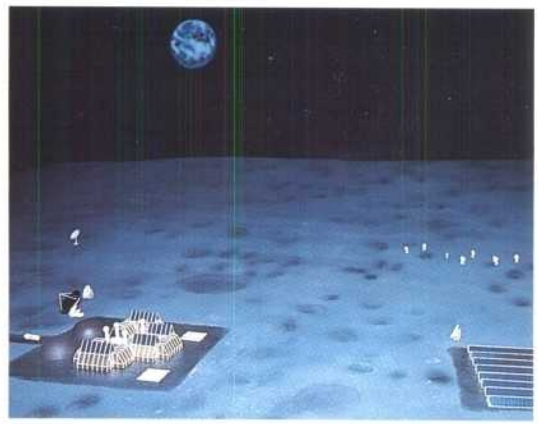
Vol. 2, No. 4: Oct.-Dec., 1989
Special Design Project Issue

SICSA OUTREACH
Sasakawa International Center for Space Architecture

The Manned Lunar Outpost (MLO): a NASA/USRA-Sponsored Study

On July 20, 1989, the 20th anniversary of the date when humans first set foot on the surface of the Moon, President George Bush put forth his administration's agenda for the coming decade in space and beyond "...for the 1990s, Space Station Freedom, our critical next step in all our space *endeavors. And* next, for the new century, *back to the Moon. Back to the* future. And *this* time, *back* to *stay. And then, a journey into* tomorrow, *a journey* to *another planet; a manned mission to Mars":*

President Bush's commitment to a renewed presence on the Moon and manned exploration of Mars are consistent with key recommendations released in a July, 1986 report prepared by the National Commission on Space which emphasized "natural progression for future space activities *within the* Solar System"; and "establishing *human-tended* lunar surface *outposts,* primarily for a variety *of scientific studies" :* A NASA task group headed by astronaut Sally Ride endorsed these recommendations. Their report titled, *Leadership and* America's Future *in* Space released in August, 1987, concluded: "The *establishment of* a lunar *outpost would be* a significant step outward from *Earth,* a step that combines *adventure, sciences, technology, and perhaps the seed of enterprise. Exploring and prospecting the Moon, learning* to *use lunar resources and work within lunar constraints would provide the experiences and expertise necessary* for further *human exploration of the Solar* System ".



Site Model of a Mature Lunar Base

GENERAL DYNAMICS
Space Systems Division
1300 Hercules, Suite 204, Houston, Texas 77058
PO Box 85990, San Diego, California 92138

Brown & Root U.S.A., Inc.
A Halliburton Company
Post Office Box 3, Houston, Texas 77001-0003

SICSA is grateful to General Dynamics, Space Systems Division in San Diego and Houston; and Brown & Root, Inc. for donating funds to cover printing costs for this issue.

MLO Rationale

A permanently manned lunar outpost can be an important element of a space transportation and operations infrastructure to support exploration of other planets. Such an initiative can greatly advance scientific knowledge and progress towards realizing self-sufficiency as well as possible industrialization of near-Earth space. Useful products can include plants grown for dietary supplements, oxygen for breathing and propellant, helium-3 for nuclear fusion power, and a variety of materials for construction. Examples of construction products are structures and components made of sintered and cast basalt, anhydrous glass, lunar concrete and metals.

The *Manned Lunar Outpost (MLO)* described in this report proposes early construction and operational stages for a much more expansive and potentially self-sufficient development which will evolve over time. Important study objectives are to document key factors influencing site planning and architectural design. Preliminary design ideas presented herein are intended only as conceptual scenarios for illustration purposes.

Key MLO Applications

Science and Technology

- *Studies of the Solar System's origin and features.*
- *Physics and astrophysics research in a high vacuum space environment.*
- *Medical/physiological research for planetary exploration programs.*
- *Plant growth experiments, potentially leading to lunar agriculture.*
- *Testbed for Mars surface operations and technologies.*

Lunar Resource Utilization

- *Oxygen processing for breathing, propellant and power.*
- *Ceramics, glasses and metals for structures and components.*

MLO Design Priorities

Efficient Implementation and Operations

- *Effectively utilize the Space Station Freedom and available Space Transportation System as an infrastructure to support assembly/transfer of structures and materials to and from the lunar surface.*
- *Utilize available and proven equipment systems and procedures where possible to minimize R&D costs, test requirements and failure risks.*
- *Achieve the highest practical level of self-sufficiency at the earliest possible stage of development to minimize material resupply costs.*

Versatility and Value

- *Plan accommodations to support a broad range of worthwhile scientific, technological and industrial uses warranting international/public support.*
- *Emphasize modularity in the design of habitats and equipment systems to facilitate evolutionary changes and updates.*
- *Incorporate means to achieve economical expansion of facilities and operations over several decades of use.*
- *Accommodate experiments to determine the feasibility of large scale mining and processing of lunar materials.*

Human Safety and Productivity

- *Provide means to protect the crew from radiation and other health/safety hazards within habitats.*
- *Provide crew support and safety measures to extend crew duty cycles to practical limits, minimizing personnel rotation requirements and costs.*
- *Design systems to provide easy servicing access for routine and emergency maintenance.*
- *Incorporate automated, teleoperated and robotic systems where possible to minimize crew labor requirements and work hazards.*
- *Design habitats and equipment systems to optimize human comfort, convenience and satisfaction.*

MLO Study Considerations

Mission Requirements

- *Space transportation requirements to establish surface facilities/operations.*
- *Science activities/equipment influencing site selection and facility planning.*
- *Equipment and procedures for collecting, separating, processing and utilizing lunar materials.*
- *Facilities and support systems for lunar agriculture/aquaculture to reduce dependency upon food supplied from Earth.*
- *Special support requirements, including labor, automation/robotics and logistic resupply needs that influence operations, transportation and scheduling.*

Site Selection

- *Features of candidate sites that influence potential mission applications.*
- *Influences of candidate sites on* Space Station Freedom *and space transportation operations and schedules.*
- *Influences of candidate sites upon facility construction and power systems.*

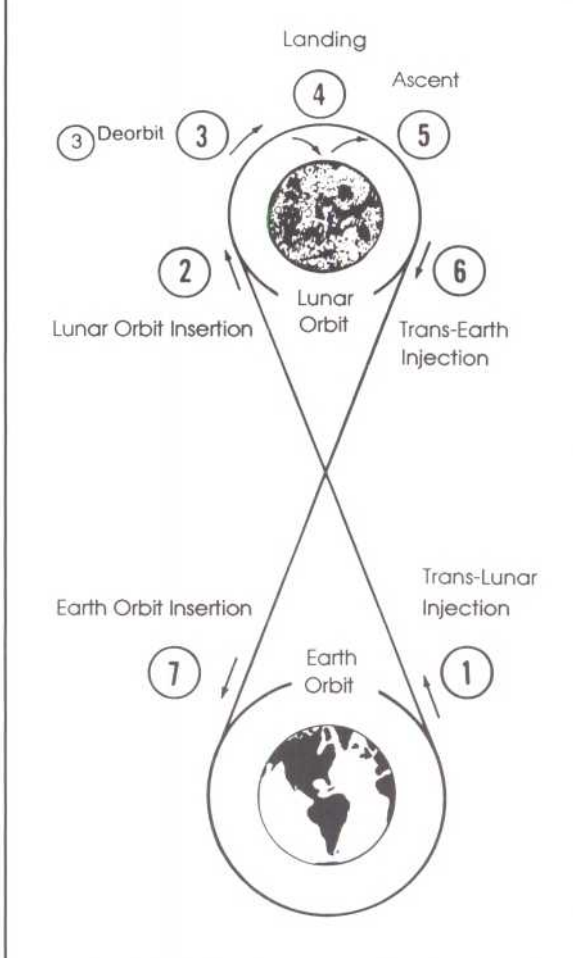
Surface Systems

- *Living and work habitats including support systems and interior furnishings.*
- *Pressurized enclosures and environmental support systems for lunar agriculture/aquaculture experiments.*
- *Utility systems, including life support, waste treatment/recovery and power.*
- *Site preparation and construction equipment for grading/excavation, load transfer and assembly of structures.*
- *Surface transportation systems for personnel, materials and equipment.*
- *Hangars and repair facilities for surface transportation and industrial mining/processing equipment.*
- *Pressurized and unpressurized storage for fuel and processed materials.*
- *Landing/launch pads with accommodations for vehicle refueling and servicing.*

MLO Support Requirements

Constraints imposed by high costs to transport people, equipment and supplies to and from the MLO site dramatically influence nearly all aspects of planning. This study assumes that a fleet of heavy lift launch vehicles is available.

The space transportation infrastructure systems to support the MLO must include orbital nodes with accommodations for vehicle servicing/refueling, assembly of large structures, and transfer of payloads to and from the lunar surface. This study assumes that Space Station *Freedom* is fully operational, potentially augmented in its MLO services by other transfer depots and assembly facilities (spaceports) in low-Earth and/or lunar orbits.



Earth-Lunar Transportation Concept
Source: NASA JSC. *1989. Lunar Outpost. JSC-23613.*

Research Applications

The MLO can accommodate personnel who will undertake research that will yield information about the Solar System and requirements posed in its exploration by humans. Astronomical studies can utilize automated and teleoperated devices installed at sites which are remote from the MLO, including locations on the Moon's far side. A major MLO benefit will be to support installation, monitoring and periodic maintenance of these systems.

Astrophysics and physics experiments using MLO surface detectors can measure and record solar winds, cosmic ray bombardment and the effects of these and other factors upon various physical processes. Data can be analyzed at the MLO and/or transmitted to Earth for processing.

Geology and geoscience research will entail surface EVA missions. Typical equipment includes portable fluorospectrophotometers, seismometers, radiation detectors, and core drilling/ sampling devices. Some data would be analyzed by MLO crew and computers. Soil and rock samples would be sent periodically to Earth.

