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ASTROTECTONICS[1]: AN OVERVIEW

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Abstract Astrotectonics is the science of construction in space of both orbital and planetary structures and facilities, as well as orbitally assembled interplanetary spacecraft. The success of man's construction activities is dependent on the development of support equipment and assembly techniques using man alone, man and robotics, or robotics alone, depending on the work to be performed and the hazards present. The separation of Astrotectonics into distinct genre's of orbital and planetary facility construction due to subtle differences in the environment and subsequently, the equipment, is discussed.

INTRODUCTION

In comparison to the complex structural and civil projects undertaken on Earth throughout the centuries, construction in space may appear simple. In the absence of the forces imposed on a structure by wind, weather and gravity, the design and assembly of orbital space structures should be straightforward. In reality however, nothing could be farther from the truth. Orbital structures experience no wind loading or weathering, but must instead withstand a hard vacuum, high radiation and the corrosive effects of the Earth's atmosphere while in low Earth orbit (LEO). The absence of gravity loading is countered by extreme temperature variations and enormous dynamics loads during orbit insertion and with each position correction while in orbit.

Astrotectonics (astro = space; tectonics = building) is the science of construction in space of both orbital and planetary structures and facilities, incorporating issues in architecture, structural and system design, program management and material/labor estimating standards and guidelines. The United States has recently unveiled a number of ambitious goals for space exploration over the next fifty years (36,37). To meet these goals, Astrotectonics must quickly evolve from its current infancy to a comprehensive construction management system. Development of this system has progressed at a cautious pace, based on data gathered from extensive terrestrial and space experimentation (Breeding R.E and Griswold, H.R. 1981; Card,M.E. et.al. 1986; Covault, C. 1987; Gossain, D.N. et.al. 1985; Hall,S.B. 1979; Heard, W.L. et.al. 1986), testing designs of structural systems and components, as well as many handling and assembly techniques. The operation of the U.S. Space Station - the first large dimensional habitated structure to be truly

1. For the term 'tectonics' this paper uses the preferred definition: "Building, or any assembly of materials in construction"; rather than the more recent usage of the term in the field of geology regarding land structures.

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'constructed' in space- will add enormous amounts of data and expertise to the U.S. Space program and the field of Astrotectonics. The technology and construction techniques proven in LEO will benefit the construction of the first lunar base.

Figure One shows a schematic breakdown of the various facilities proposed for extra-terrestrial use in the next century. Dominated initially by orbital construction development through the mid 1990's by the Space Station, the U.S. Space Program will enter a new phase of space structures development by the turn of the century with the construction of the first permanent human outpost on another planetary body - the moon.

