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A MANNED LUNAR OUTPOST

Design Considerations for Three Key Elements in an Initial Manned Lunar Outpost

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SASAKAWA INTERNATIONAL CENTER
FOR
SPACE ARCHITECTURE

COLLEGE OF ARCHITECTURE
UNIVERSITY OF HOUSTON

Faculty Advisors:

Larry Bell
Guillermo Trotti
Jeff Brown

Group Members:

Nilanjan Bhattacharya
Nathan Moore
Tom Polette
Larry Toups

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FOR FURTHER INFORMATION
Write to:

Sasakawa International Center for Space Architecture
ARCH 122
University of Houston
4800 Calhoun
Houston, Texas 77004

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LIST OF ACRONYMS

EVA	Extra Vehicular Activity
HLLV	Heavy Lift Launch Vehicle
IMLO	Initial Manned Lunar Outpost
LEM	Lunar Excursion Module
LEO	Low Earth Orbit
LLO	Low Lunar Orbit
LMSTS	Lunar Mobile Surface Transport System
MFV	Multi-Functional Vehicle
MLO	Manned Lunar Outpost
OTV	Orbital Transfer Vehicle
RCS	Reaction Control System
RSS	Regolith Support Structure
STS	Space Transportation System

ABSTRACT

The Initial Manned Lunar Outpost (IMLO) is proposed as the initial permanent base for manned activities on the Moon. The study concentrated on identifying the equipment, support systems, and initial base configuration necessary to accomplish the various science, industrial and exploration activities envisioned.

The primary concepts of the MLO were the use of hard modules for habitation areas creating a flexible, modular transportation system; designing a multi-functional vehicle; and using an overhead radiation protection system.The transportation system, dubbed the Lunar Mobile Surface Transport System (LMSTS), carries the hard modules to the surface of the moon and provides a method to move them to the desired location through the use of interchangeable pallets. The avionics pallets are changed-out with wheel and hitch pallets, transforming the LMSTS into a "tractor trailer" used with the Multi-Functional Vehicle (MFV). The modules are placed under the Regolith Support Structure (RSS) which provides a stable environment and radiation protection for the entire base. The overhead structure was chosen over simply burying the modules to provide a study on the advantages and disadvantages of this type of system. The advantages include easy access to the exterior of the modules, providing a protected area for vehicles and equipment used in EVA, and creating an area of constant temperature. Disadvantages include a need for prefabrication of structural components, including the pre-construction and construction phases of the initial MLO. The design appoach taken considered existing and near-term materials and technology only, without the consideration of possible future building technologies.

INTRODUCTION

A permanently Manned Lunar Outpost (MLO) will be an essential element of a space transportation and operations infrastructure to support the exploration of other planets. A MLO, besides conducting scientific research, would extensively use in-situ lunar materials in the manufacture of products that would support itself and the space station. The ultimate nature and configuration of such a permanent MLO would be greatly determined by the success of, and comprehensive investigations by an Initial Manned Lunar Outpost (IMLO).

Mission determinants for an IMLO should include:

- The scientific exploration of the lunar environment.
- Life science experiments.
- Industrial processing experiments that would demonstrate the feasibility of using in-situ lunar materials.
- The development of processes that would specifically support the Low Earth Orbit (LEO) space station.
- The development and refinement of systems that will eventually lead to self-sufficiency.

The success and failure of such experiments would then determine the future activities and therefore the ultimate configuration of a permanent MLO.

Being unable to initially rely on the use of in-situ materials for construction, the IMLO would necessarily need to consist of components fabricated mainly on Earth and at LEO and assembled at the lunar surface by a construction team. The construction of an IMLO may require as many as seven crew members working over a construction period of up to 18 months.

Components of the IMLO that would be delivered to the surface for assembly would include: pressurized aluminum modules, of space shuttle payload dimensions, consisting of one habitat module, one life science module, and one industrial science module; two air lock/scrub room modules; interconnect nodes; logistics modules; a multi-functional vehicle (MFV) for construction; and a lunar Regolith Support Structure (RSS) to provide above surface radiation protection.

In this report we will discuss possible designs for:

The Lunar Mobile Surface Transport System (LMSTS)

The Multi-Functional Vehicle (MFV)

The Regolith Support Structure (RSS)

1.0 PROJECT OBJECTIVES

1.1 EFFICIENCY

- Effectively utilize the Space Station and available Space Transportation System (STS) 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 wherever possible to minimize research and development costs, test requirements and failure risks.

1.2 ECONOMY AND SELF-SUFFICIENCY

- Work towards the highest practical level of self-sufficiency at the earliest possible stage of development to minimize resupply costs.

- Facilitate an economical expansion of facilities and operations over a prolonged period.

- Emphasize modularity in the design of habitat and equipment systems to facilitate changes and updates.

1.3 HUMAN HEALTH, PRODUCTIVITY AND SAFETY

- Provide means to protect the crew from radiation and other health/safety hazards during EVA operations on the lunar surface.

- Incorporate automation/robotic systems wherever possible to minimize crew task time and work hazards, particularly with respect to lunar surface operations.

- Provide easy servicing access for routine and emergency maintenance.

2.0 BACKGROUND

2.1 GENERAL

In July, 1986, the National Commission on Space released a report that proposed space program goals for the next fifty years. Key recommendations are:

- Natural progression for future space activities within the Solar System.
- 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, 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 seeds of enterprise. Exploring and prospecting the Moon, learning to use lunar resources and work within lunar constraints, would provide the experience and expertise necessary for future human exploration of the Solar System.

2.2 MANNED LUNAR OUTPOST RATIONALE

A permanently manned lunar surface outpost will be an essential element of a space transportation and operations infrastructure to support exploration of other planets. Such an initiative can greatly advance scientific knowledge and offer progress towards realizing the industrialization of near - Earth space.

A MLO can support comprehensive investigations of the Moon and its environment to yield new information about the early history of the Earth. This will offer a framework for interpreting other observations about our Solar System.

Ways to acquire and process lunar materials for use in space can also be demonstrated at the base. A challenging and long - term MLO objective is to conduct research and development leading to a self supporting settlement.

2.0 BACKGROUND

2.3 SOLAR SYSTEM EXPLORATION BASE

Programs to expand our human presence into the Solar System must be guided by an economical, phased approach through which each step provides enabling technology for the next.

- The first priority is to acquire a safe, reliable, affordable and versatile system to transport people, their living supplies, and work tools beyond Earth and LEO.

- We should also determine the ability of people and other life forms to adapt and function on extended planetary missions.

- There should be a demonstration of systems and procedures to support life and industry.

