SPACE COLONIZATION PROGRESS

Research And Technology For Space Utilization

July/August 1991 ***Vol. 2 No. 4***

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[Editor's Note: the first two articles are adopted from topics of papers presented at the Space 90 Conference held April 22-26, 1990 in Albuquerque, New Mexico. For more detailed information, see *Engineering, Construction, And Operations in Space II: Vol 1 & 2, Proceedings of Space 90, published by American Society of Civil Engineers, 345 East 47th Street, New York, NY 10017*]

PROPOSAL FOR A SPACE ENGINEERING FACILITY

Some time in the next two decades humanity will return to the moon. We will be living and working there and eventually on other worlds, as well. Engineers are thinking about how to build structures and operate machinery in space and on the surfaces of other planetary bodies. To help design equipment and processes for this endeavor, a need has arisen for a facility that can simulate extraterrestrial (ET) environments in which experiments can be conducted. The purpose of this facility would be to develop technologies pertaining to engineering and fabrication methods on other worlds. It would have to be built soon if lunar construction is to begin around the turn of the century.

A Center For Extraterrestrial Engineering And Construction (CETEC) has been proposed to fill this need in a paper at the Space 90 conference by a team* of researchers from academia and industry. The environment of space and on the surfaces of other planets present design challenges that must be addressed in a laboratory setting before actual hardware is deployed on a mission.

Areas of proposed research are erecting structures in ET environments, handling ET soils for construction materials or shielding, mining and extracting ET mineral deposits, maintenance and repair of equipment in ET environments, and chemical processes for extricating basic elements from ET soils.

CETEC as currently envisioned will place experiments into vacuum chambers through airlocks. Since extensive processing of simulated lunar material will be required in the

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chambers to achieve high vacuum, the chambers will not be exposed to air once they are prepared. This will require heavy reliance on robotics and teleoperation for remote manipulation of the experiments inside the tanks.

CETEC would be used to investigate construction technologies before utilization of planetary environments can begin. Teleoperated and robotic equipment must be tested in fine grain soil and cycled through extreme temperature ranges that would be encountered on the Moon. Methods must be developed for the prevention of build up of dust on mating surfaces which will be assembled together. This research would lead to designs for automated cranes and assembly techniques which will minimize the need for humans to don space suits and work in hazardous environments.

Planning the sequence of assembly of components in ET environments will be crucial to the success of any space facility. CETEC could be used to gain confidence in preplanning each stage of assembly so that mating assemblies fit together in spite of temperature differences or dust build up on components.

Facilities on the Moon and beyond will have extensive power requirements. Since no system can be 100% efficient, waste heat will be generated. On airless bodies, this implies the use of radiators to reject heat to the vacuum of space. The effectiveness of these waste heat rejection systems can be degraded by contamination of their radiator surfaces. Thus, large environmental chambers will be required to test the radiator designs through varying temperature extremes in the presence of simulated dust clouds.

CETEC would be composed of an array of interlinked vacuum chambers to simulate both lunar and martian environments with appropriate simulated soils. A several acre parcel of simulated lunar soil adjoining the vacuum chambers would be used to test construction equipment prior to introduction into the vacuum environment. Habitats will be included for studying human factors that will influence the design of equipment, architecture, and closed ecological life support systems.

The organization that would be responsible for CETEC was proposed as a consortium of universities, government laboratories, and industry. Such a facility would be a valuable national asset for testing engineering prototypes and systems for construction and operations in ET environments.

LUNAR CONSTRUCTION TECHNIQUES

Civil and structural engineers have started to get involved in the design of facilities that will be built on the Moon. A survey of some of their proposed construction techniques was presented at Space 90 in a paper by Larry Toups of Lockheed Engineering and Sciences Co., Houston, Texas. In addition to identifying and defining the techniques, the criteria for evaluating each method was discussed, and then some possible applications were suggested.

Lunar construction techniques can be classified into three categories. Earth dependent, use of natural lunar features, and lunar resource utilization.