Studies of human acclimation to the lunar environment must involve both physiological and psychological testing. Non-invasive techniques should be emphasized to analyze immunological, metabolic, hormonal and anatomic reactions to extended low gravity exposure and other environmental conditions. Typical equipment includes EKG and heart rate monitors and exercise/diagnostic devices.

Plant, animal and microbial studies will investigate ways the lunar environment affects reproduction, growth and vitality of a variety of living organisms. Important concerns are health maintenance and disease control; candidates for food production; and potential support systems for lunar agriculture/aquaculture. Important facility elements will include growth chambers, cages and fish tanks with means to control contamination, atmospheric pressure, temperature, humidity and light.

Science and Technology

Space and Planetary Sciences

- *Astronomy – conduct Earth, Solar System and galactic studies using optical, radio and spectrographic methods.*
- *Astrophysics – study properties and influences of the Sun; measure cosmic rays, magnetic field, and other phenomena.*
- *Physics – conduct experiments benefitted by reduced gravity, high vacuum conditions on the Moon.*
- *Geology – conduct comprehensive surveys of the composition, structure and other properties of lunar soil.*
- *Geoscience – investigate seismic activity, thermal surface conditions, and effects of solar winds.*

Life Sciences

- *Human life science – determine the ability of people to adapt and perform under extended low gravity conditions.*
- *Plant and animal biology – identify and quantify effects of reduced gravity, radiation, and other environmental factors upon reproduction, growth and vitality.*
- *Microbiology – investigate use of microorganisms to extract volatiles from lunar soil.*

Technology Demonstrations

- *Automation – install teleoperated and automated robotic systems to excavate, move and process lunar soil.*
- *Material processing – test hardware systems and procedures that can extract/ produce useful materials from lunar soil.*
- *Environmental systems – establish partially closed-loop systems to treat and recycle materials vital to life.*
- *Power systems – develop advanced power generation and storage devices.*
- *Waste management/storage – apply systems and procedures for treating, handling and containing hazardous materials.*
- *Construction – validate technologies to create structures using prefabricated elements and indigenous materials.*

Materials and Food Production

Mining and Material Handling

- *Exploration – determine preferred mining locations in the lunar maria and highlands considering site accessibility, abundance of materials and geological/environmental factors.*
- *Demonstration – determine the most efficient and reliable means to acquire large quantities of material.*
- *Transportation – determine the best surface method to move large quantities of regolith, processed materials and wastes considering capacity, automation potential, range, modularity and maintenance requirements.*
- *Storage – demonstrate means to safely and easily store and transfer processed pressurized gaseous and liquid materials.*

Material Processing

- *Oxygen – determine which processes can most economically and reliably produce oxygen from regolith considering energy requirements, yields, hardware mass, and automation potential.*
- *Cast basalts and glasses – demonstrate the feasibility of producing bricks and other structural components from lunar regolith using simple melting, casting, and extrusion processes.*
- *Concrete – demonstrate processes for producing concrete from lunar materials which require little or no water; evaluate characteristics and applications.*
- *Metals – demonstrate approaches for capturing/processing aluminum, titanium, and other metals from lunar soil.*

Agriculture/Aquaculture Experiments

- *Demonstrate and evaluate means to grow and process plants to supplement crew diets and ultimately reduce dependencies upon the need for food supplied from Earth.*
- *Demonstrate and evaluate means to grow and process seafood and animals as food sources.*

Technology Demonstrations

A key MLO function will be to undertake technology demonstrations to support scientific activities and advance industrial and agricultural programs. Some of these technologies may apply terrestrial systems and methods. Others developed specifically for space and planetary applications may have beneficial uses on Earth.

Harsh environmental conditions on the lunar surface and severe limitations on available crew time will require an emphasis upon teleoperated and automated robotic systems. Since the Moon has no radiation-absorbing atmosphere, nor magnetic field to deflect radiation transport of cosmic ray nuclei, periods of extravehicular activity (EVA) must be minimized. Significant excavation and material processing operations, for example, will have to rely heavily upon systems and processes that demand little human intervention for control or servicing. The equipment must operate effectively and reliably under conditions of long-term exposure to temperature extremes and abrasive dust.

A major technological objective must be to develop and demonstrate closed, biologically-based life support systems. **Processes employed should be capable of collecting, separating and recycling valuable components of solid and organic wastes, including oxygen, hydrogen, nitrogen and carbon. These materials are esential for activities associated with human habitats and agriculture/aquaculture facilities. Nitrate solutions produced in fish and shrimp production, for example, can be used as nutrients for plant growth, which in turn will release oxygen.**

Candidate power system demonstrations include advanced nuclear generators and solar collectors with fuel cells for electrical/chemical storage. Helium-3, an isotope which is rare on Earth but believed to be abundant on the Moon, might be used as fuel for nuclear fusion power generation. Substantial amounts of energy will ultimately be required for industry-scaled lunar mining and material processing.

Environmental Influences

Planning of surface operations on the Moon must take important environmental conditions into account. For example, the 1/6 Earth gravity which can facilitate moving of large items also poses problems in creating resistance anchorage needed by soil excavation equipment. Radiation hazards limit allowable EVA time, and pressure suits reduce physical dexterity during these periods. Micrometeoroid bombardment and extreme temperature fluctuations will deteriorate exposed materials. Sticky, abrasive dust will cling to EVA suits and equipment, potentially creating friction in mechanical connections.

In 1610 Galileo characterized the Moon's surface according to two classifications: flat maria plains and heavily cratered, hilly terrae regions (or highlands). Maria regions contain both the smoothest and roughest surfaces, while the highlands have the steepest slopes and moderate roughness. Regolith, a fine sand-like material composed primarily of silica resulting from repeated meteroid impacts, covers maria areas to a depth of approximately one meter and highland areas to about 20 meters. Oxygen-rich basalt underlies regolith in the maria. Less dense subsurface materials containing substantial quantities of aluminum and calcium-rich rocks are prevalent in the highlands.

The most prominent features on the Moon, the highlands in particular, are craters. Some are as large as 227 km (141 mi) in diameter and 5 km (3.1 mi) in depth. There are two types of crater origin, one associated with volcanic activity and the other attributed to impacts of meteoroids or comets. The Moon also has mountains reaching as high as 6 km (3.7 mi) above the surface.

The Moon has two types of moonquakes: deep, periodic occurrences related to tidal stresses (<1 on the Richter Scale); and stronger, less well understood shallow occurrences (up to 5 or more on the Richter Scale) which may be related to thermal stresses. These forces should be considered in the planning of lunar facilities.

' In *Lunar Bases and Space Activities of the 21st Century,* Lunar and Planetary Institute, Houston, TX.

Moon Characteristics

General Properties

- *Mean distance from Earth: 384,403 km (238,863 mi).*
- *Diameter: 34,761 km (21,600 mi) (approx. ¼ of Earth).*
- *Axial rotation: 27.32 Earth days.*
- *Circular velocity: 1.68 km/sec (1.04 mi/sec).*
- *Average orbit eccentricity: 0.0549.*
- *Inclination of orbital plane to ecliptic plane: 5°-9′.*
- *Inclination of lunar equator to ecliptic plane: 1°-32′.*
- *Inclination of lunar equator to orbital plane: 6°-41′.*
- *Mass: 7.35 x 10^{25} gm (approx. 1/82 of Earth).*
- *Mean surface gravity: 162.3 cm/sec^2 (approx. 1/6 of Earth).*
- *Escape velocity: 2.38 km/sec (approx. 1/5 of Earth).*

Environment

- *Average daytime temperature high: 134°C (270°F).*
- *Average night time temperature low: -170°C (-270°F).*
- *Day/night length: 13.66 Earth days.*
- *Albedo: 0.07 (approx. 1/4 of Earth).*
- *Surface radiation: hazardous during large solar proton storms; constant galactic cosmic ray bombardment.*
- *Atmosphere: less than 10^{-13} of that on Earth (hard vacuum).*
- *Magnetic field: less than 10^{-3} of that on Earth.*
- *Seismic activity: magnitude of 5 or more possible.*
- *Surface material: fine, silica-rich sand and dust.*
- *Topographical features: craters, rilles, hills and high mountains.*

	Lunar Highlands Soils (%)	Lunar Low Titanium Mare Soils (%)	Lunar High Titanium Mare Soils (%)
SiO_2	45.0	46.4	42.0
TiO_2	0.5	2.7	7.5
Al_2O_3	27.2	13.5	13.9
FeO	5.2	15.5	15.7
MgO	5.7	9.7	7.9
CaO	15.7	10.5	12.0
Total	99.3	98.3	99.0

Major Element Composition of Lunar Soil
Allton, J.H., et al. 1985. "Guide to Using Lunar Soil and Simulants for Experimentation." '

Site Selection Considerations

Site selection for a *Manned Lunar Outpost* must take a broad range of considerations into account. Important types of influences include environmental priorities dictated by MLO research and technology requirements; available resources to enhance self-suffiency and possible future industrialization; topographical features impacting facility development and operations; accessibility to space transportation and logistics; and line-of-sight to Earth and orbiting spacecraft for communications and psychological contact.

There are presently a large number of unresolved programmatic decisions, technology issues and scientific questions that make MLO site recommendations premature at this time. It is possible, however, to build scenarios that reveal advantages and constraints posed by general MLO siting options. Comparative assessments of alternative possibilities can then be made to correlate near-term and evolutionary implications.

Specific lunar science objectives can be expected to influence site selection in fundamental ways. Locations on the far side of the Moon, for example, would offer radio interference-free access to the Solar System for radio astronomy. Site placement on the equatorial limb near a radio telescope facility could enable communications with Earth to be maintained. Lunar resource investigations, on the other hand, might take advantage of Apollo landing sites where geological conditions and soil composition are quite well understood. Manned surveys indicate that lunar regolith contains as much as 40 percent oxygen in some locations. Maria sites are known to also possess large quantities of silicon, aluminum, iron, titanium, magnesium and other materials.