2.4 SUMMARY

The IMLO proposed in this report presents early construction and operational stages for a much more expansive and potentially self-sufficient development which will evolve over time. Assumptions and concepts are presented for illustrative purposes and as a basis for future requirement/option assessment.

3.0 PROJECT ASSUMPTIONS

3.1 GENERAL

Constraints imposed by high costs to transport people and equipment were given careful consideration in the current project. The availability of an International Space Station and a fleet of Heavy Lift Launch Vehicles (HLLVs) is assumed. The resumption of service of the Space Shuttle is also an important element in the mission planning. It is assumed that reliable and consistant launches will take place over the long - term. Based on current work and projected agendas an Orbital Transfer Vehicle (OTV) is considered an essential cog in the transportation system needed for lunar missions.

3.0 PROJECT ASSUMPTIONS

3.2 INFRASTRUCTURE ELEMENTS

SPACE SHUTTLE

To be used as a primary workhorse for delivery of earth - manufactured payloads to Low Earth Orbit (LEO). Also is the key element in crew transport.

HEAVY LIFT LAUNCH VEHICLE (HLLV)

Will have the ability to deliver larger payloads to LEO. The chief advantage of an HLLV is that you would have the capability to deliver major structural pieces without the need of a crew. This would have a significant impact on costs and scheduling.

LEO SPACE STATION

Would serve as the main staging facility for the LEO - LLO infrastructure. It is assumed this will involve international powers such as the United States, France and Japan and be a versatile, multifunctional facility.

ORBITAL TRANSFER VEHICLE (OTV)

This type of vehicle would be parked and refueled at a LEO Space Station rather than returning to earth after each mission. It will be necessary to transfer large payloads beyond LEO and this is the vehicle to perform that function. This vehicle will also incorporate a reusable aerobrake. The transfer vehicle be fueled by liquid oxygen and liquid hydrogen and be capable of delivering a payload of 27,000 kg. to LLO.

3.3 INTERNATIONAL COOPERATION

International participation and support are likely to be necessary to distribute the financial burdens posed by this costly program. Such cooperation can and should involve developing as well as developed spacefaring nations. For this to happen, the U.S. must work to resolve any diplomatic and/or philosophical differences it might have with potential partners on this mission. Current Antartic, Outer Space, Law of the Seas, and Moon treaties offer conceptual precedents. These agreements address representative issues including province, sharing of benefits, common heritage of mankind, and rights and obligations beyond a nation's territorial limits.

4.0 PROJECT DESCRIPTION

4.1 IMLO PRECONSTRUCTION PHASE SEQUENCE

The initial Earth based fabrication would be necessary for the following IMLO components: all man rated modules; systems equipment; structural components; MFV components; and LMSTS components. Delivery of all these components to LEO would be accomplished by the space shuttle or a Heavy Lift Launch Vehicle (HLLV) (**A**) which would have payload dimensions as a multiple of that of the space shuttle. With the delivery of these components to a LEO space station (**B**), additional assembly will occur, with the assembled components then being loaded onto their respective LMST. The unmanned payloads loaded onto their LMSTS would then be delivered to Low Lunar Orbit (LLO) via an Orbital Transfer Vehicle (OTV) (**C**). Once at LLO, the LMSTS will disengage from the OTV and be teleoperated to the lunar surface from the space station at LEO (**D**). After all the outpost components have been delivered to the site, the construction crew will arrive in a Lunar Excursion Module (LEM) derived vehicle. This event would initiate the IMLO construction phase.

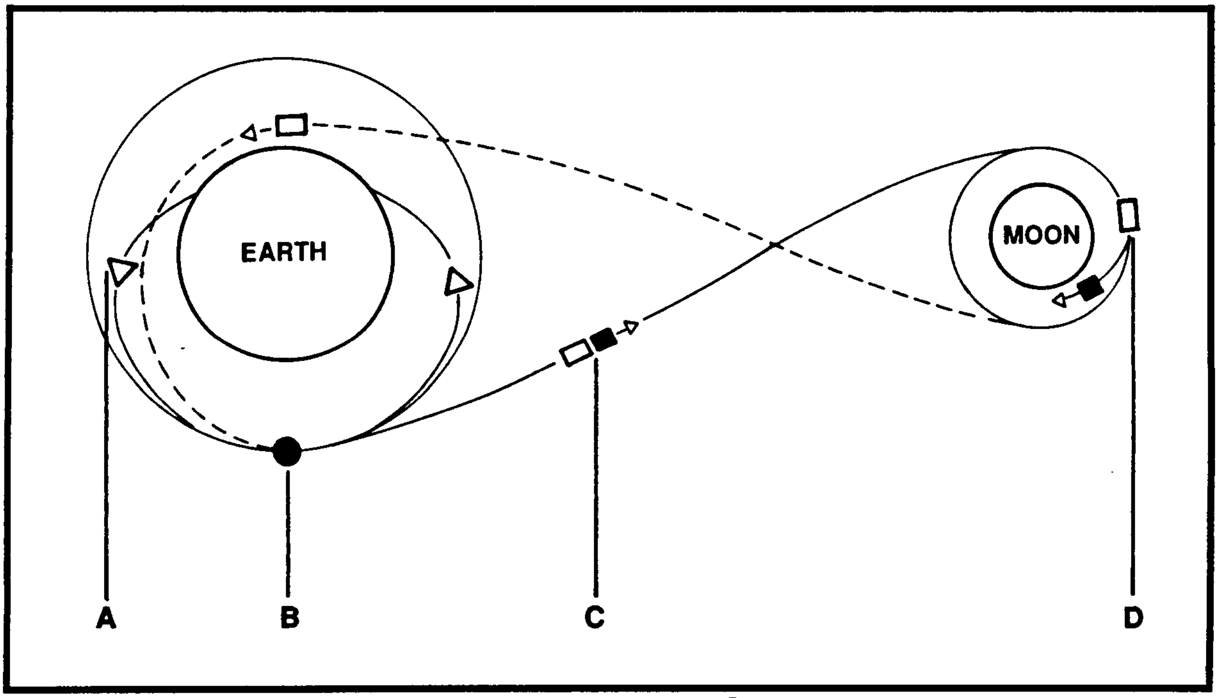

Figure 1. Preconstruction Implementation Sequence

4.0 PROJECT DESCRIPTION

4.2 IMLO CONSTRUCTION PHASE

After the arrival of the crew, the MFV (being the last unmanned payload to be delivered) is driven off its LMSTS via specially provided ramps. Using the MFV, the crewmembers would then assemble and render operational an initial "construction shack", consisting of one habitation module and one air lock module docked together. The construction shack, as well as the LEM derived vehicle and the MFV, would provide life support quarters for the crew.