Earth Dependent Techniques

The first category imports all materials from Earth and would include prefabricated structures, inflatable modules, prefabricated frame structures, tent structures, and tunneling methods.

Prefabricated structures would be pressurized habitats assembled and outfitted on Earth, perhaps derived from modules used on Space Station Freedom. Once delivered to the lunar surface, these structures would be fully self-contained and functioning without the need for assembly. The drawback to this approach is that module size is limited to launch vehicle payload bay size.

Inflatable structures would use the pressure of a gas to support themselves. With this architecture either individual structural elements such as a wall, column, or arch, could be inflatable or the entire structural shell would be supported by a gas. This technique has the potential to provide large enclosed volumes with relatively light materials which can be folded into small spaces. They can be used for habitable structures, food greenhouses, or unpressurized hangers/warehouses.

Prefabricated frames are composed of strong trusses which are joined together in a matrix to form a framework which, when covered with air tight material, can be pressurized. Familiar forms of this architecture are space frame structures and geodesic domes. Like the inflatable option, frame structures pieces can be packed into a small volume but assembled into large volumes. The disadvantage of this method is that it is very assembly intensive requiring extensive EVA time.

Tents would be composed of stressed fabrics supported by masts, arches, or ribs with cables carrying most of the load. They could provide unpressurized protected shelters for storage and could be disassembled and moved as changing conditions arose.

The last form of Earth dependent construction is the process of tunneling a passageway or subsurface cavity for occupation or storage. Advanced tunneling machinery and technology have been proven on Earth and would include the use of explosives, boring, creating shafts, and melting soil. The spaces hollowed out of the lunar rock could hold the habitat or be the habitat themselves.

Use Of Natural Lunar Features

Structures utilizing natural lunar features could make use of existing craters or lava tubes. Craters could simply have a roof structure laid over them to provide a natural shelter or they could provide an entrance to a tunnel. The crater must have a depth to diameter ratio of 1:6 to be considered. Spans would be laid across the diameter of the depression or, if the diameter is large, additional structural supports at the rims may be needed. Craters provide a natural depression for radiation protection and support for canopies.

Natural caverns are created when lava flows under ground horizontally from its source. When these lava tubes drain and cool, they provide open volumes which can be sealed and pressurized for habitation with minimum expenditures in energy and manpower. They also provide a natural source of shielding. However, the whereabouts of these tubes is currently not known which implies that extensive reconnaissance may be required to pinpoint their location.

Lunar Resource Utilization

The third category utilizes a wide variety of naturally occurring lunar resources to provide building materials. These would include lunar concrete, casted/sintered basalt, glass fiber/matrix, and metals. Lunar concrete would be composed of a mixture of lunar soil and a bonding agent in a non-water based media. Blocks, columns, or walls could be built using this method which could provide support for lunar soil shielding.

The dense, dark volcanic rock on the moon called basalt, can be melted and cast into tiles, bricks, or even pipes. This same material could be sintered, a process through which fine grains are elevated to high temperature resulting in adhesion between particles. Sintered basalt could be used as foundations for buildings or formed into blocks for use in radiation shielding.

Lunar soil contains significant amounts of different types of glass, the most abundant being silicon dioxide. Glasses can be melted and drawn into fibers which can be spun into a variety of composites and matrices for building materials. Fiber cloths, stranded cords, and cables all have applications in the construction of habitats.

Metals such as aluminum, titanium, iron and magnesium are present in lunar soil. These metals can be extracted and cast into beams, plates, and columns for structural supports in buildings or drawn into fibers for reinforcing matrices and cables. Fasteners could be fabricated reducing the need for welding.

Any combination of the above categories could be used to create hybrid structures which make maximum use of available materials and properties. For example, concrete columns could carry exterior compressive loads from lunar soil shielding while an inflatable structure contained internal atmospheric pressures. The whole building could rest on a foundation of sintered basalt.

Engineers have already begun studying techniques of construction on the moon. Armed with an array of methods making the most efficient use of imported and indigenous materials, humanity will soon be ready to erect permanent structures on the lunar frontier.