An equatorial base on the near side would afford direct line-of-sight with Earth for ease of communications and psychological benefits to inhabitants. Far side or polar locations would require a satellite communication network.

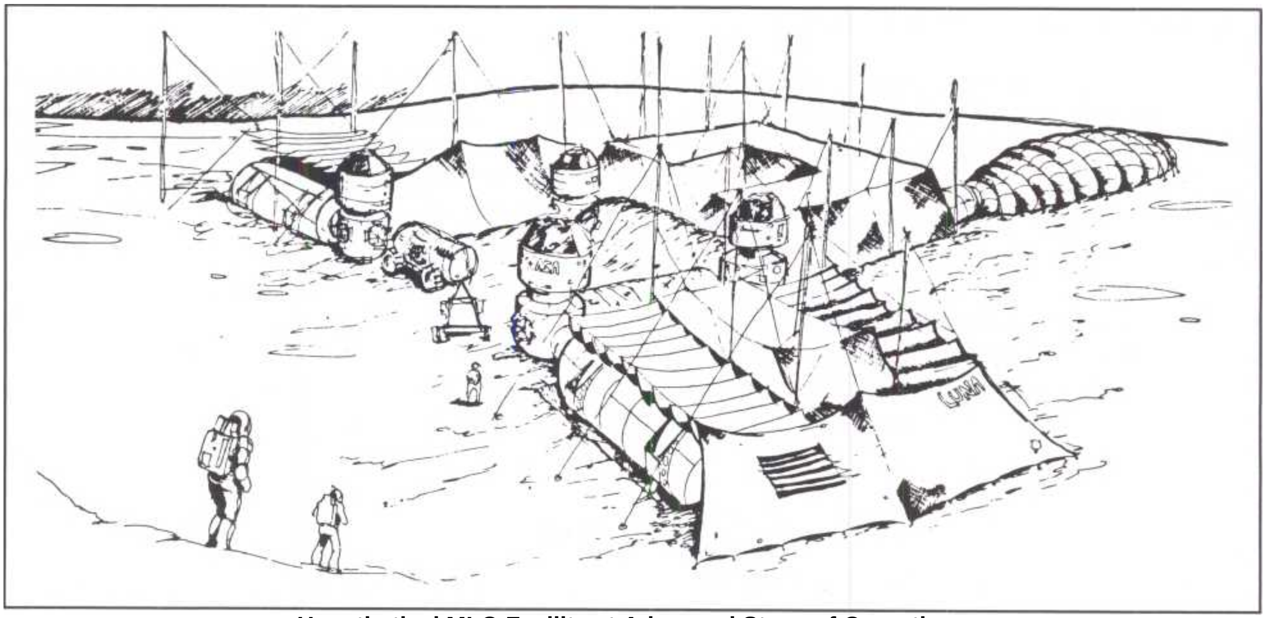
General Site Options and Features

	Polar	Near Equatorial	Far Equatorial	Limb Equatorial	Mid Latitudes
Average Temperature	220K	254K	256K[1]	255K	220K<T<255K
Temperature Cycles	±10K[2]	±140K	±140K	±140K	±110K
Sunlight	Long days and long nights[3]	354 hr days	354 hr days	354 hr days	354 hr days
Earth Light & Line-of-Sight Communication	Sometimes	Yes	No	Sometimes	If on near side
Eclipses	Sometimes	Mid-day	No	Sunrise or Sunset	If on near side
Geography	Highlands	Varied	Varied	Varied	Varied
Logistics	Once per orbital period		Once per orbital period		Once per day
Astronomy	½ view	All of celestial sphere			½<V<all
Perpetual Shade	Much[4]	None naturally occurring			Maybe
Minerals	Water (??)	Various oxide rocks		Various oxide rocks	

Notes:

1. The far side of the Moon is closer to the Sun at noon than the near side is, so its gets approx. 1% more solar energy.
2. Average temperature has a yearly variation which makes it very cold (T<200K) for several weeks.
3. Day length varies from 0 to 708 hours.
4. "Mountains of perpetual light" have not been found.

Source: Dalton, Charles, et. al. 1972. "Design of a Lunar Colony", NASA Grant NGT 44-005-114.



Hypothetical MLO Facility at Advanced Stage of Operations
Drawing by E. Akhidime

Site Development Considerations

The *Manned Lunar* Outpost would be developed through a staged approach beginning with a site characterization and preparation phase and potentially leading to a relatively self-sufficient colony. Early stages which may occur over a period of a decade or more can be expected to be very modest in scale, supporting fewer than a dozen residents. Advanced stages which extend beyond the scope of this MLO study might conceivably have populations of 100 or more people.

Primary habitat facilities during early (and perhaps all) MLO phases will quite certainly be comprised of prefabricated modules similar in general respects to those planned for Space Station *Freedom.* Some of these modules may be set into trenches and covered with lunar regolith to provide "storm shelters" offering emergency radiation protection during large solar particle events. (See SICSA Outreach Vol. 2, No. 3: July-Sep., 1989 "Space Radiation Health Hazards: Assessing and Mitigating the Risks".) Others, covered only by canopies for thermal and debris shielding, might rest directly on the surface.

Protection from dust and debris ejected during vehicle landing and launch operations is a special priority. This requirement applies to all vulnerable areas and equipment, including exposed solar power arrays, optical systems and pressurized storage tanks. Rocket pads should be located as far away from these locations as practical surface transportation permits and should be planned to avoid overflights of facilities. Pad locations might take advantage of natural surface barriers such as crater ridges or mountains, and should be 3-5 kilometers from the main base; ideally 10 kilometers or more from dust-sensitive areas. Nuclear power systems, the most promising source of primary energy, should also be remotely placed and shielded.

Inflatable structures can supplement prefabricated modules for habitats, plant growth facilities, and storage applications which exceed transportation payload constraints for fixed volumes. Such enclosures can be rigidized following deployment by means of resin foams that harden within wall bladders when vented to the lunar vacuum conditions.

Site Elements

Habitation Accommodations

- *Crew quarters – living and leisure facilities including wardroom/galley, personal hygiene and waste management, sleeping, recreation/exercise, and storage areas.*
- *IVA work areas – interior laboratories and maintenance/storage facilities related to science and technology demonstrations.*
- *Health and safety emergency areas – diagnostic and health care facility and safe havens with emergency equipment and rations.*

Agriculture/Aquaculture Environments

- *Greenhouses – facilities and equipment to support plant growth and processing experiments aimed at advancing self-sufficiency.*
- *Animal and seafood holding areas – environmentally controlled habitats for animal, fish and shrimp experiments.*

Industrial Accommodations

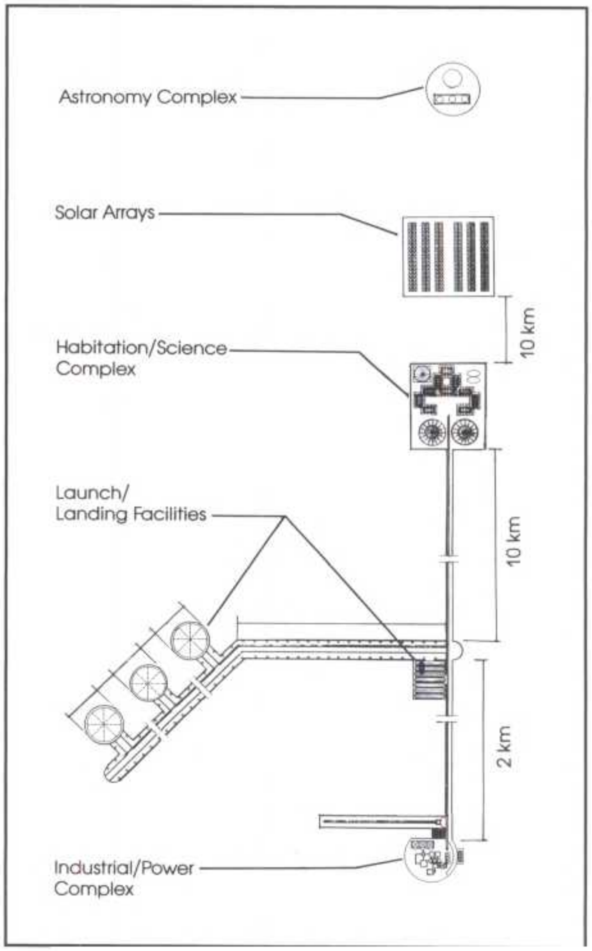
- *Maintenance/repair facilities – for lunar soil excavation, separation, transport and processing equipment.*
- *Material processing facilities – with teleoperated/automated/robotic systems and dust control/safeguards.*
- *Storage facilities – containment and handling systems for catalysts/solvents, processed materials and hazardous wastes.*

Transportation Systems

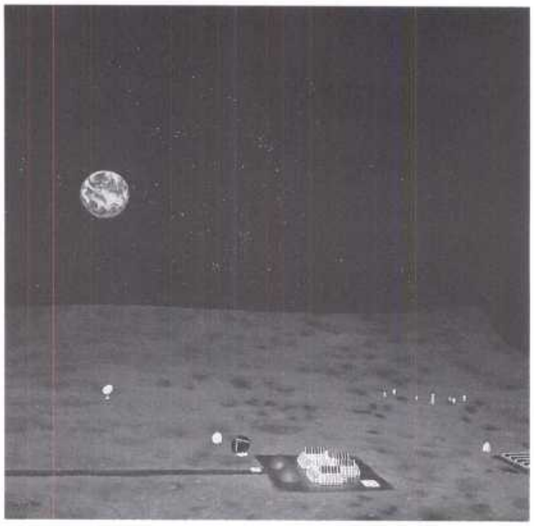
- *Launch/landing facilities – surface pads and maintenance/refueling depots.*
- *Hangars – unpressurized enclosures to protect surface transportation vehicles during servicing and storage.*