The major construction assembly performed by the crew would be the installation of the above surface Regolith Support Structure (RSS) for radiation protection. This installation would occur away from the construction shack, involving the use of the MFV to place the foundation columns and spaced frame panels of the RSS. Final completion of the RSS would involve the placement of lunar regolith on its upper surface.

After completion of the RSS, the outpost modules, resting on their integral LMSTS trailer frames, are moved and oriented beneath the regolith structure using the MFV. At this step the habitation module and the air lock module of the construction shack are disconnected and also moved to their respective locations beneath the RSS. All modules would then be levelled and docked to each other, and with the necessary systems connections, made operational.

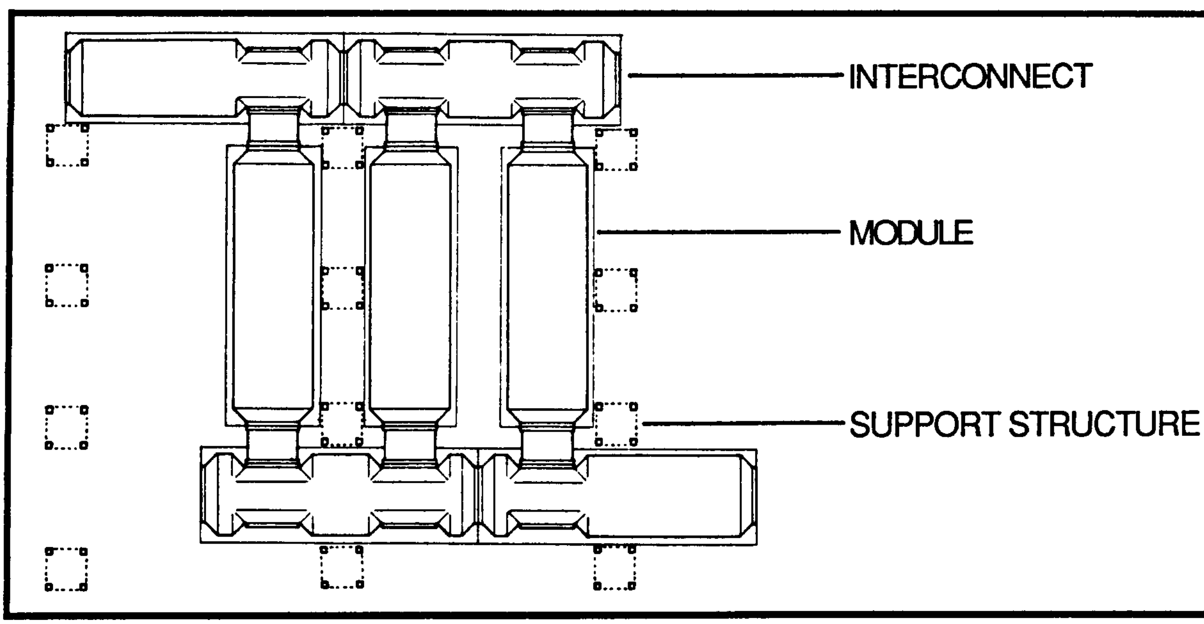

Figure 2. Possible IMLO Configuration

4.3 THE LUNAR MOBILE SURFACE TRANSPORT SYSTEM

A key element in the establishment of an IMLO is the development of a flexible transportation system. With the assumption that there will be an HLLV and an OTV complementing the space shuttle (NCOS, 1986), there would be the need for a vehicle to deliver unmanned payloads to the lunar surface from LLO. Once on the lunar surface, the payloads would have to be transported along the surface to a site location. There would be a significant economy of weight and labor if the same vehicle were to deliver payloads from LLO and facilitate their transport along the surface.With these intentions:

The Lunar Mobile Surface Transport System (LMSTS) was designed to:

Serve as a lunar lander teleoperated to deliver unmanned payloads such as habitation modules, equipment, and a Multi-Functional Vehicle (MFV) to the lunar surface from LLO.

Serve as a mobile surface trailer, supporting its payload as it is pulled by the MFV to its surface destination.

Serve as a support and leveling system for the pressurized modules of the outpost.

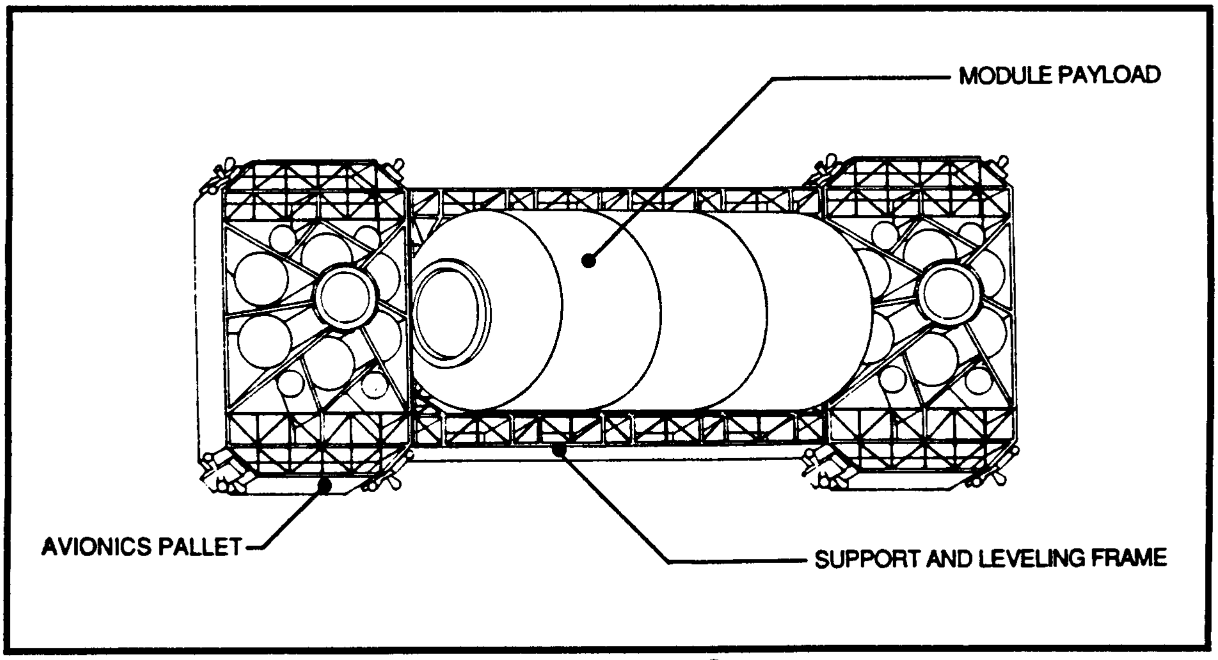

Figure 3.Lunar Mobile Surface Transport System

4.0 PROJECT DESCRIPTION

4.4 MAIN COMPONENTS OF LMSTS

A major component of the LMSTS is the payload platform. A framework measuring 7.3Mx12.8M constructed of high strength aluminum alloy trusses and weighing 450 kg, the platform provides a structural support to which an unmanned payload is secured. Being exposed to both microgravity and lunar gravity, the framework was sized accordingly to support payloads up to 14,000 kg as well as pressurized modules 4.5Mx12M in size with sufficient stability.