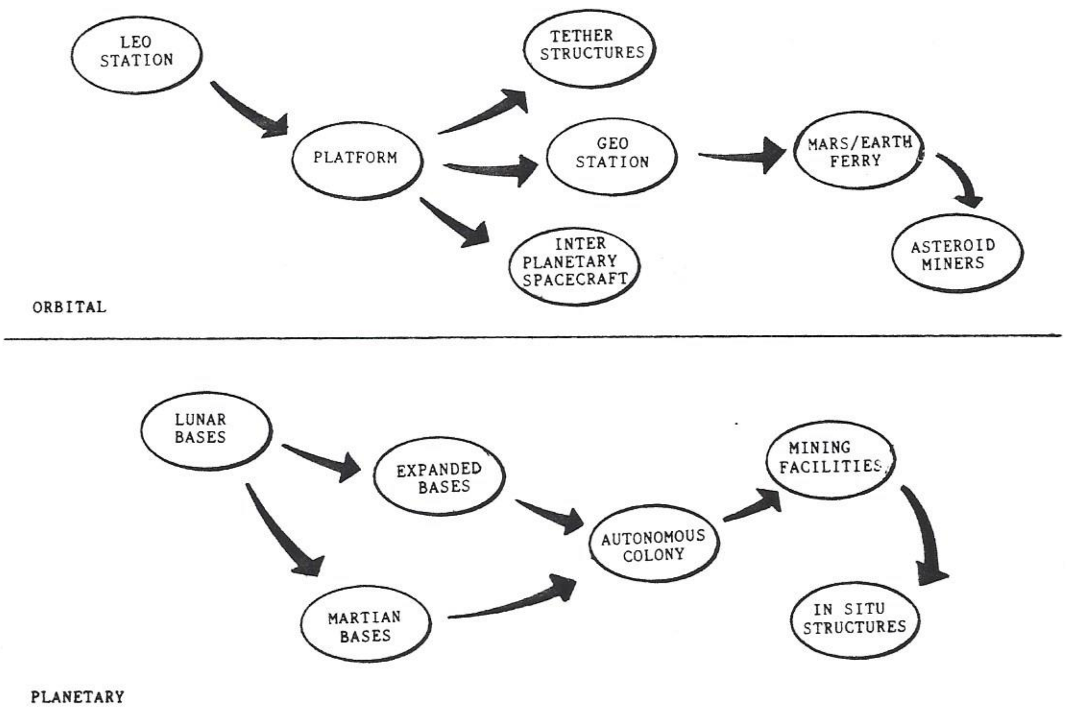

FIGURE 1. SPACE STRUCTURE EVOLUTION

ORBITAL FACILITY CONSTRUCTION

The United States and the U.S.S.R. have maintained activities in space for three decades through a variety of manned and unmanned crafts and satellites. After a series of short duration programs by each country, man now maintains a permanent presence in LEO with the launching of the U.S.S.R.'s Mir Space Station. The deployment of this station however, barely qualifies as being constructed in space, since

Mir is a collection of Earth-built modules requiring only docking for assembly. To prepare for work on the U.S. Space Station, experiments have been performed by crews of the Shuttle (Card, M.E. et.al. 1986; Crockford, W.W. 1986), as well as Earth based crews operating in neutral bouyancy tanks (Covault,C. 1987). Results of each series of experiments show that current assembly times on Earth are comparable to actual assembly time in space.

Orbital structures consist of three basic classifications: deployable, deployable-partially assembled and space fabricated. An example of a deployable structure would be a typical satellite launched for communications or remote sensing. A deployable-partially assembled structure would be the U.S. Space Station which requires an orbitally assembled super structure to support pressurized modules that are fabricated on Earth. An example of a space fabricated structure would be a space platform assembled in orbit using components fabricated in orbit from raw stock, using a device called a beam builder (Gvamichava, A.S. and Koshelev, V.A. 1984; Johnson, R.W. 1981; Kline, R.L. 1979).

Methods of assembly for orbital structures fall into two categories (a) single point and (b) variable point (Gould, C.K. 1981; Koelle, H.H. 1986). The single point method - used primarily for linear truss platforms (see Fig. 1) - allows the structure being assembled to move about a fixed assembly/fabrication point. This method is ideally suited for Shuttle operations, where the holding fixtures will be located in close proximity to the cargo bay and the structure can be assembled along a displaced x,y axis. The variable point method uses an asembly station that moves along the x,y axis of the structure being assembled. This system is ideally suited to large scale space fabricated structures, using an assembly station consisting of beam builders and remote manipulators mounted onto a space crane which tracks along the trusswork of the structure being built.

Support Equipment

To accomplish the assembly of large structures in LEO and beyond, astroworkers must depend on an array of support equipment. Development studies have produced prototypes and operational techniques for a number of categories, such as: space crane (Gunkel, R.J. et.al. 1978); telerobotic manipulators (Gvamichava,A.S. and Koshelev,V.A. 1984; Greely,R. and Williams, R.J. 1987; Matsumoto, K. et.al. 1986; Nagatomo, K. et.al. 1985); holding fixtures (Gould, C.C. 1981; Katz, E. and Roebuck, J.A. 1981); manned remote workstations (Nathan, C.A. 1978, Nassiff, J.A. 1978); and space suit development for extended extravehicular activities -EVA's- (32,33).