INNOVATION AND SPACE EXPLORATION

To colonize the last frontier, a fundamentally new approach to the design and implementation of space projects must be considered that would involve industry, academia, and the public. New ways of solving problems related to space travel must be accepted and occasional mistakes tolerated if progress is to be made. Jesko A. Von Windheim of The University of Guelph, Ontario discusses this approach in an article entitled "On Innovation, Error, And Space Exploration" in the journal *Space Power*, No. 4, 1990.

Progress in technology often stems from mistakes in the laboratory that have lead to breakthroughs. Scientists and engineers learn by tinkering. But experimentation in space is currently a costly, time consuming, and bureaucratic nightmare. Errors are not permitted in the Space Shuttle program. By insuring that this technologically complex system is as safe and error free as possible, NASA is actually impeding progress. Low cost easy access to space is what will drive the expansion of the final frontier.

Von Windheim draws two analogies from history to illustrate how entrepreneurs, unencumbered by bureaucratic red tape, can drive technological progress. These are the mass-production of automobiles and the personal computer.

Henry Ford's model T was not the only car of its time or the best. But Ford's innovation of the assembly line produced an inexpensive and reliable car that changed the face of personal transportation for good. Why after two decades since landing on the moon can we not make a 'model T' launch vehicle? The answer is that NASA has a monopoly on the space business. In a commentary in the May 13 issue of *Space News* Rick Tumlinson, president of the Space Frontier Foundation writes:

"Instead of making space an arena of opportunity for American businesses which would spawn a launch infrastructure and an in-space services industry dwarfing anything yet dreamed of, the nations's leaders are totally devoted to preserving and expanding the government monopoly over all non-defense space activities, killing any new entrepreneurial initiatives which make them uncomfortable or might embarrass them by moving faster than the national program."

Another example from the past is the personal computer. The founders of Apple, Jobs and Wozniak, built affordable desk top computers in a garage. This was back when it was generally believed that the only serious computing had to done on mainframes supervised by government scientists. This situation is not unlike the restrictions imposed by NASA on access to launch facilities.

The two innovations above took complicated and costly technologies and simplified them to the point where they could be mass produced cheaply. This increased access lead to further expansion of capabilities, increased markets, and the rest is history. Two things were common to both examples. They were unpredictable, arising from unlikely sources and they were replete with errors in development. This approach is not possible in today's space industry. Multibillion dollar government backing is accepted as the only recourse, while other strategies are simply not considered. Space commercialization and colonization should be taken out of the hands of government bureaucrats and put into the hands of entrepreneurs, students, or basement tinkerers where the real innovation will flourish.

SOLAR POWER SATELLITE: THE STRATEGY

The solar power satellite (SPS) concept is a promising alternative to fossil fuels for the world's energy needs in the 21st century. Conceived by Peter Glasser in the 1960s, the SPS would consist of an array of solar cells in geostationary orbit collecting the sun's energy which would be converted low power density microwaves and beamed to a receiving station on Earth to be converted to electricity. The main problems are financial (and therefore political) rather than technological in nature. The initial cost of one 5 gigawatt system is estimated to be over 100 billion 1977 dollars. Although the SPS would eventually turn a profit, the payback period is expected to be on the order of one to two decades.

To lower the risks associated with a project of this magnitude, an evolutionary strategy is required in which the elements of the system are developed step be step with payback at each stage. Such an evolutionary path to SPS development has been proposed by Geoffrey A. Landis of Sverdrup Technology, Inc., Cleveland, Ohio. Landis described his approach in *Space Power* No. 4 for 1990.

The solar cell array of the SPS has been identified as a high risk element in the system. Therefore, the first step in the process is to develop ground-based solar power systems to gain experience in mass production of photovoltaic cells, reduce their costs, and increase their efficiency. Ground based systems would be located in regions with high percentages of clear skies and would supplement power requirements at peak periods. Construction leadtimes are short so photovoltaic arrays can be added quickly as market demands increase. But terrestrial solar power systems will not be able to provide all the power anticipated to be required in the next century, especially in more northern latitudes. By that time however, manufacturing technology of solar cells will have improved to the point where it will no longer be a major concern for the SPS system. The next critical element is power beaming (transmission of electrical power via microwaves or lasers).