A secondary system of truss frames act as a cradle support for the placement of pressurized modules, lowering the overall center of gravity, providing additional stability to the structure during landing and surface transportation. Positioned below this secondary truss system would be a 2.5M diameter docking ring assembly to allow an OTV to deliver the payload/LMSTS to LLO from LEO. Electromechanical jacks , extending 2.7M from a collapsed length of .9M (Jakubowski,1986), would be used to raise and lower the platform (and its payload) at different stages during surface transport and placement. Coupling devices would be located at both ends of the platform for the addition and removal of different systems pallets.

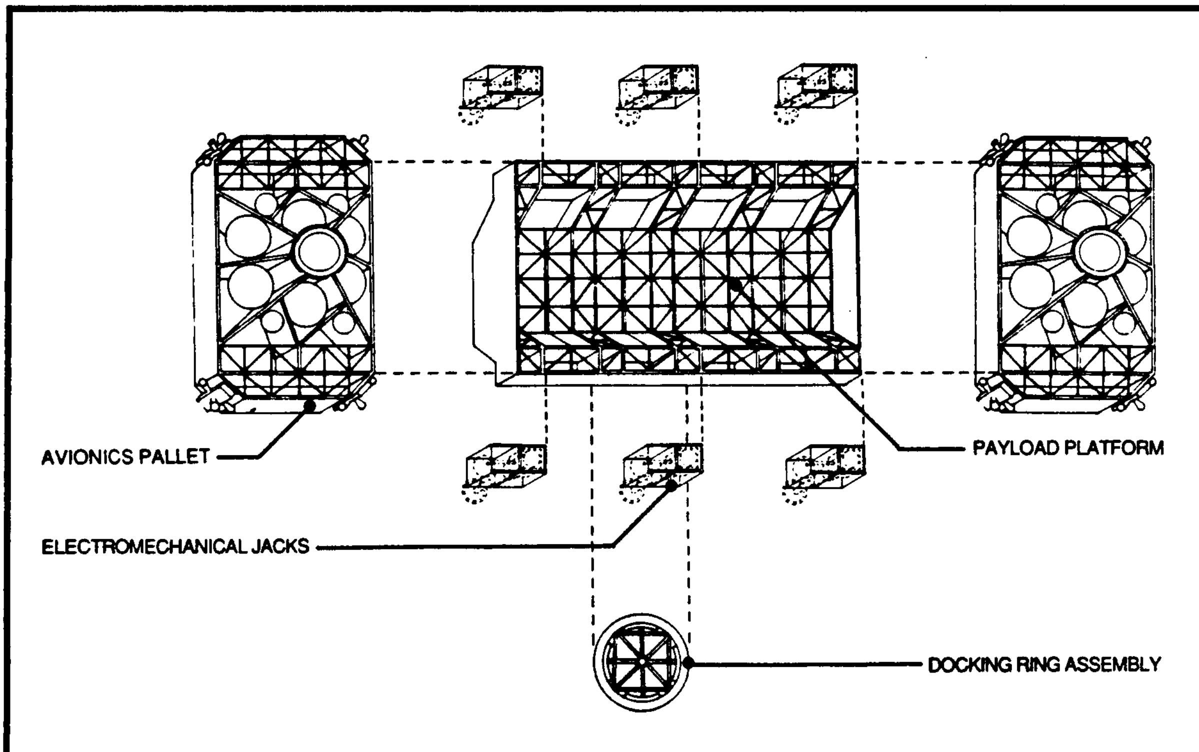

Figure 4. Major LMSTS Components

4.0 PROJECT DESCRIPTION

Two teleoperated avionics pallets, one located at either end of the platform would provide the thrust required to deliver the payload from LLO to the lunar surface. These pallets would be constructed of the same high strength aluminum alloy as the truss frame of the platform, having positioned in its center a liquid oxygen/liquid hydrogen propulsion engine that would provide a delta V of 2 km/sec.

Propellant would be stored in five spherical tanks of 1.8M diameter for the liquid hydrogen and six spherical tanks of 1.2M diameter for oxygen (Fielder, 1988), all being radially located about the engine. Included on the 5.5M x 7.3M pallets are the following. RCS thrusters and their fuel storage would be located at four primeter points on the Avionics Pallets. These would provide for maneuvering and necessary control redundancy. Independent avionics controls would be located in an area to distribute the mass and provide an autonomous landing system. There would be four landing legs on each Avionics Pallet. These would be constructed of a high strength, light-weight material and would contain crushable honeycomb cartridges which would have to be changed out once the Avionics Pallet was delivered back to LEO after its delivery mission. Integral to the pallet are two 2.5M docking rings above and below the engine. These ring assemblies would allow for the coupling of used avionics pallets and an OTV in LLO. The described equipment and other weight considerations bring the total weight of an individual pallet to 10,000 kg (including fuel). Further research work is necessary to consider additional flight dynamic factors involved with these small "lunar tugs".