The space suited astroworker, floating amongst the structural framework of orbital facilities will remain a familiar sight for decades to come. Rather than replacing man in space, this support equipment will aid him in three distinct ways: provide greater torques and larger forces at greater reaches; provide stability to a structure to prevent tumbling about one or more axes; replace man during periods of high radiation flux. The use of these remotely operated cranes and manipulators will bring about the formation of

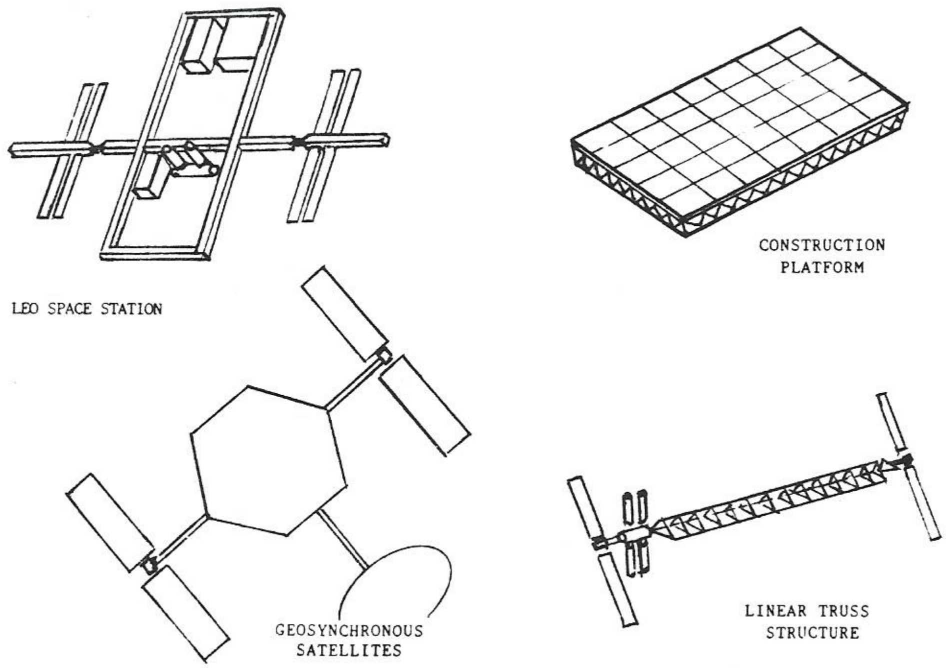

FIGURE 2. ORBITAL SPACE STRUCTURES

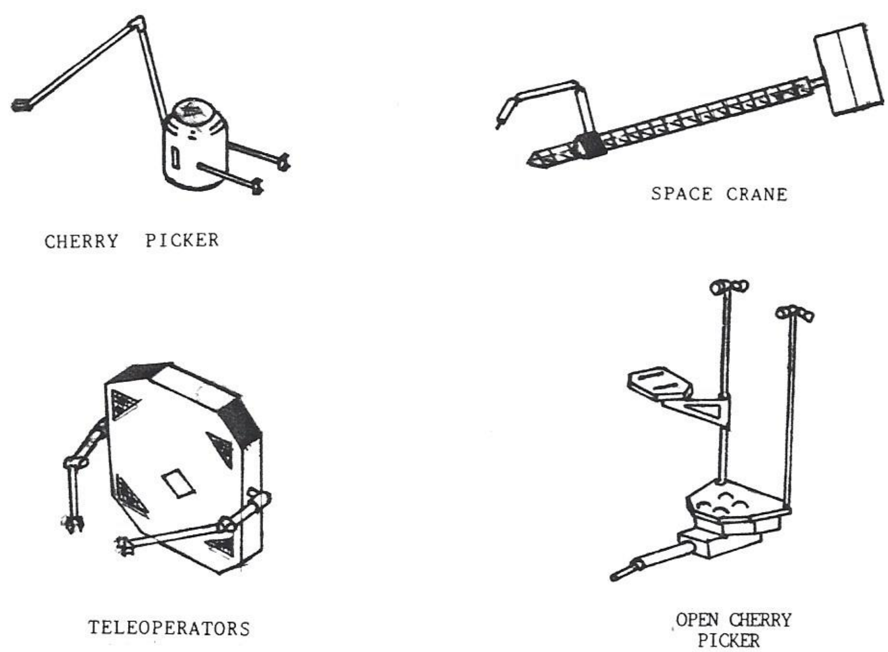

FIGURE 3. ORBITAL SUPPORT EQUIPMENT

a new class of astroworker - the teleoperator technician - skilled in operating cranes, cherry pickers or manipulators from a remote location in the Space Station or the Shuttle; or from a remote workstation of a construction platform. Data from a sophisticated system of video, lighting and instrumentation will be all the feedback the operator has to control activities that may be a kilometer away.

