SPACE COLONIZATION PROGRESS

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MODULAR MOONBASE ASSEMBLED ON ORBIT

Our second stepping stone to the stars will be an outpost on the Moon - the first being Space Station Freedom (SSF). The initial phase of establishing this outpost will require a test facility, the first permanently manned lunar base. This early base will be a safe haven for exploration, experimentation, and science on the moon and a springboard for expansion. It will be a precursor to a self-sustaining colony.

The prevailing plans for building an early habitation base incorporate space station modules currently being designed. These cylindrical modules would be transported to the lunar surface one at a time and assembled by astronauts and teleoperated robots. Much of the equipment needs to be sent ahead of time and a satellite network placed in lunar orbit enabling teleoperations from Earth. This strategy requires several precursor missions and repeated orbital transfers of equipment. In addition, extensive risky extravehicular activity (EVA) would be required to assemble the base.

A less risky and costly approach would be to assemble the base ahead of time in low Earth orbit (LEO). If this method is employed, only one orbital transfer is needed and the base becomes immediately operational upon descent to the lunar surface. This strategy is described in the July 1991 *Journal of Aerospace Engineering* by Madhu Thangavelu of the Institute of Aerospace Systems Architecture at the University of Southern California.

Modular assembly on orbit takes advantage of the infrastructure that will be in place by the end of the century. The Space Shuttle along with a heavy lift launch vehicle (HLLV) currently under study will be the primary mode of transport to LEO. SSF will furnish on orbit support while its ground based tooling will be used for the lunar base modules. In addition, an orbital cryogenic fuel depot is envisioned to be operational by the year 2000.

The modular lunar base system is comprised of three elements. The habitat, a transfer vehicle, and a descent stage. Structurally strengthened SSF modules make up the habitat. A horizontal layout of the habitat is preferred over a vertical orientation for several reasons. The interior layout could be the same as SSF, thereby reducing design costs and easing crew adaption. Stability is enhanced on the moon because of a wider landing footprint. Finally, additional modules could be easily attached for expansion.

Several configurations of the habitat are possible, the most rudimentary being one module. Other arrangements include two modules side by side, three linked end to end in a triangular orientation, or four laid out in a quadrangle. Thangavelu presents the case for the triangular arrangement which contains all the necessary systems for a crew of four on a 3 month rotation period.

The three modules are linked by utility nodes at the apexes of the triangle. One of the modules is the primary habitat which includes sleeping quarters, a recreation facility, and galley. The node at one end contains sanitation and hygiene facilities incorporating solid-waste and water reclamation equipment. Another module is a laboratory outfitted with interchangeable experiment racks. A second node contains the primary airlock with all the EVA suits and equipment to inhibit backtracking of lunar dust. The third module carries the power generation apparatus composed of either solar panels or a nuclear power plant, both of which would be deployed externally. The final node contains environmental controls and life support systems.

The whole system is strengthened by a truss superstructure which absorbs the forces of orbital transfer and descent to the lunar surface.

The orbital transfer vehicle, designed for boosting the system from LEO to lunar orbit, could utilize either electric or chemical propulsion systems. Electric rockets provide low thrust requiring a gradual spiral ascent to lunar orbit. A chemical rocket system is preferred over electric propulsion since it could take advantage of existing space shuttle main engine (SSME) technology utilizing cryogenic liquid oxygen and hydrogen as fuel. The SSMEs could be clustered together for redundancy and transported to LEO by the HLLV. This system provides higher thrust than the electric rocket allowing a faster more direct transfer orbit.

The landing stage is used to brake the system out of lunar orbit and provide a soft landing on the lunar surface. Like the orbital transfer vehicle, cryogenic chemical propulsion systems are preferred for the landing stage. An existing rocket engine already exists called the RL-10 that could be utilized in this application.

The assembly and deployment of the modular lunar base is envisioned to take place in the year 2000. The sequence of events might begin with the launch of the lunar base modules by the space shuttle to LEO near SSF. The space station provides a stable platform and the necessary labor to assemble and outfit the modules within the truss superstructure. The lunar descent stage is brought up by the shuttle or an HLLV and integrated with the truss superstructure at appropriate thrust distribution points. The descent stage is then fueled at the cryogenic propellant depot.

Finally, the shuttle brings up the orbital transfer vehicle modules which are clustered together and fueled at the propellant depot. The orbital transfer vehicles are first mated to the lunar base - descent stage stack and then fired to thrust the whole system to lunar orbit.

Upon reaching the moon, the transfer vehicle modules are jettisoned and the descent stage fires to gently lower the base down to the surface. After touching down, the power and communications systems are deployed and the first permanent lunar base becomes operational.