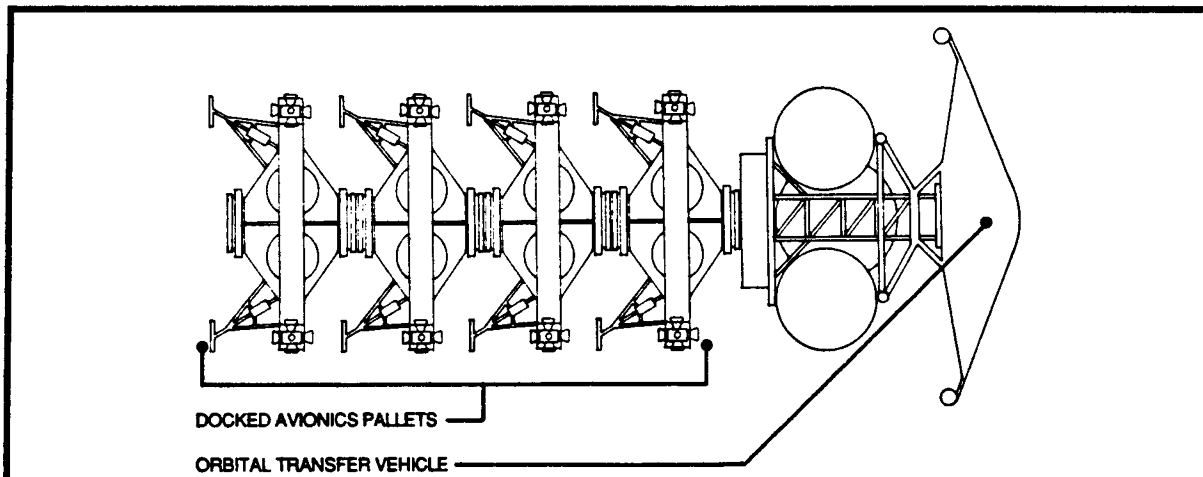

Figure 5. OTV Transporting Avionics Pallets

4.0 PROJECT DESCRIPTION

Surface mobility pallets would replace the avionics pallets, once the LMSTS has landed. Both mobility pallets would consist of high strength aluminum truss framework. However, one pallet would act as a trailer hitch while the other would be a wheeled dolly. The wheeled pallet would contain eight 1M wide aluminum rollers clustered in pairs with an active suspension system controlling each pair. This suspension system would sense the change in level of the payload as it traverses the surface, adjusting its position accordingly. The hitch pallet would only contain a cantilevered truss frame that couples to the chassis of the MFV, and allows for three dimensional movement.

4.0 PROJECT DESCRIPTION

As a lunar lander, the LMSTS would be deployed in the following sequence:

Final assembly of the LMSTS would be performed at the LEO space station.

The Unmanned payload would be secured to the LMSTS and the entire assembly would be docked to an OTV.

The OTV would deliver the LMSTS and its payload to LLO.

The LMSTS would then be teleoperated to deliver its payload to the lunar surface.

The two avionics pallets, using their remaining fuel, are removed and launched back to LLO.

At LLO, the pallets are coupled together, docked with an OTV and delivered back to LEO.

In the surface mode, the LMSTS becomes a mobile trailer and would be deployed in the following sequence:

After landing, the LMSTS platform is lifted by the integral jacking system in order to remove the avionics pallets.

The hitch and wheeled pallets are then coupled to each end of the LMSTS by the MV.

The LMSTS and its payload is then pulled to the outpost location by the MFV. Upon delivery, the pallets are removed.

Final alignment, docking and leveling of the module payload is assisted by the LMSTS platform.

4.0 PROJECT DESCRIPTION

4.5 THE MULTI-FUNCTIONAL VEHICLE

A Multi-Functional Vehicle (MFV) capable of performing construction phase tasks as well as the operational phase tasks of the IMLO has been studied. Crucial to the assembly of the outpost is the transporting of lunar modules by pulling the trailer portion of the LMSTS. This construction phase activity as well as the lifting of the RSS components into place would be accomplished by the MFV. To perform construction phase activities the MFV would have use of a permanent crane arm as well as add on implements such as a box blade for grading, an auger drill and a regolith conveyor system. Finally, the MFV would provide a temporary safe haven, providing protection for the crew from solar flare events.

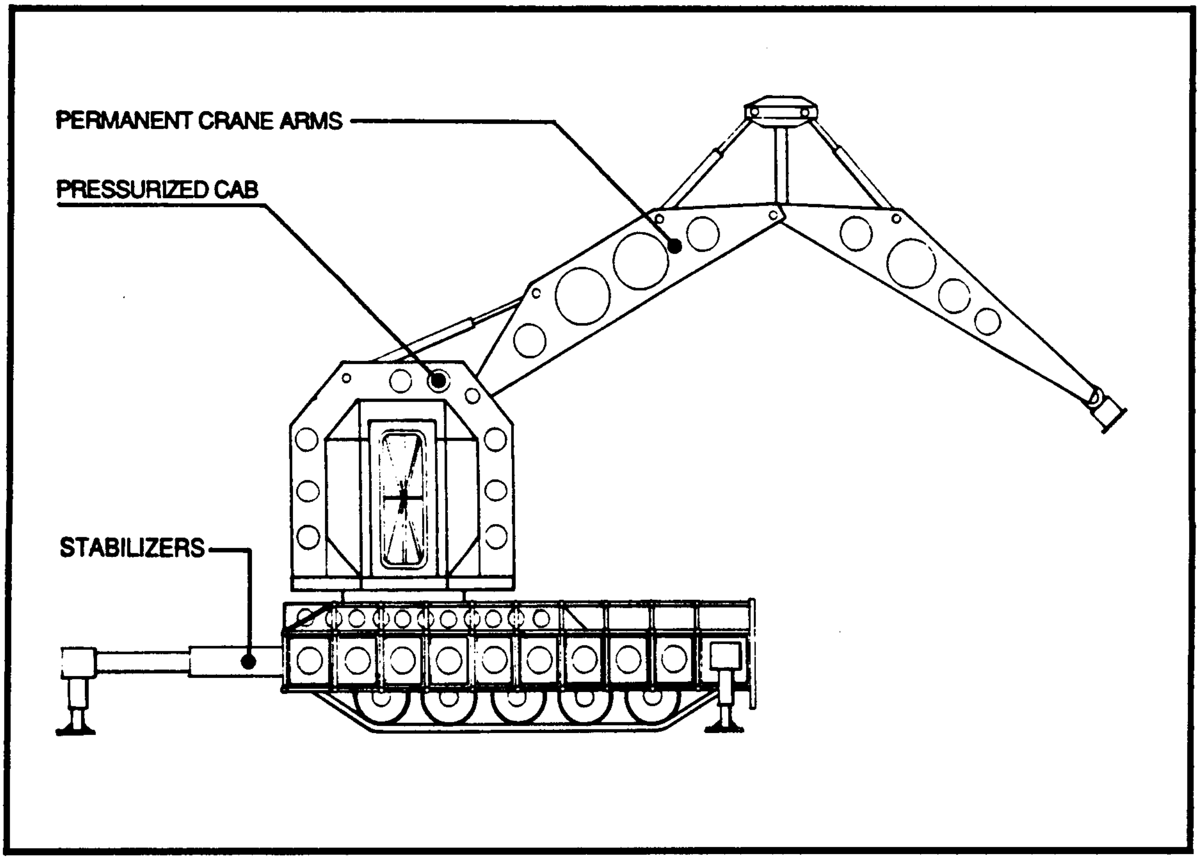

Figure 6. Elevation of Multi-Functional Vehicle

4.6 MAIN COMPONENTS OF MFV

The MFV would consist of two major components: a pressurized cab that rotates with an attached crane arm; a chassis consisting of an electric motor, batteries and a track propulsion system. The pressurized cab provides life support for two crewmembers and doubles as an airlock, requiring the cab to be depressurized before the hatches can be opened. The cab would be constructed of thick aluminum panels forming an octagonal shape having two hatches on opposite sides and three protected viewing ports. The crane would be integrated with the structure of the cab, and the entire assembly would rotate 360 degrees. To provide a safe haven for the operators during a solar flare event, the rear wall of the cab would consist of aluminum plate exceeding 13 cm in thickness. At first warning of a possible solar energetic particle event, the cab would be rotated such that the 13 cm plate would be positioned between the crew and the sun.