Connection designs for trusswork systems used on space platforms are an important element of overall assembly time for orbital projects. The use of a hub spar and strut system similar to the Star Bay System (Bak, D.J. 1987; Covault, C. 1987) is a likely candidate for the Space Station. This 'push and lock' type of connection lessens hand fatigue for the astroworker and is easily worked by remote manipulators. Larger structures will require the use of detachable and non-detachable connections , such as a combination of the hub and strut system with welded or soldered joints.

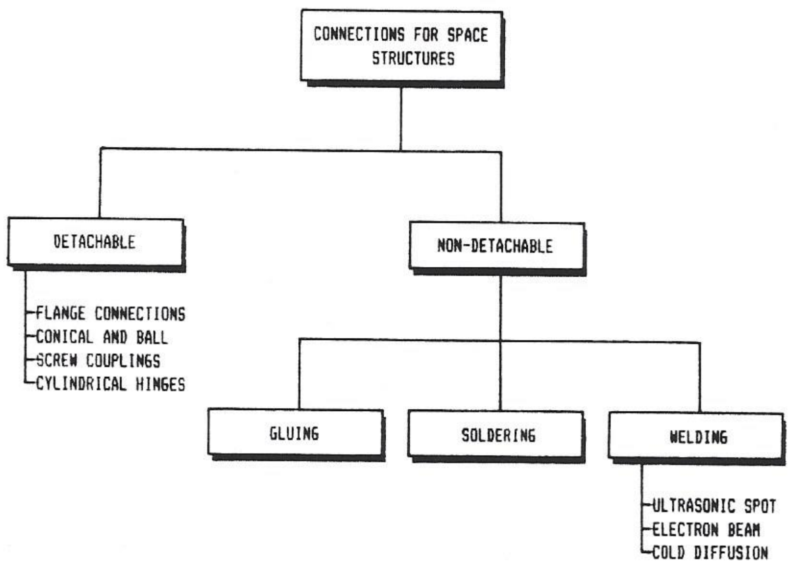

FIGURE 4. CONNECTIONS FOR SPACE STRUCTURES

PLANETARY FACILITY CONSTRUCTION

The establishment of early outposts on the Moon and Mars for research and colonization will rely on the use of Space Station-like habitat and laboratory modules (Duke,M. et.al. 1985). Colonies assembled from these modules satisfy three key problems faced in establishing early outposts: (1) rapid deployment and burial necessitated by the radiation hazards on the surface of the Moon and Mars (Adams, J.H. 1985); (2) the confidence instilled by using proven technology; (3)cost savings of avoiding additional technology development for these habitats.

As these outposts increase in size and mature in function, emphasis will shift from Earth-fabricated environments to in-situ built structures using local raw materials (Hoffman S.J. and Niehoff, J.C. 1985; Land, P. 1985; Lin, T.D. 1985). Unique to the planetary bases is the coexistence of conditions found in free space along with the constrants found on the surface of an Earth-like body. The hard vacuum of space exists on the surface of the Moon along with the associated temperature extremes. Mars possesses an atmosphere too thin to stabilize day/night temperature variations, but is dense enough to support high velocity winds capable of producing global dust storms.

Also unique to planetary conditions are gravity and day/night or seasonal cycles. The presence of 1/6 Earth gravity on the Moon and 1/3 Earth gravity on Mars precludes the large spider-like trusswork structures of orbital facilities, replaced by terrestrial-like structural systems. Revolution about the Earth produces day/night cycles on the Moon of 14 Earth days each, necessitating the use of nuclear generated power and the development of operating techniques and procedures for this extended 'night'. The rotation of Mars produces day/night cycles similar to Earth, but the revolution of Mars produces climatic changes responsible for the global dust storms mentioned earlier, which will dramatically effect surface activities and resupply.