There are several advantages in this approach over assembly of the system on the moon. First, assembly in LEO offers a safer environment for EVAs because Earth's magnetic field provides a natural shield against harmful radiation. LEO is also a "cleaner" work area which obviates the need for dealing with troublesome lunar dust. The techniques for modular assembly and truss-construction as well as commonality of hardware are inherited from SSF. This reduces design, manufacturing, and training costs. Only one trans-lunar rocket firing is needed as opposed to several for lunar surface assembly. Finally, the base is operational upon touchdown eliminating the risks and costs of many EVAs on the dusty lunar surface. The first phase of colonizing the moon could then begin right away.

CIVIL ENGINEERING APPLICATIONS IN SPACE

Just about every profession will be needed to colonize the final frontier. The field of civil engineering will be one of the first to be utilized. In every milieu humanity has colonized there has always been a need for dwellings, transportation systems, power plants, and water handling facilities. Space is no exception. In fact, civil engineers (CEs) have gotten a head start. This oldest of engineering professions has amassed a storehouse of knowledge since the first roads and aqueducts were built. This vast wisdom can be applied when building habitats in space and on the surfaces of other worlds.

The role of CEs in building space facilities is discussed in the October 1991 issue of *The Journal of Aerospace Engineering*. The author, Ramesh B. Malla, is Assistant Professor of Civil Engineering at the University of Connecticut. Some modern examples of civil engineering accomplishments cited by Malla include power generation plants built in harsh locales, facilities for drilling and transporting oil, bridges spanning large bodies of water or deep gorges, and tunnels excavated under mountains and rivers. There have been tall buildings erected on difficult terrain in harsh environments, scientific stations established in remote and desolate Antarctica, and canals constructed to connect two oceans. Sophisticated transportation and sewage systems support every city.

This knowledge base can be tapped to create a suitable infrastructure and safe facilities in Earth orbit, on the Moon and Mars, and beyond. CEs have already played an important Earth-based role in construction of facilities for the space program such as spacecraft manufacturing plants. Other examples include rocket engine test structures, launch gantries and landing strips, and extraterrestrial environment simulation facilities.

The space-based role for CEs will require contributions from all branches of the profession. Construction of structures in space as on the ground requires careful planning. Activities and arrival of materials must be precisely scheduled in optimum sequence. Experience gained on Earth from construction in remote and hazardous areas has dictated modular assembly, automation, and uncommon transportation techniques. These practices can be directly translated to extraterrestrial (ET) construction projects. Modern bridge building methods can be applied to space truss structures.

In the specialty of earthquake engineering, transient vibration analysis and foundation isolation of buildings can be applied in space and on different worlds. Spacecraft and payload designs require similar analysis to protect them from the forces experienced during launch and acceleration. The foundations of structures on the Moon and Mars will be designed using the same principals as those built on Earth.

Habitats in space will require power, water, and waste management systems - areas which CEs have pioneered on Earth. This experience can be expected to eventually lead to completely closed ecosystems required for self sufficient space colonies.

Geotechnical disciplines like soil mechanics can be applied to the design of lunar bases. There is no bedrock on the Moon - only irregular soil formations. Thus, structures will have to be built on foundations of either mats or floats. Extensive use of underground excavation and construction techniques will be required. The thermal, mechanical, and electrical properties of lunar soil need to be characterized. For instance the bearing capacity, cohesion properties, and void ratios need to be determined. CEs are experts in determining these characteristics.

With respect to the properties of materials in general, the relative value of a material in any particular building application is based on several factors. Strength, weight, durability, availability, and ease of construction are variables to be considered. In space, other wild cards come into play such as low gravity, radiation, and large temperature extremes. Materials that are not useable on earth may be satisfactory for a particular application in space. For example, a thin membrane would not make a good building on Earth because of gravitational and atmospheric constraints. However, such a structure would work fine in the low gravity, airless environment of the Moon.

Structural engineers will play a vital role in building space stations and structures on planetary surfaces. Techniques for designing buildings in harsh environments to withstand dynamic loads can be applied to ET habitats. The lattice truss structures used in the current design of Space Station Freedom were pioneered in modern bridges on Earth. Inflatable membrane structures pioneered in the 60s have been proposed as lunar habitat enclosure. CEs have already started research into development of concrete made from materials available on the Moon.

In the field of transportation, CEs should apply the fundamental concepts of high speed train designs to development of electromagnetic launch systems and mass drivers. These electric accelerators could provide a low cost alternative to conventional launch systems (SCP; November/December 1991). Experience from building Earth-based highways can be utilized in constructing roads on the moon. CEs should in general team with aerospace engineers to develop safe and efficient ET transportation systems.

The profession of civil engineering has much to contribute to the development of facilities in space. Experience gained from building structures on earth in difficult, hazardous, or remote locations can be directly applied in space or on planetary surfaces with little or no modification. Techniques developed by civil engineers for analysis of structures and properties of materials can be utilized to build habitats and transportation systems that will open the final frontier for colonization.