The crane arm would be constructed of perforated aluminum plate consisting of two 4.5 cm segments controlled by three electromechanical actuators. The arm would have the ability to fold 180 degrees on itself for storage, and when fully extended would have a reach of 9M. Maximum loading for such a crane arm would be approximately 1800 Kg. With a cab height of 4.5M, the maximum vertical reach of the crane would be 13.5M.

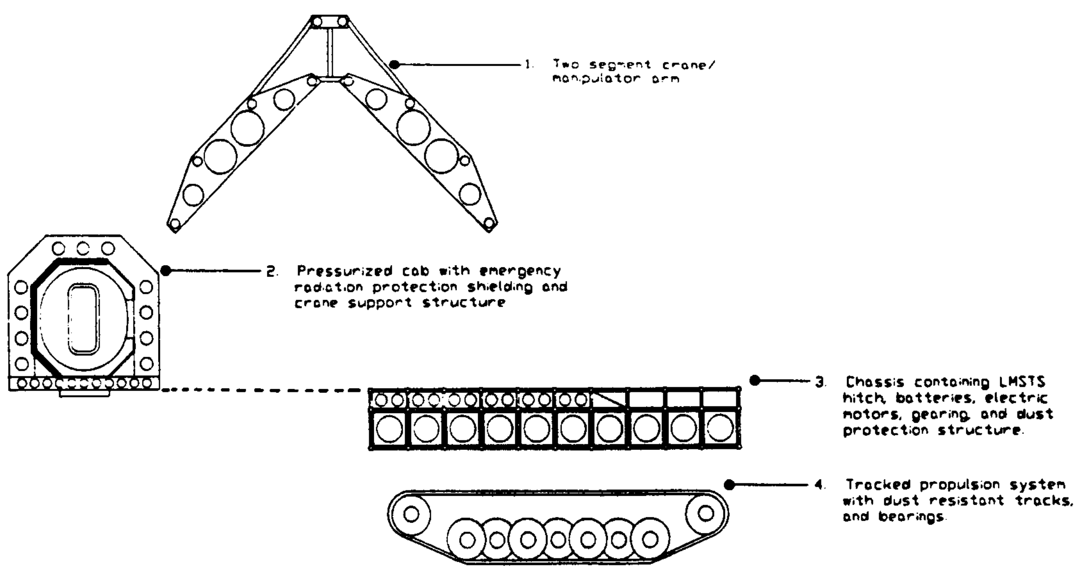

Figure 7. Major MFV Components

4.0 PROJECT DESCRIPTION

The chassis would be constructed of a 7.5 cm O.D. high strength aluminum alloy tube truss structure with pan infill. The overall dimension would be 5.5M wide by 6.5M in length. The single 125 hp electric motor, located in a dustproof housing, would propel the vehicle at a maximum velocity of 4 km/hr by way of a composite track link system. Requiring 125 kW per hour of electric power provided by rechargeable batteries, the maximum traverse time would be 4 hours, providing a maximum range of 16 km. Finally, the MFV would be able to traverse sloped grades of up to 30 degrees.

The deployment sequence of the MFV is described as follows:

The disassembled and folded MFV, weighing 7730 kg is delivered to LEO in one Shuttle launch.

The MFV is assembled into its operational configuration and anchored to a modified LMSTS lander.

The lander/MFV is delivered to LLO by an OTV.

The MFV is delivered to the lunar surface via the teleoperated lander, being the last payload prior to arrival of the crew.

The avionics pallets are removed, the lander framework lowered to the surface, and the operational MFV is driven off the lander.

4.7 THE REGOLITH SUPPORT STRUCTURE (RSS)

An IMLO would require considerable protection from the harsh lunar environment to allow crewmembers to safely perform missions of long duration. Having no radiation absorbing atmosphere, the moon is constantly being irradiated by galactic cosmic radiation having energies in the range 1-10 billion electron volts/nucleon (Taylor 1975), producing an annual dose equivalent of approximately 30 rem at times of solar minimum (Silberg, 1985). The absence of a magnetic field to deflect charged particles results in intense bombardment of the lunar surface due to solar energetic particle events. The intensity of solar energetic particles ranges from negligible to more than 70,000 times that of galactic cosmic radiation (Adams, 1985).

Silberg et al (1985) has determined that a depth of regolith greater than 400gm/cm2 will provide sufficient mass to shield crewmembers from all but 5 rem per year dosage of both types of radiation at solar minimum. In times of large solar flares, additional protection will be required. The soil mechanics of lunar regolith, however indicate that there will be problems in its excavation. The shear stress properties of lunar regolith at the surface is low enough to cause traction problems for a vehicle trying to move large quantities. In addition there is an increase in shear stress with an increase in depth of the regolith, indicating that it would take more force to excavate a large volume of soil than just working against the force of gravity. (Aldridge et al, 1986).

The bulk density of lunar soil ranges from 0.9 to 1.1g/cm3 at the top surface, whereas the density increases markedly to 1.9g/cm3 approximately 20 cm below the surface (Taylor, 1975). to facilitate excavation, we decided that the use of the 0.9-1.1g/cm3 density layer would decrease the associated problems inherent with moving large quantities of soil. Assuming a worst case density for this layer to be 0.9gm/cm3, and not considering additional compaction of this soil once delivered, the calculated depth of regolith required to produce 5 rem/yr protection is 4.4m. Such radiation protection would weigh 660 kg per square meter of surface area protected.

4.0 PROJECT DESCRIPTION

The installation of a regolith layer held in place above the lunar surface provides certain advantages over burying or directly covering modules and equipment. Besides providing radiation protection for habitation modules, an overhead regolith layer would allow for expansion of the outpost, by the additional removal and reconfiguration of the modules, without necessitating the excavation of the regolith. A RSS would allow unimpeded access to the module exteriors allowing for maintenance and repair. The RSS would provide sheltered Extra Vehicular Activity (EVA) areas and extra storage areas from micrometeorite erosion as well as radiation. Finally, the RSS would provide a constant temperature environment, protecting the outpost from the extreme changes of temperature (+111 deg. C to -171 deg C) found at the lunar surface.

