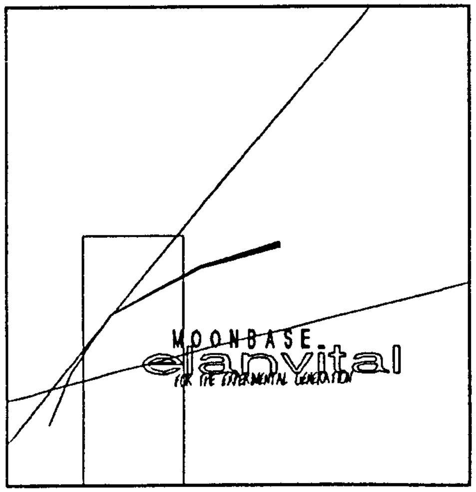
COMMUNICATION

COMMUNICATION VIA RADIO AND COMPUTER IS LAID OUT ON THE PERIMETER OF THE BASE. ACCESS TO IT IS VIA LOCAL COMPUTER TERMINALS OR PERSONAL CONVERTIBLE THAT CREWS CARRY WITH THEM





OBSERVATION MODULE SECTION



PROJECT SUMMARY

Thomas M. Crabb and Mark K. Jacobs
Managers, Space Station/Manned Basing
Astronautics Technology Center
Astronautics Corporation of America

The students and faculty of the University of Wisconsin-Milwaukee School of Architecture and Urban Planning can be proud of the quality of effort put forth in this first studio class on Lunar Base Architecture. In the approaching era of long duration space operations, the ideals and fundamentals of architecture must be applied to efficiently, productively, and comfortably support the activities of humans beyond our terrestrial, everyday life. A major architectural challenge exists to derive a new set of references and criteria because standards of terrestrial architecture do not apply. However, the ultimate architectural design objectives remain applicable. The process of applying architectural objectives and approaches to the lunar base in this studio created an innovative learning environment for students, faculty, and ourselves.

Members of the aerospace industry, including the Astronautics Technology Center in Madison, Wisconsin, met with the class throughout the semester to provide specific information as input to the architectural design of an evolutionary lunar base as well as comments on the students' design approaches. The interaction of students with private industry created an excellent environment for innovative ideas. At the start of the class, students were provided with data on the lunar environment and lunar surface characteristics. Information on previous lunar base concepts was reviewed and basic design requirements for construction and operation on the Lunar surface were determined. Each team of one to three students began design work on their own lunar base concepts using computer-aided design techniques. Each team took a unique approach to the problem covering many aspects of establishing a lunar base. Major concerns included minimization of transportation costs, use of modularity for expansion, use of internal volume, protection from the lunar environment, base construction, and safety.

The students presented their concepts and showed how they dealt with major concerns of lunar base development in "pin-up" sessions. These sessions provided an excellent forum for student-faculty-industry interaction. The students demonstrated a remarkable increase in awareness of the technical problems and human factors associated with costly transportation and long duration operations of an evolutionary lunar base. Some concepts demonstrated initial construction objectives including module placement and regolith management operations for radiation protection. Others stressed the strategic placement of these modules to maximize safety, base operation efficiency, and future base expansion. Specific innovative concepts which should be continued include: use of truss structures for radiation shielding with lunar regolith, evolution from small modular components to large enclosed volumes, regolith management for radiation protection, material selection for internal habitat components/structures, site preparation techniques, and the use of lunar resources. Overall, the students' concepts demonstrated good comprehension of critical issues in lunar base development.

The students, under the direction of Tony Schnarsky and interaction with professionals in advanced space development fields, gained valuable architectural experience and knowledge working on what may be one of the greatest accomplishments of the architectural, engineering, and human factors disciplines -- a permanently manned extraterrestrial base.

We look forward to a continued working relationship.

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