CONFERENCE ON NEW FIELD: BIOASTRONOMY

We would like to take a break from technological issues through an interlude on a subject that is important for space colonization. Sooner or later (hopefully sooner), humanity will colonize all of the solar system and begin to venture beyond. Will we find that other stars in our galaxy harbor planets (a fact not yet proven)? If planetary systems exist around other suns, what are the chances that intelligent life has evolved there and progressed to an advanced stage? If advanced alien cultures exist, eventually we will discover them or they will approach us.

Contact with alien civilizations may be beneficial to humanity - especially if the civilization is more advanced than our own. We may be able to tap their vast wisdom for answers to problems of survival. Or first contact may unite us as one species heralding an end to war.

A small but growing contingent of scientists have taken it upon themselves to address the theoretical basis for extraterrestrial life and methods of detecting it. A conference showcasing their latest research was held in June of 1990. A summary of the topics discussed was reported by Michael D. Papagiannis in the *Journal of the British Interplanetary Society* for August 1991. Papagiannis is an astronomer at Boston University who attended the conference.

There were six major sessions categorized as cosmic evolution, organic and prebiotic evolution, primitive evolution, searches for advanced civilizations, possibilities of advanced evolution, and wider inter-disciplinary connections.

Cosmic Evolution

This topic covered research on the formation of planetary systems around other stars. One study consisted of a survey of 550 main sequence stars in young star clusters. The researchers found excess infrared emissions indicating the existence of dusty material around many of the stars - clues that planets may be forming there.

Another investigation examined the radial velocities of 20 solar-type stars looking for the gravitational influence of large hidden planets. The results looked promising but further analysis was needed to confirm the findings.

Two new methods of detecting planetary companions around other stars were presented which should be utilized soon. The first procedure attempts to detect low frequency radio emission from the interaction of a planet's magnetic field with the solar wind of its parent star. The other technique looks for reduction of a star's brightness due to partial eclipses by large planets. The latter technique will be used shortly by the European Southern Observatory in Chile.

Also discussed in this session was a new orbiting telescope in the planning stage by the Jet Propulsion Laboratory. Called the Astrometric Imaging Telescope, the device will have such high resolution that it will be able to detect Uranus-size planets around hundreds of nearby stars.

Organic & Prebiotic Evolution

This session dealt with research on the formation of organic molecules in the interstellar medium, comets, asteroids, and on moons within our solar system. These complex molecules when mixed with water form the building blocks of life.

One study reviewed 90 molecules that have been discovered in deep space, many necessary for carbon-based life. Energy sources contributing to their formation include cosmic rays, ultraviolet light, and heat within stellar atmospheres.

Another paper reviewed the search for water in space which always seems to accompany other carbon based molecules like CO, CO_2, CH_4, and H_2CO. Alternate paths for the formation of organic double layered membranes were discussed, the precursors of single-celled organisms.

The results from the probes sent to comet Halley were summarized. The composition of comets includes many carbon-based molecules which have significant implications for the origin of life. The presence of carbon compounds and water on Earth may be due to the impacts of comets after its formation.

Primitive Evolution

Papers in this category discussed the appearance of life on Earth & other planets and the possibilities for detecting extraterrestrial life. One study examined the chemistry of early life on Earth and compared it to the chemical processes occurring in the atmosphere of Titan, Saturn's largest moon. Titan's atmosphere could become a good laboratory for studying primitive life because it contains many organic molecules.

A review of the extent of habitable regions around stars was presented. It was pointed out that as stars evolve, they become hotter expanding the life-zone further out. This implies that the habitable environment may be larger than previously thought. The case for liquid water on Mars in the past was discussed. It was suggested that primitive life may have existed in deep lakes covered with ice and that areas of parallel strata would be a good place to search for evidence of its previous existence.

This paper also discussed the possibility that an ocean may exist beneath the thick surface ice of Europa, the enigmatic moon of Jupiter. The idea that conditions may be conducive for life to evolve on Europa was first predicted by Arthur C. Clark.

Search For Advanced Civilizations

A summary of projects underway around the globe by the Search for Extraterrestrial Intelligence (SETI) using radio receivers was presented. It was noted that benefits had been realized in the form of improved antenna and receiver design but that an increase in interference was anticipated from expanding commercial use of radio frequencies. It was suggested that searches of nearby stars be conducted at which we may have sent accidental signals while using the Arecibo radio telescope to bounce radar signals off of planets within our own solar system. A sufficient period has elapsed from the time of some of these radar studies for the signal to reach the stars and a reply to be sent.

A theory was presented on the possibility that advanced alien civilizations might communicate using narrow laser or radio beams. It was recommended that an international search of nearby stars be conducted for this type of signal.