Support Equipment

Construction requirements for planetary bases include the building of protective structures; establishment of ground transportation systems; erection of power generation facilities; and the deployment of scientific experiments. The development of heavy equipment for non-terrestrial construction is paramount to the success of man's efforts to colonize other worlds (Podnieks,F.R. and Roepke, W.W. 1985; Crockford, W.W. 1986). Excavation and earthmoving requirements of habitat burial under several meters of regolith (soil) will be fulfilled by bulldozers and compactors. Cranes will be necassary to off-load modules and equipment from the landers; while trailers attached to these cranes are necessary to haul this equipment.

Rock melters, which have been proposed for use in establishing in-situ colonies (Bova, B 1987; Rowley, J.C. and Neudecker, J.W. 1985) may find use in exploratory drilling for scientific experiments, but will more likely become operational during later base expansion, as will fully robotic excavators.

The harsh conditions on the surface of other planetary bodies, forcing man to burrow under the surface for safety, also put demands on the equipment he will use there. Each machine will be equiped with a self-contained life support system to provide a shirt sleeve environment for the operator. In addition the operators module must have shielding to offer the operator protection from the radiation environment. If the 5 REM/yr exposure limit for Earth based radiation workers is adopted for the colonies, regular working hours will be restricted to about 1800 hours per year inside these enclosed vehicles. EVA work must be further restricted. However, it will only be after these colonies have grown to a sufficient size (Koelle, H.H. 1986; Dalton, C. and Degelman, L.O. 1972) that the surface activity restrictions will bear a marked impact on project programming, though the need for manufacturing operations in producing local building materials (Young, J.F. 1985; Khalili, E.N. 1985; Blacic, J.D. 1985) may coincide with the use of robotic mining machines. The use of robotic miners would dramatically reduce the need for men to be involved in the mining and processing operations that would require more and more surface time.