Support Systems

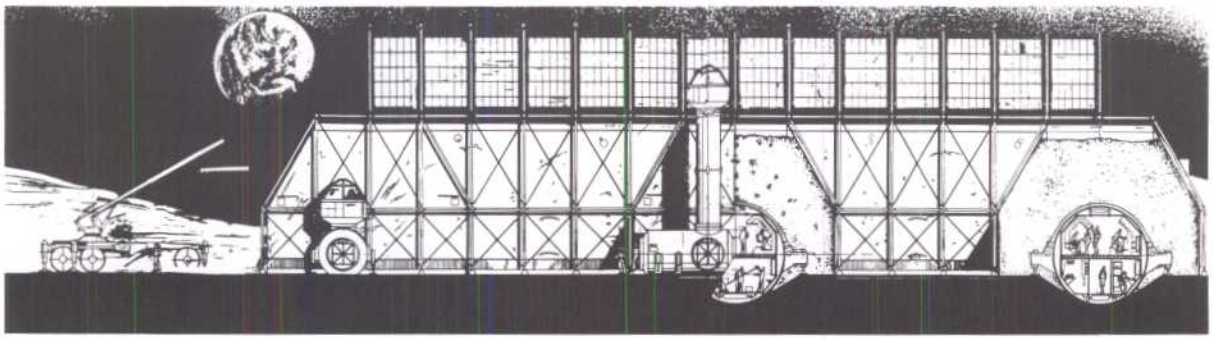
- *Power generation and storage – primary and backup systems for habitation and industry.*
- *Waste treatment/environmental controls – for crew habitation, agriculture/aquaculture and industrial processing.*
- *Data management/communications – centralized and distributed primary and backup systems.*



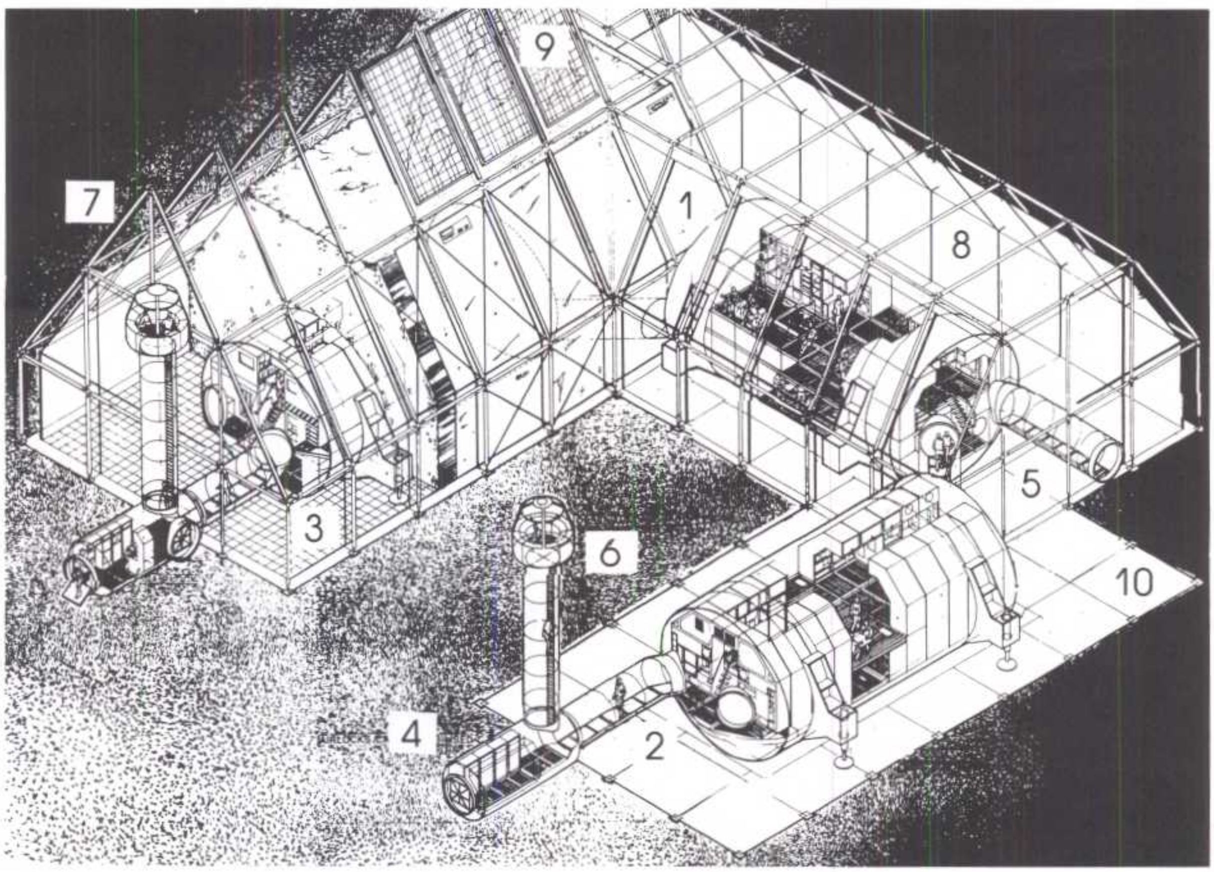
Advanced Site Development Concept
Drawing by D. Lund



SICSA IVILO Site Concept
Model by M. Bunch, J. Lorandos and D. Lund

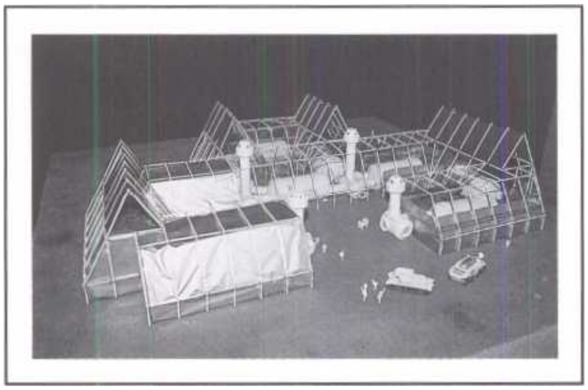


Section Through Habitation/Science Complex
Drawing by E. Akhidime

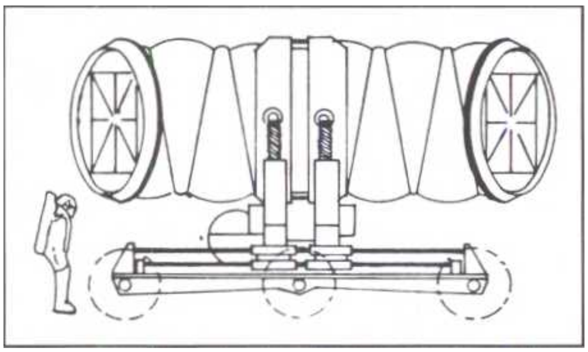


1. Habitat Module/Construction Shack
2. Lunar Sciences Laboratory Module
3. Life Sciences Research Module
4. Airlock Module with Dust Removal
5. Flexible Module Interconnect Tunnel
6. Site Observation Cupola
7. Regolith Retention Structure
8. Kevlar Regolith Retention Skin
9. Photovoltaic Power Panel
10. Sintered Basalt Pavement

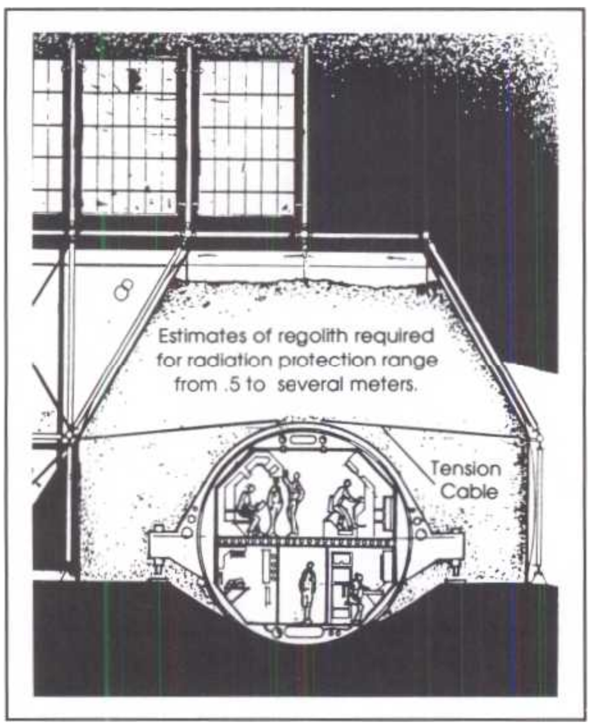
Isometric View of Habitation/Science Complex
Drawing by E. Akhidime