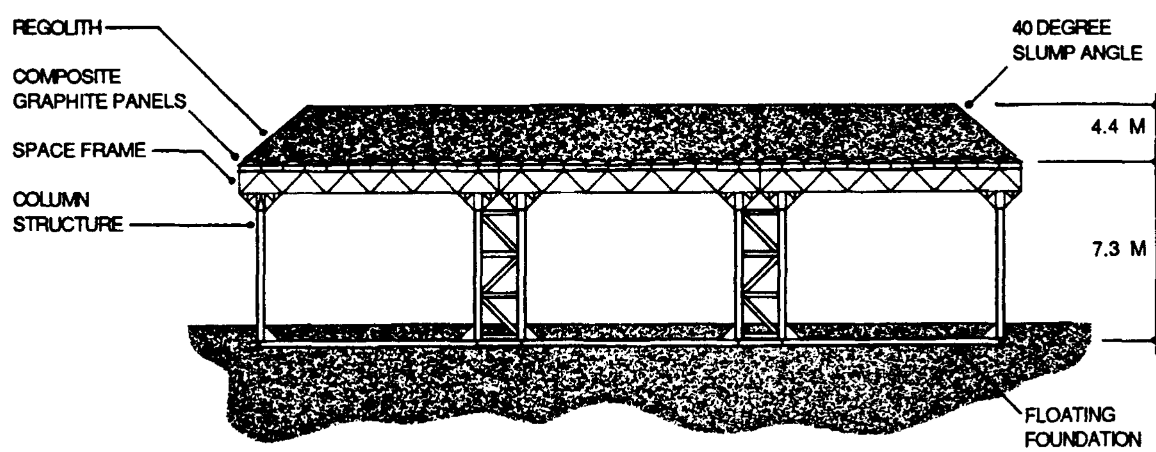

Figure 8. Cross Section of Regolith Support Structure

To provide protection from low incident angle radiation, berms equal in height to the top of the habitation modules would be needed to be installed along the perimeter of the RSS. In addition, the modules would need to be placed beneath the RSS so that there would be sufficient overhang of the RSS to lower the incident angle of radiation enough to have the perimeter berms provide sufficient blockage. The perimeter berms would also need to be staggered in order to provide protection as well as unimpeded vehicular access to the outpost.

4.0 PROJECT DESCRIPTION

In determining the materials for the RSS we chose 70 KSI steel over aluminum and titanium. Aluminum, with it's low KSI, would require a sharp increase in the number of structural elements, also sharply increasing the complexity of the structure. Titanium has a higher KSI, but would be difficult to be formed and welded at the section thickness required. Consequently, A-441 steel was chosen providing high strength components in fewer numbers albeit higher payload weights.

4.8 Main Components of Regolith Support Structure

The components of the RSS would consist of:

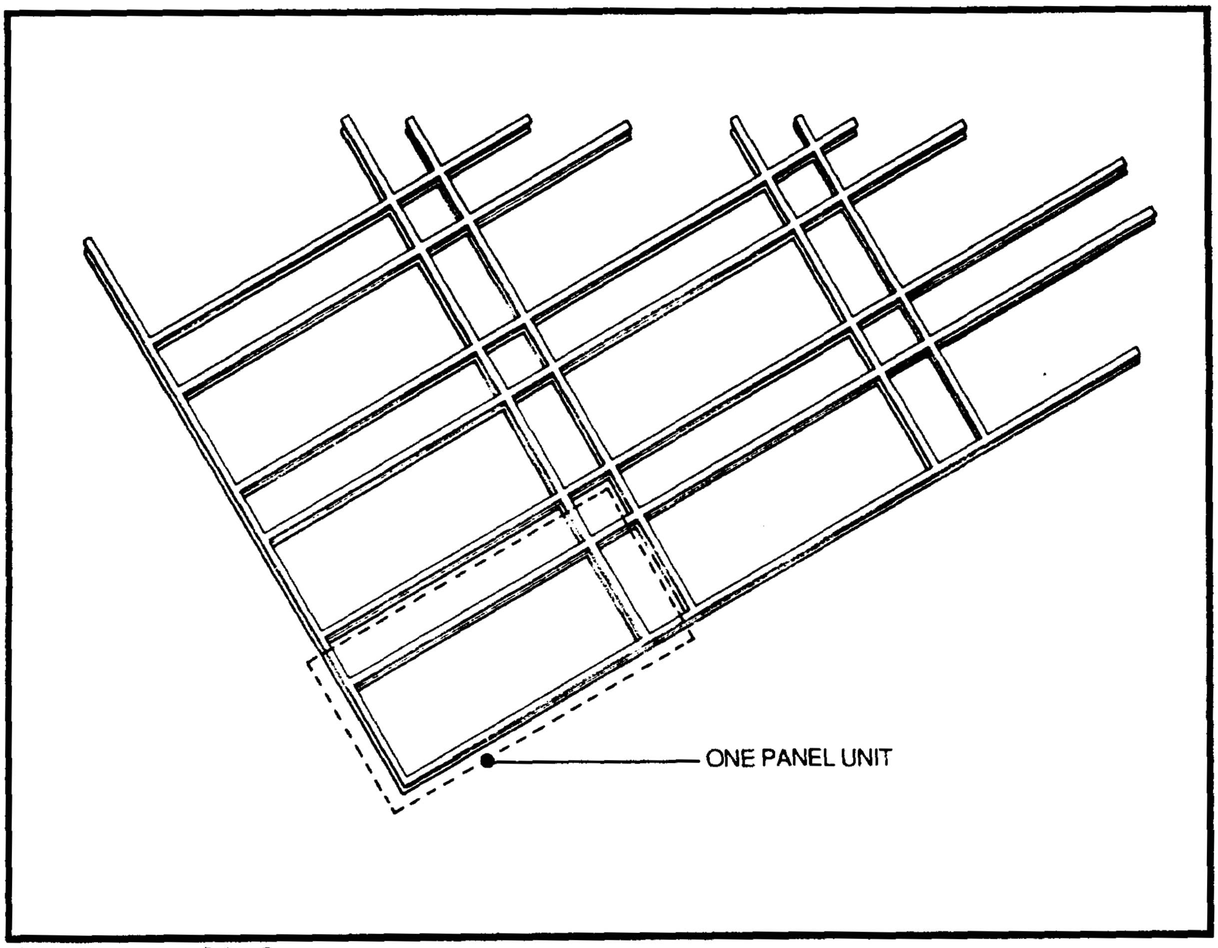

Figure 9. RSS Component

A floating foundation of 40 cm x 45 cm steel beams fabricated in panels roughly 7.3 m x 14.6 m in dimension and weighing .1 tons.