There are several markets for small scale power beaming in space that could help prove the technology for this element. Power in space is currently quite expensive. Satellites depend on expensive solar cell arrays when in sunlight and batteries when in the shadowed part of their orbits. One possible application is to beam power to satellites when they are in shadow which would eliminate the high cost of heavy batteries. Another would be to provide power for a lunar base. These power stations would be composed of a solar cell array and microwave transmitters - essentially a small scale pilot SPS which could be positioned where needed to provide power in space.

A third opportunity is orbital transfer vehicles powered by electric propulsion. This type of rocket uses high voltage to accelerate ionized gas molecules to provide low thrust, high efficiency performance. They require little fuel but have a large power consumption rate making them ideal for beamed power. Such a craft would not need to carry the heavy hardware of a power supply, only the relatively light receiving antenna for the microwave beam. The weight savings would allow delivery of larger payloads to high orbits.

By aggressively pursuing applications for beamed power in space, the technology for this element of an SPS could be commercially available by the time that the photovoltaic industry matures. There is one more ingredient that is necessary for SPS construction: large-scale space infrastructure.

Building a Solar Power Satellite will involve moving and assembling a large amount of material in space. This will require extensive space transportation and manufacturing systems to be in place and working. To develop these systems as part of an SPS business plan would be an unacceptable risk factor. Thus, development and testing must be accomplished before a commitment to build an SPS would ever be considered.

The infrastructure required will be orders of magnitude larger than the current satellite industry space transportation systems. Development of this infrastructure could be accelerated with identification of near-term commercial markets in space such as space tourism. Since this sector as of yet is still undefined, the only large-scale operations proposed are exploratory missions to the moon and Mars. The exploration of space will drive the development of the infrastructure needed for an SPS. Technology developed for exploring the solar system can be applied to the SPS. For example, utilization of lunar materials can significantly reduce the cost of an SPS. The techniques for extracting basic elements such as oxygen, aluminum, and silicon from lunar soil and refining them into usable materials will be acquired as part of a program to explore the Moon and Mars. Oxygen will be required as a component of rocket fuel. Aluminum and silicon will be needed to construct solar cell arrays which could be marketed initially in the sectors identified previously for power beaming. These manufacturing methods will be directly applicable to building an SPS.

When the three elements have been proven all that is needed is to integrate the pieces. An SPS will fall out of the natural evolution of generic technologies developed as part of the exploration of the Solar System.

High Frontier News Briefs

Solar Concentrator Demonstrates Lunar Construction Method

(From Space Studies Institute newsletter *Update*, May/June 1991)

On March 7 an experiment to fuse two bricks together with simulated lunar mortar heated by focused solar energy was successfully completed through a joint effort between the Space Studies Institute and McDonnell Douglas Space Systems. This experiment is part of an effort to develop methods of construction on the moon and in space using simple materials and solar energy.

The two bricks and simulated mortar were placed at the focus of a parabolic concentrator which generated a temperature of 1200° C. The simulant fused successfully to the bricks proving a joining method. This technique could have applications in paving roads, landing pads, and dust shields.

New Publication On Space Resources

A study called "Using Space Resources" has been released this year by NASA Johnson Space Center. This comprehensive work covers the latest research on refining lunar soil into building material, energy from the Moon, resources on Mars, and some of the steps that need to be taken to further develop technologies for these ventures.

The study is availabe from the U.S. Government Printing Office as publication number 1991-561-653

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SPACE COLONIZATION PROGRESS is published 6 times a year by:

STAR PUBLISHING COMPANY
754 Glenview Drive #308
San Bruno, California 94066
Subscription Rates: Regular: $18.00; Student: $12.00
Editor-in-Chief: John A. Jossy