SICSA Model of MLO Construction Concept
Model by J. Lorandos and E. Akhidime



Flexible Module Interconnect Tunnel
Concept adapted from Eagle Engineering



Section Through Regolith Retention Structure
Drawing by E. Akhidime

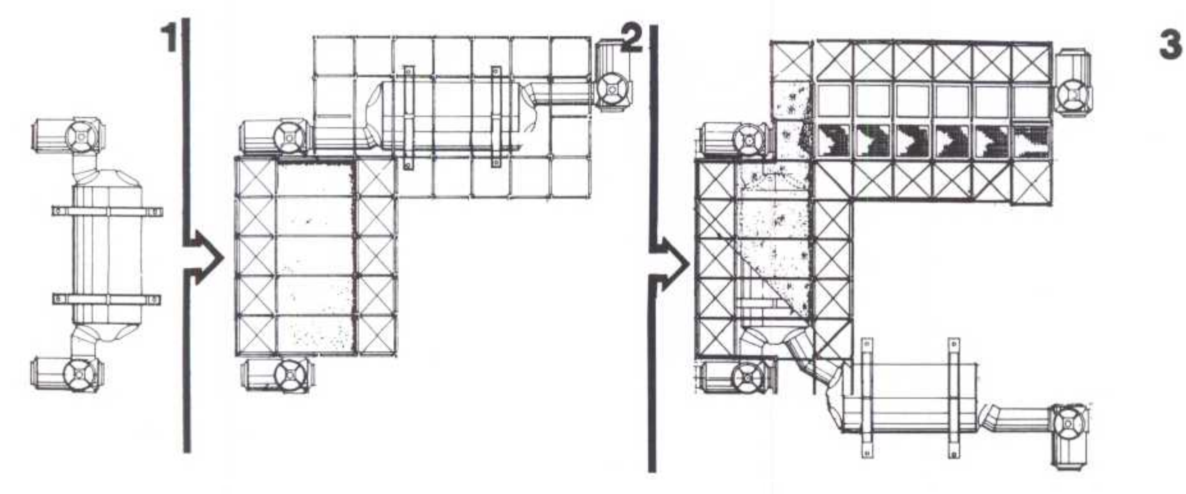
Site Preparation and Construction

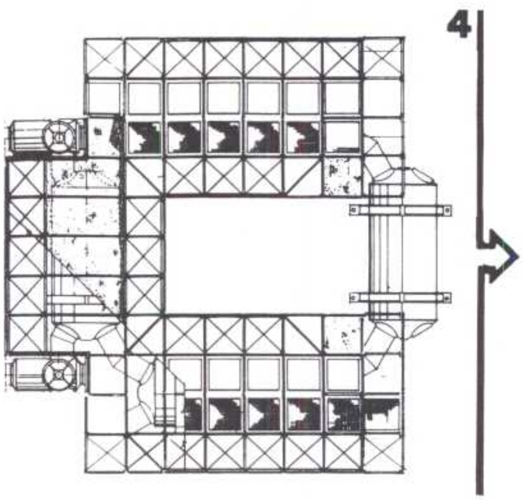
Lunar construction must be planned to minimize human effort and equipment requirements to the greatest extent possible. This objective can only be accomplished through coordinated planning of all systems and operations associated with site preparation, payload transfer to the lunar surface, ground transportation and construction/ assembly processes. Robust teleoperated and automated devices will be essential to compensate for severe limitations upon on-site labor and allowable EVA exposure to radiation.

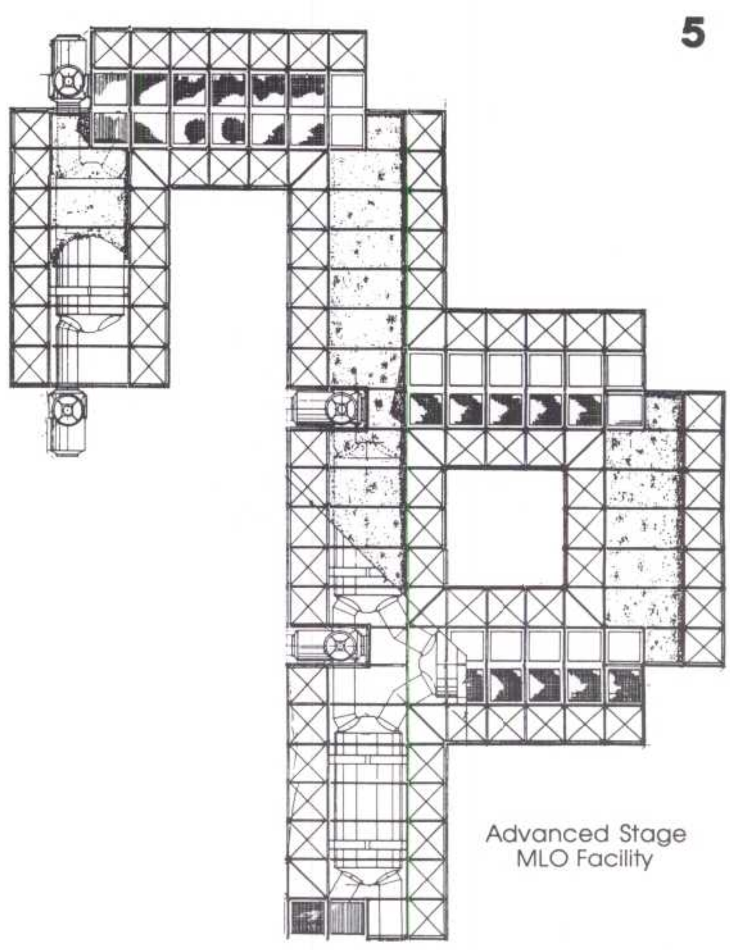
The first crews to arrive at the MLO site may live in a temporary modular habitat directly set in place by a landing vehicle. It will be their roles over the course of several missions to survey the region to select the best locations for various MLO facilities; deploy and check out surface power, transportation and site preparation equipment; and initiate automated pre-construction operations. Surfaces for future landing and launch pads, roadbeds, and base facilities may need to be leveled, filled and "paved", possibly using microwave heating to sinter the top layer of the lunar soil. Trenches might be excavated to receive permanent modules that follow

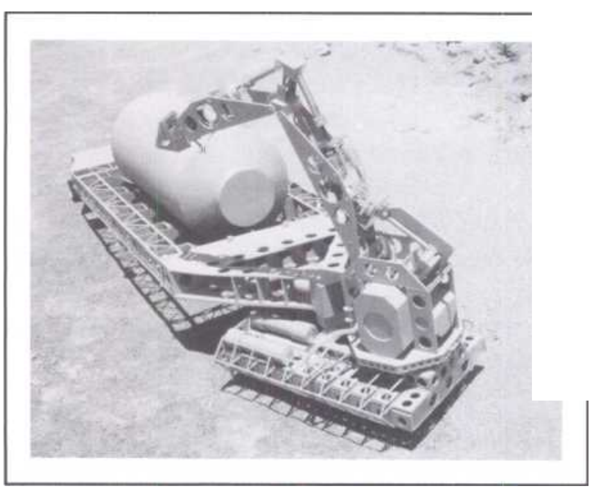
One possibility is to bury the first permanent module entirely below the surface as a storm shelter for major solar particle events (SPE) as well as to provide a crew habitat and "construction shack". This module might be similar in size to those planned for Space Station *Freedom.* **Some or all of the larger surface modules that are to be added later might be enclosed within frame structures with Kevlar skins to retain lunar regolith used as a radiation barrier and dust control device. The outside of these retention skins must be treated to resist material deterioration resulting from ultraviolet exposure. The depth of regolith required for protection against primary and secondary radiation effects remains an unresolved issue.**

Flexible connecting tunnels can be used to join modules together. These elements will facilitate hookups and compensate for misalignments.



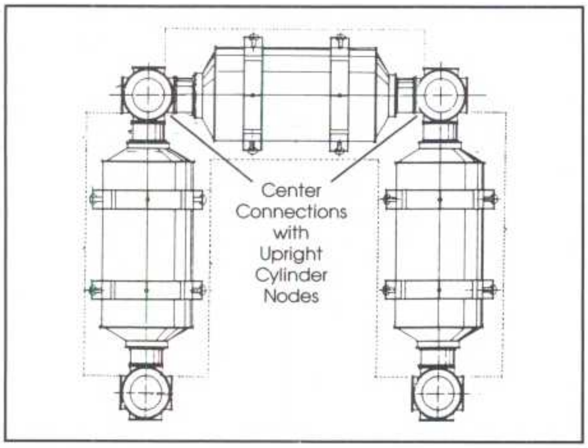






Landing Pallet and Surface Transport Concept
SICSA Concept and Model by N. Moore, T Polette, L. Toups