Advanced Evolution Possibilities

A wide range of possibilities for advanced civilizations was presented. One prospect involved searching the catalog of infrared objects discovered by the Infrared Astronomical Satellite (IRAS) for signs of Dyson spheres - shells of planetary material constructed by an advanced civilization to completely enclose and harness the energy of their sun. Another paper suggested searching for alien starships which might use antimatter or nuclear fusion propulsion systems. Such spacecraft could be detected as fast moving gamma-ray sources.

Besides searching for extraterrestrial signals beyond the solar system it was recommended that we look for artifacts within the solar system that may have been left by visiting aliens.

A discussion on technological evolution of intelligent beings was presented which suggested that one possible outcome would be self-destruction unless the beings impose restrictions that prevent annihilation. Contact with these advanced cultures may give humanity a prescription for its own survival.

Interdisciplinary Connections

The final session dealt with broader perspectives on the origins of life on Earth, the consequences of first contact with aliens, and theories that there may be a goal in cosmic evolution. One paper discussed life as a cosmic process of chemistry, the result of stellar winds and supernovas distributing the 27 chemicals of life throughout the galaxy making life on Earth possible. Another view went further to show that life evolves constantly toward greater complexity and it has the power to alter its surroundings to its own advantage.

Mr. Papagiannis presented the belief that the processes of chemical, biological, and technological evolution leads to two possible outcomes: either self-destruction or a progression towards more advanced intellectual and spiritual states. These higher stages may be the ultimate goal of evolution and may be aided by science through such fields as genetic engineering and nanotechnology.

One of the final presentations asserted that advanced civilizations probably require global unification to survive. There are some indications that the human race is headed in that direction although we have a long way to go. Discovery of an extraterrestrial civilization may advance us toward that goal.

PULSED FUSION ROCKETS FOR STAR FLIGHT

In 1978 a design for an interstellar robotic probe was conceived by the British Interplanetary Society that could traverse the 5.5 light year distance to Barnard's Star within the lifetime of the mission designers. Called Project Daedalus, the one-way fly-by mission could be completed in 40 years because of the innovation of a pulsed fusion rocket stage. This propulsion system utilizes small pellets of frozen hydrogen shot into a thrust chamber and compressed by electron beams to thermonuclear temperatures. The thrust chamber is surrounded by coils that generate magnetic fields against which the high energy plasma pushes to provide thrust. Power for the magnetic coils and electron beams is generated by the hot ionized gas flowing past induction coils at the exit of the thrust chamber.

The disadvantage to this approach is that flexibility at the end of the mission is limited. Its fuel all but expended, the craft would hurl through the target star system with minimal capability for course corrections. Only a brief chance to study any planets and other objects of interest is afforded.

A variation on this theme has been suggested by Raymond J. Halyard in the August 1991 *Journal of the British Interplanetary Society*. Halyard proposes a vehicle that orbits the star and has fuel left over for excursions to interesting planetary targets. Data retrieval and science would be increased by carrying a suite of planetary probes. But there is a trade-off. After an interim coast phase, the craft must decelerate long enough to drop into orbit around the star. This effectively doubles the travel time.

Another problem surfaces with this approach. One possible fuel to be used in this system is a mixture of deuterium and He3. Deuterium, the heavy isotope of hydrogen, is abundant in sea water. He3 is an isotope of Helium rare on earth but abundant in lunar soil (SCP; September/October 1990) and in the atmospheres of the gas giant planets in the outer solar system.

The original designers of Daedalus realized that the fusion reaction between deuterium and He3 would require higher temperatures than could be attained with the electron beams. This problem was solved by placing a more easily ignitable fuse at the center of each fuel pellet. This fuse was composed of deuterium and tritium, the radioactive isotope of hydrogen. Tritium has a half-life of 12.5 years. A sufficient amount would have to be carried to allow for the decay rate throughout the 40 year journey.

Although not a problem for the fly-by mission, most of the tritium will decay during the longer travel time of the orbiting probe. The solution suggested by Halyard is to generate excess tritium during the acceleration phase so that a sufficient amount remains for a restart after the coast period. This can be accomplished by placing a circulating blanket of lithium around the thrust chamber. Neutrons from the fusion reaction* impinging on the lithium will breed the necessary tritium which can be separated easily. The disadvantage is that the lithium blanket adds weight to the system.

Given the above limitations and using the Daedalus baseline, Halyard has optimized the travel time for the interstellar orbiter mission. This is counter to the original design study which optimized the amount of fuel for the fly-by scenario. With a payload of 250 tons a trip to Barnard's star would take 73 years. However, the sacrifice in increased travel time is more than compensated by the bounty of scientific data that could be obtained from an orbiting instrumented probe.

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* For the physicists among our readers the D-He3 reaction actually produces very little neutrons. Halyard introduced an external layer of deuterium to the D-He3 fuel pellets to generate sufficient neutrons for this application.

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