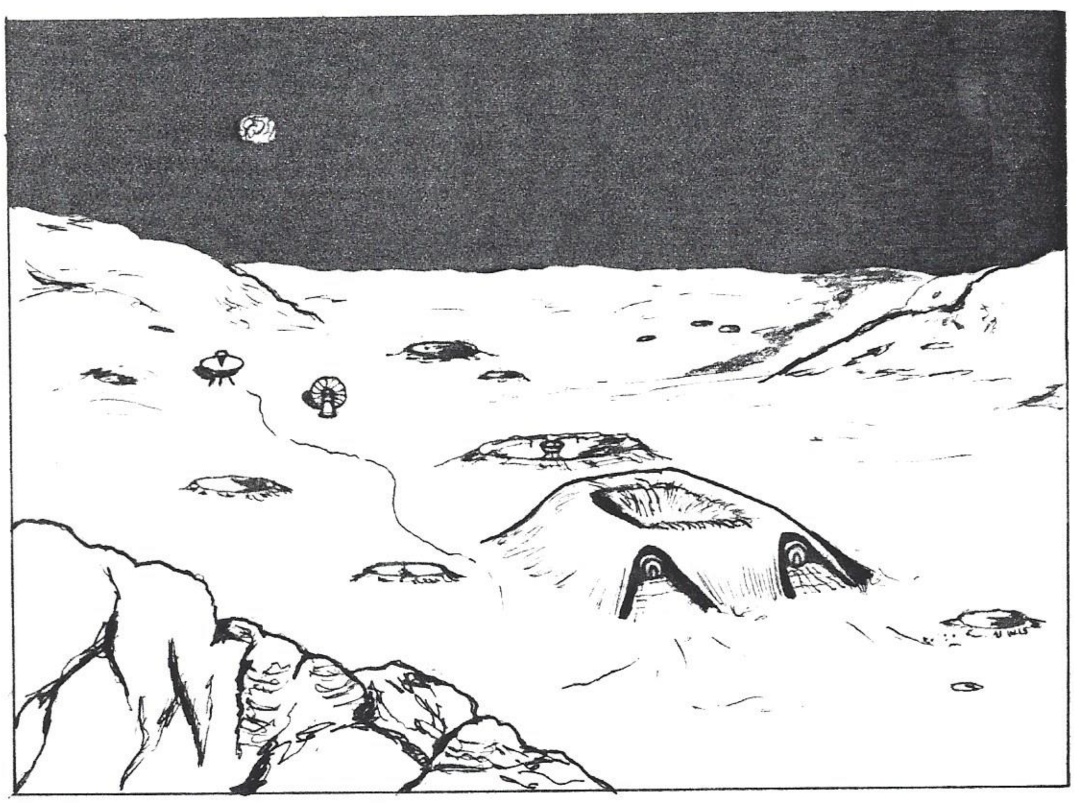

FIGURE 5. TYPICAL PLANETARY FACILITY

CONCLUSION

Terrestrial construction techniques developed over the centuries will be of little use in orbital space construction and only minimally transferable to planetary construction. For those standards and practices that will be applicable (i.e. excavation/grading techniques), the use of Earth-based machines seems unlikely. The tools of the astro - worker will carry names similar to terrestrial counterparts, but in appearance, operation and technology these machines will be vastly different.

Robotics and teleoperated manipulators must play an ever increasing role in space construction for both orbital and planetary facilities. Maturity in orbital construction will take man farther and farther outside the protective envelope of the Earth's electromagnetic field, reaching out to geosynchrnous orbit and the Lagrangian points (Johnson, R.D. and Holbrow, C. 1977). where the radiation hazard is omnipresent. This same hazard present for planetary workers will be avoided with robotics. The effective combination of man and machine will help control construction costs and at the same time aid in productivity.

The price of space construction includes launch costs, shuttle fees, ground support personnel, insurance, housing and support of crews in orbit or on planetary surfaces, and the productivity rates of both man and machine. Launch costs to LEO are estimated at $2600/Kg in 1984 dollars (Stuart, D.G. 1986), while launch costs to the lunar surface have been estimated at $13,000/Kg in 1984 dollars (Sauer, R.L. 1985). Based on terrestrial and orbital studies, human productivity for orbital construction is estimated at 75 Kg/person hour for assembly of high-tech hardware and 200 Kg/person hour for low-tech hardware (Stuart

EQUIPMENT	FUNCTION
BULLDOZER	·EXCAVATION OF REGOLITH ·COMPACTION ·MOUNDING
CRANE	·REMOVE PAYLOADS FROM LANDER ·PLACE POWER EQUIPMENT ·PLACE HABITAT MODULES ·TOW TRAILERS
TRAILERS	·HAUL MODULES AND EQUIPMENT TO SITE
PERSONNEL CARRIERS	·SCIENTIFIC EXPLORATION ·GENERAL SURFACE MOBILITY ·RADIATION SHIELDING

FIGURE 6. PRIMARY EQUIPMENT FUNCTIONS

D.G. 1986).

The more intangible and complex issues dealing with man himself, living and working in the confines of outer space is beyond the scope of this paper. However, problems concerning social dynamics, small group interactions, motivation, management structure, crew selection and habitation of workers must be an important part of Astrotectonics, having a direct bearing on the success of a project.

Given the nature of space exploration, the level of technology required for transport and life support, and the scale of future space projects - in scope and in cost - specialization is unavoidable for the astroworker. At the outset, Astrotectonics will be divided into two main categories: orbital and planetary, as outlined in this paper. While it is true that early lunar outposts will build upon expertise developed in LEO, the evolution of each genre' will rapidly accelerate the development of methods and equipment peculiar to the specific environment.

Orbital construction will evolve from simple LEO space stations to construction platforms in geosynchronous orbit using lunar materials and the assembly of vast interplanetary spaceships serving as Earth-Mars shuttles. Manned facilities will include zero-g, variable-g and Earth normal gravity environments, all possible with the use of space tethers (Bekey, I 1986). Planetary facilities will expand from collections of a handful of pressurized modules to vast underground, domed cities with populations approaching ten thousand, possessing industry, tourism, self goverment and cislunar trading.

The growth of each category will create sub-classifications for additional areas of specialization, making Astrotectonics a complex mix of engineering, system analysis, pure space science and schedueling and planning. As a science it will continue to change and expand as man reaches farther into space with increasingly complex structures.

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