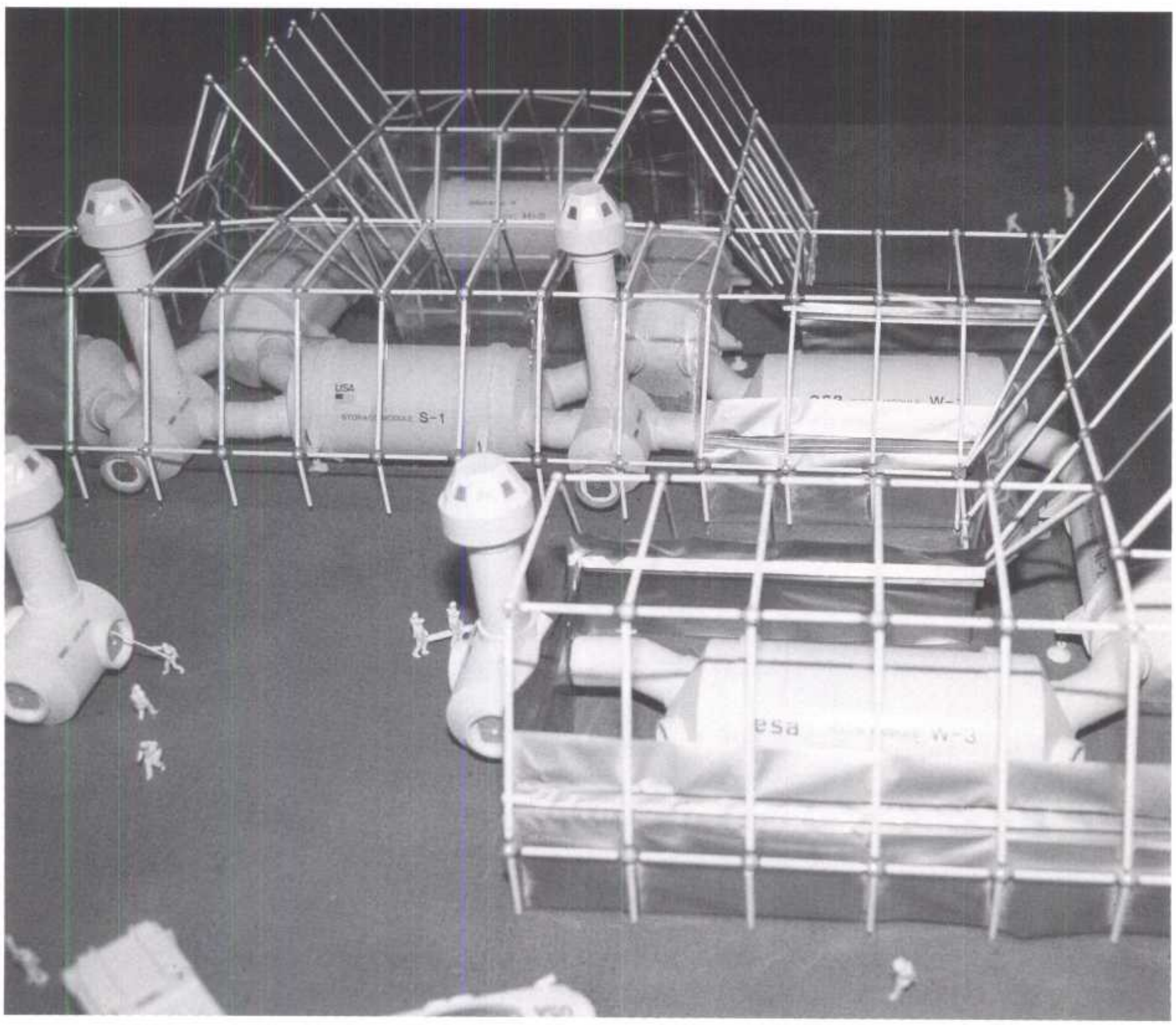
Drawings by J. Lorandos and E. Akhidime



Alternative Module Interconnect Concept

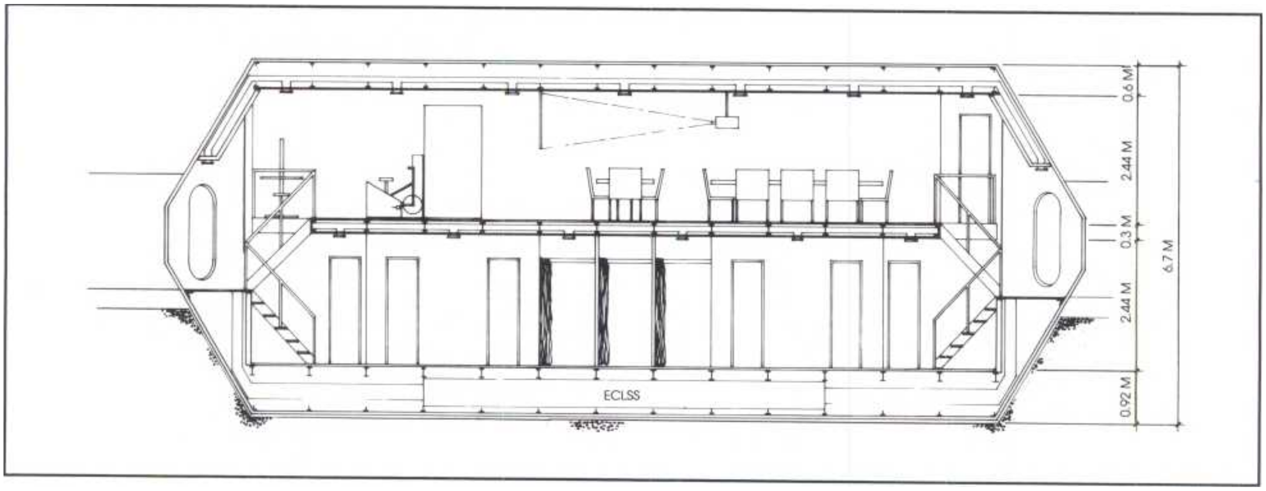
Possible MLO Growth Stages

1. *Habitation Module with connecting airlocks put in place.*
2. *Initial module covered and Lunar Sciences Laboratory Module added.*
3. *Life Sciences Research Module added; previous module covered.*
4. *Maintenance/Instrumentation Laboratory added to complete the circulation loop.*
5. *Other modules and thermal/radiation barriers added as required over time.*

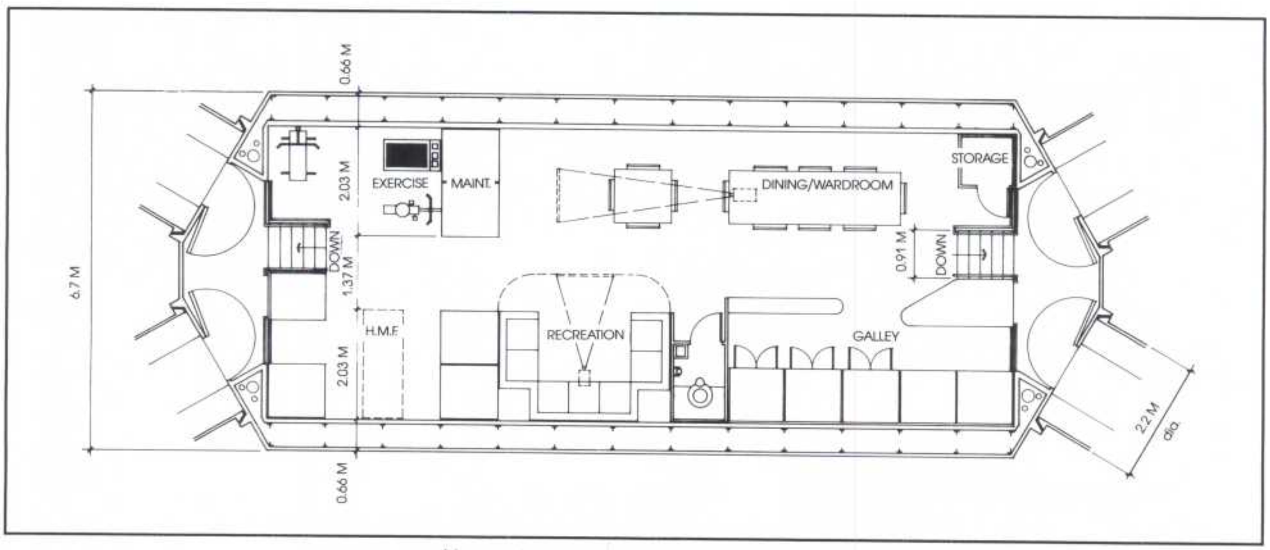


SICSA Model of MLO Construction Concept

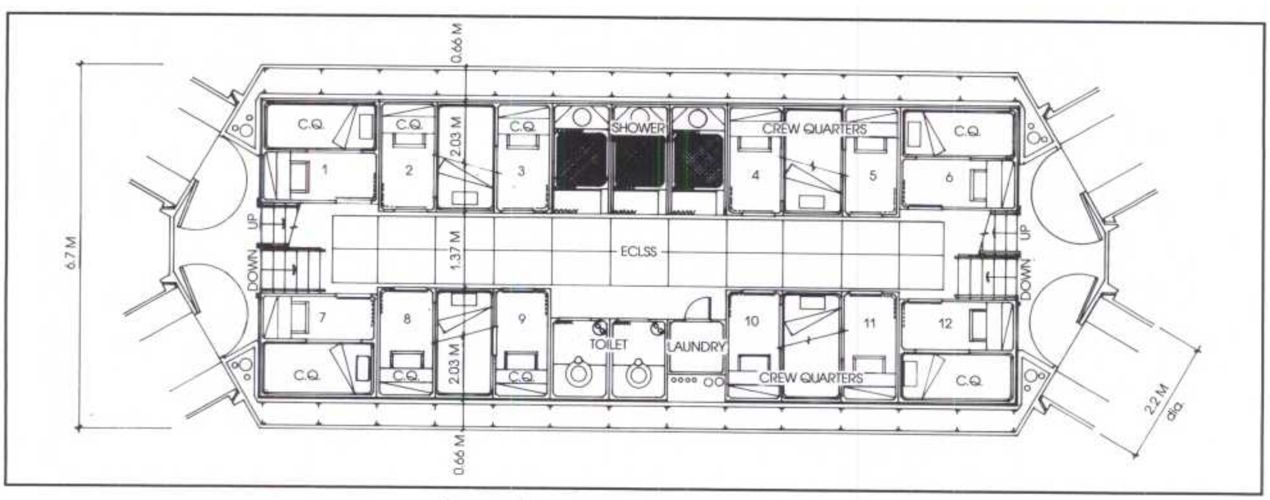
Model by J. Lorandos and E. Akhidime



Longitudinal Section-Habitat Module

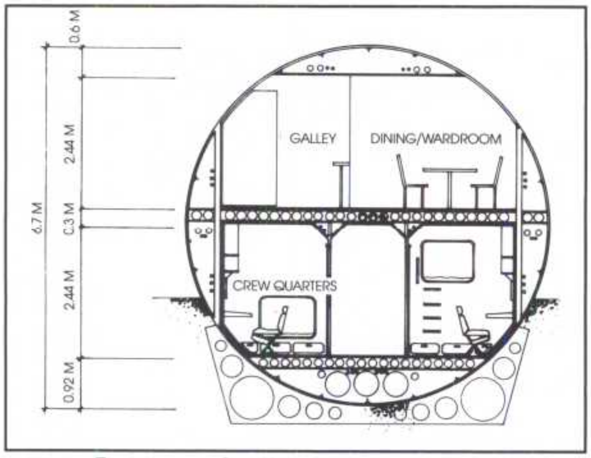


Upper Level Plan-Habitat Module



Lower Level Plan-Habitat Module

All drawings this page by S. Capps and K. Murakawa



Transverse Section-Habitat Module
Drawing by K. Murakawa

Facility Design Priorities

Crew Safety

- *Environmental controls - provide fail-safe means to ensure air quality and respond to accidental contamination.*
- *Materials - use materials that are not flammable and which do not offgas toxic substances.*
- *Control/warning systems - provide damage surveillance viewports and automated safety monitoring, alarm and control systems.*
- *Maintainability - design interiors and systems for easy access and servicing.*

Crew Comfort and Satisfaction

- *Interior environment - design to optimize convenience, variety, aesthetics and noise control.*
- *Leisure - provide places for group recreation and interaction as well as private areas for relaxation and sleeping.*

Flexibility and Expansion

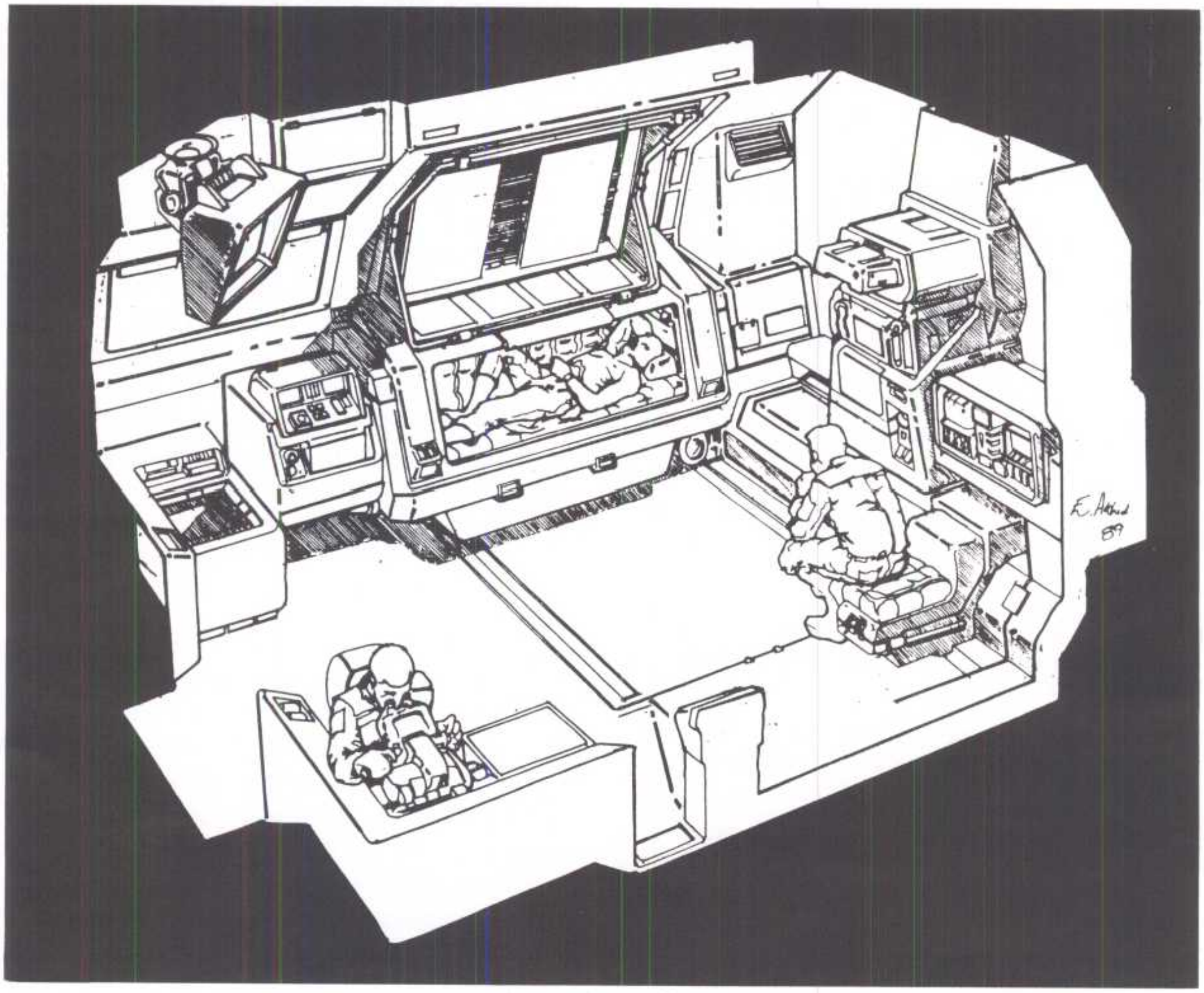
- *Modularity - design modules and interior components in a manner to enable easy reconfiguration and evolutionary supplementation.*
- *Versatility - emphasize multi-purpose areas/systems that optimize utility and efficiency.*

Module Size and Configuration

The size and internal configuration of MLO modules must be compatible with means to launch payloads and land them on the Moon, accomplish surface unloading and transportation, and undertake installation during initial and evolutionary growth stages. A cylinder offers an optimum launch shape and good pressure retention envelope for rigid modules. Inflatable structures that are transported in a collapsed state can provide larger and more varied deployed forms, but are likely to require labor-intensive integration of internal equipment systems at the site. Accordingly, pneumatic habitats may become most appropriate for relatively advanced MLO stages when scaled-up operations demand substantial volumes and when crew and equipment resources for systems integration are less constrained.

The 4.27 m (14 ft) diameter modules planned for Space Station Freedom present the smallest practical cross sections that will effectively accommodate minimum height requirements for 95 percentile American males baselined by NASA. SICSA studies indicate that larger modules only begin to offer significant functional advantages when the diameter reaches approximately 6.7 m (22 ft). At this point the cylinders can be divided into two floor levels, or can be transversely divided into "bologna slice" segments large enough to avoid seriously claustrophobic visual vistas. The transverse division is not regarded to be an option of choice for lunar applications, however, because the upright multi-level stacks will be difficult to transport over rough lunar terrain or to cover with regolith for radiation protection.

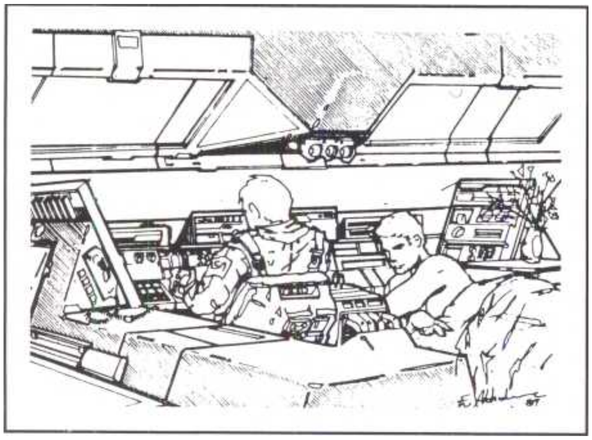
The two-level module concept illustrated in this report assumes that heavy lift launch and landing vehicles are available. The intent is to provide ample yet economical crew facilities for missions lasting a year or more. These 6.7 m (22 ft) diameter, 17.2 m (56.4 ft.) long units will be considerably more spacious than Space Station Freedom modules, supporting as many as 12 crew members with supply storage and equipment accommodations for extended missions.



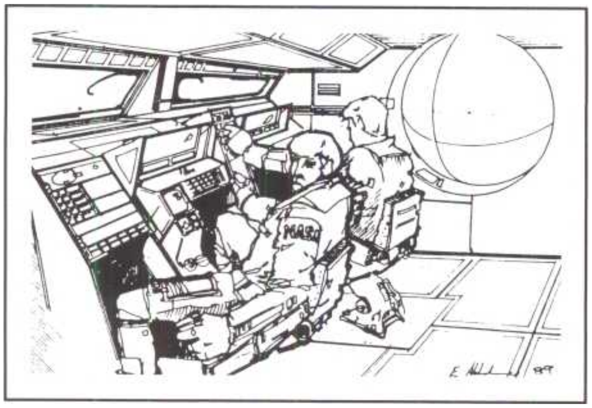
Health Maintenance Facility Concept
Drawing by E. Akhidime

Important Crew Support Areas and Equipment Systems

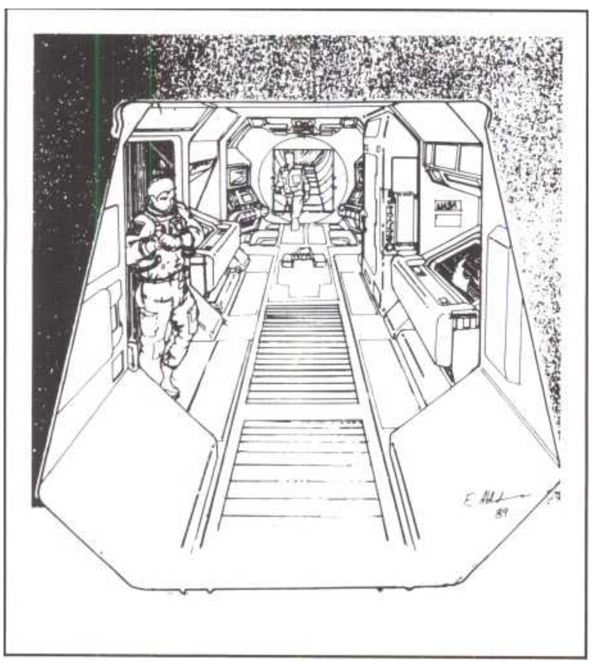
- *Crew quarters: provisions for sleeping, personal stowage, computer work station, and communications.*
- *Personal hygiene: provisions for shower, partial body cleansing and grooming.*
- *Toilets: waste management collection and treatment systems.*
- *Environmental control and life support systems: air quality, temperature and humidity controls.*
- *Laundry: equipment to wash clothing/towels.*
- *Galley: means for food preservation/storage, preparation, dispensing and disposal.*
- *Dining/wardroom: adequate seating for the whole crew during eating and other group assemblies.*
- *Exercise: equipment to minimize physical deconditioning under reduced gravity conditions.*
- *Health maintenance facility: equipment and supplies for diagnostics, health monitoring, and routine and emergency treatment.*



Work Station Concept



Control Area Concept



Crew Quarters Concept

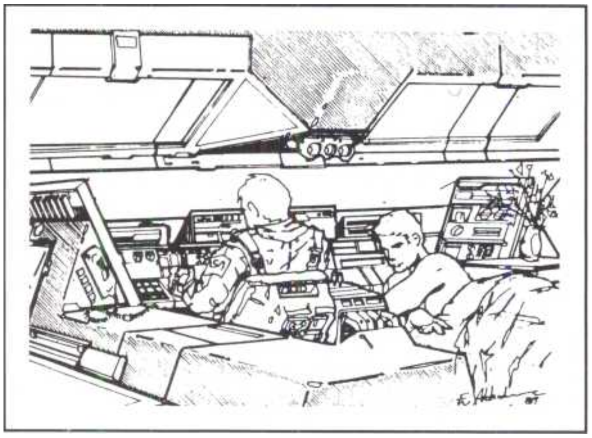
All drawings this page by E. Akhidime

Interior Planning Considerations

Lunar habitats must provide the same general types of crew support areas and equipment systems that are being developed for Space Station *Freedom*. For ease of integration, maintenance, and changeout, most fixed interior space station systems are incorporated into equipment racks and functional units. The racks contain such items as health maintenance equipment, food preparation appliances, storage units, life support and waste management systems, environmental controls and experiment hardware. Functional units are enclosures that offer privacy and accommodations for sleeping and leisure activities, personal hygiene, showers, and toilets. Both the racks and the functional units can be conveniently pivoted down for rear side servicing or removal. Similar devices might be used to contain and support many MLO service and system elements.

Partial gravity conditions on the Moon will cause some MLO interior layout and design features to differ in significant ways from microgravity space station facilities. As on Earth, there will be a mandated up-down "feet on the ground" orientation which will preclude the possible use of ceilings as work areas. Unlike in orbit, crews will be required to sleep in a conventional horizontal position rather than in vertical sleeping bags attached to walls, requiring more interior bedroom space. Alternatively, MLO crew members might sleep in small, enclosed privacy capsules within shared two or three person semi-private leisure areas.

U.S. and Soviet orbital missions have demonstrated that outside viewing is the most popular recreational activity. Earth watching is particularly interesting and satisfying. Assuming a near side MLO location, the Earth will shine brightly in the lunar sky, offering a primary visual attraction and source of psychological reassurance. If the modules are covered with soil however, outside viewing will only be possible during extravehicular activities unless special observation cupolas are provided.



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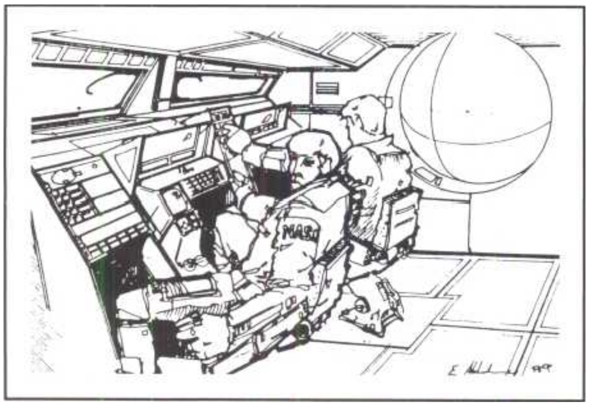

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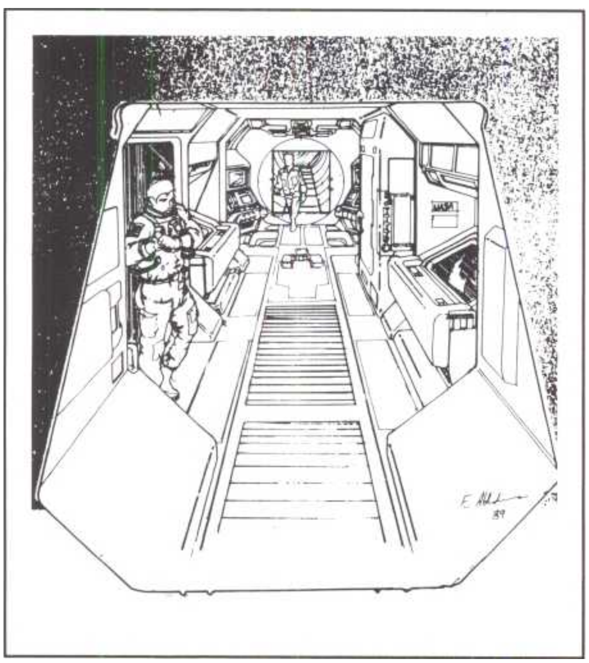

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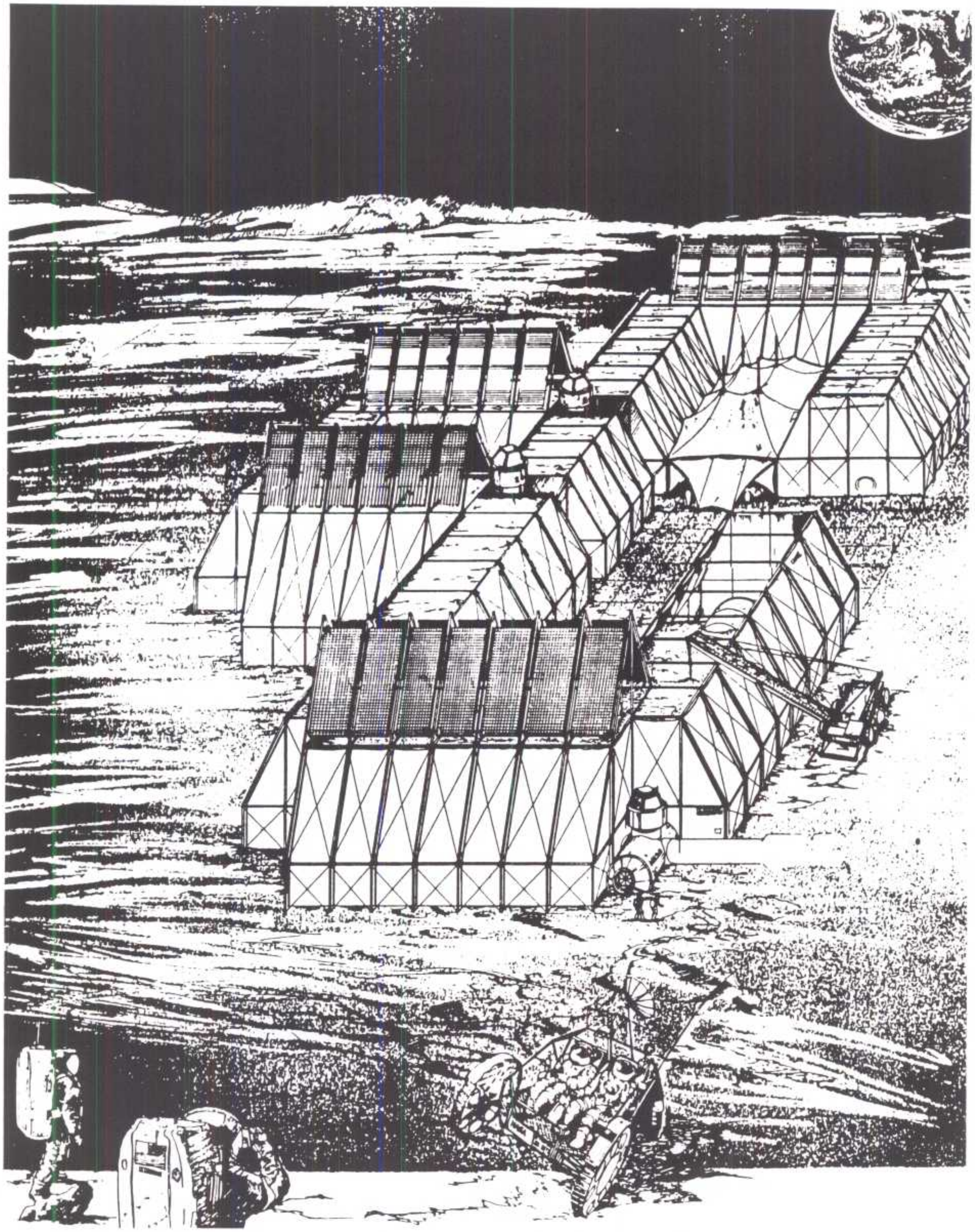

Habitation/Science Complex under Construction

Drawing by E. Akhidime

SICSA Background

SICSA is a nonprofit research, design and education entity of the University of Houston College of Architecture. The organization's purpose is to undertake programs which promote international responses to space exploration and development opportunities. Important goals are to advance peaceful and beneficial uses of space and space technology and to prepare professional designers for challenges posed by these developments. SICSA also works to explore ways to transfer space technology for Earth applications.

SICSA provides teaching, technical and financial support to the Experimental Architecture graduate program within the College of Architecture. The program emphasizes research and design studies directed to habitats where severe environmental conditions and/or critical limitations upon labor, materials and capital resources pose special problems. Graduate students pursue studies which lead to a Master of Architecture degree.

SICSA Outreach highlights key space developments and programs involving our organization, our nation, our planet and our Solar System. The publication is provided free of charge as a public service to readers throughout the world. Inquiries about SICSA and Experimental Architecture programs, or articles in this or other issues of SICSA Outreach, should be sent to Professor Larry Bell, Director.

Project Team Leaders and Consultants:
L. Bell, G. Trotti, D. Neubek and Dr. A. Binder.
Graduate Student Project Team Members:
Pictured (1988-89): K. Murakawa, S. Capps, D. Lund, (seated); E. Akhidime, J. Lorandos, (standing); M. Bunch (missing). Not pictured (1987-88): N. Moore, T. Palette and L. Toups.

The MLO study which began in September 1987, was conducted by graduate students in the Experimental Architecture program under supervision of SICSA faculty and staff. Activities are being coordinated with multiple advanced planning groups at the NASA Johnson Space Center through the auspices of the NASA/USRA University Advanced Design Program. NASA's project advisor is Dr. Michael B. Duke, Chief of the NASA JSC Solar System Exploration Division.

Sasakawa International Center for Space Architecture

Room 122 ARC, University of Houston
4800 Calhoun, Houston, Texas 77004

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