4.0 PROJECT DESCRIPTION

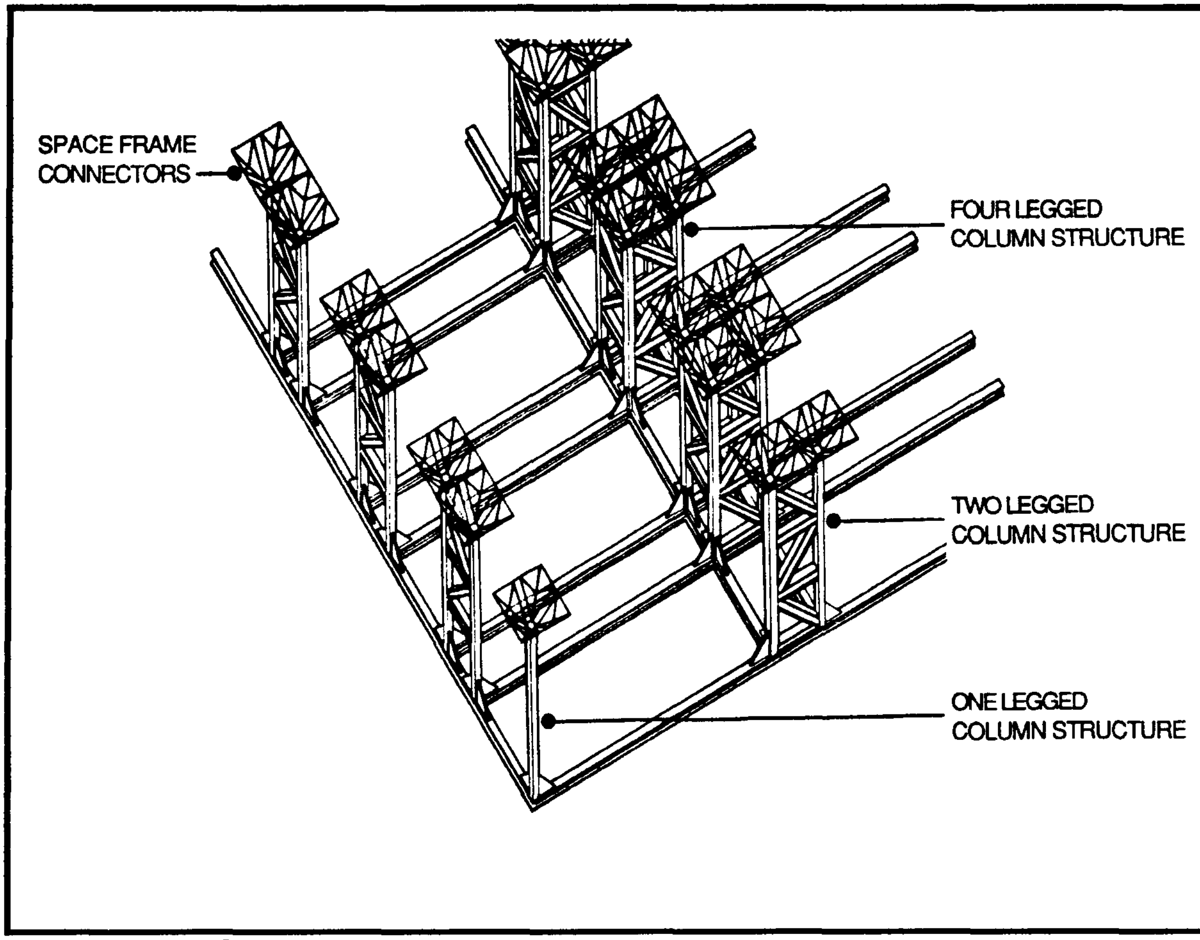

Figure 10. RSS Component

One, two and four legged column structures consisting of 7.3 m long and 35 cm x 40 cm steel columns laterally supported and weighing a maximum of 544 kg.

4.0 PROJECT DESCRIPTION

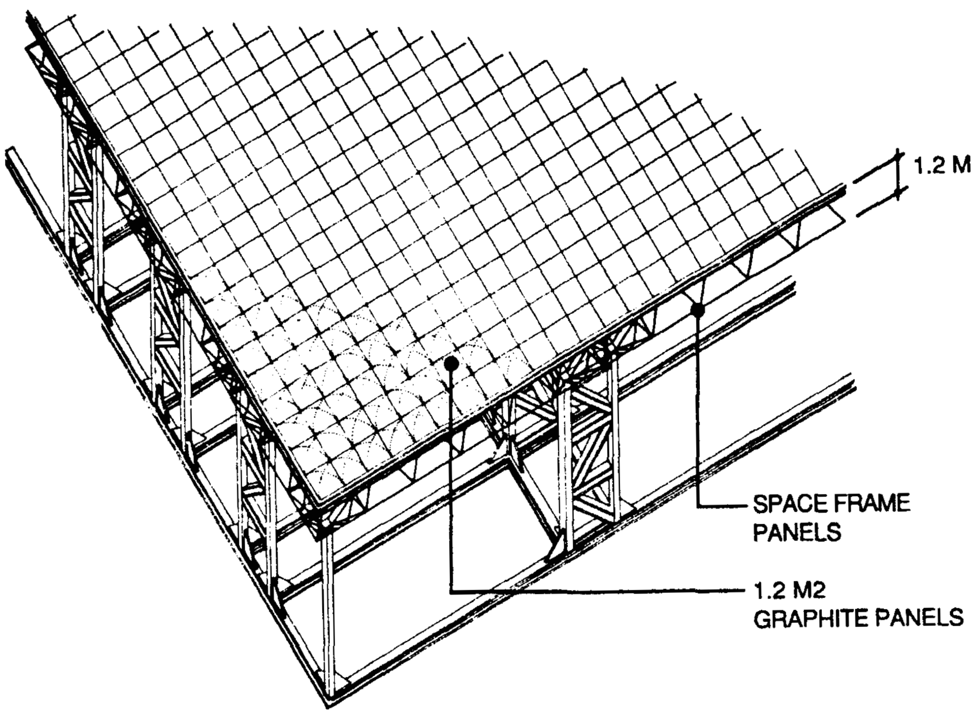

Figure 11. RSS Component

Space frame panels 7.3 m x 14.6 m in size, consisting of 7.5 cm O.D. steel tubes that produce a space frame 1.2 m in depth with 2.4 m grid spacing and weighing approximately 1,460 kg per panel.

4.0 PROJECT DESCRIPTION

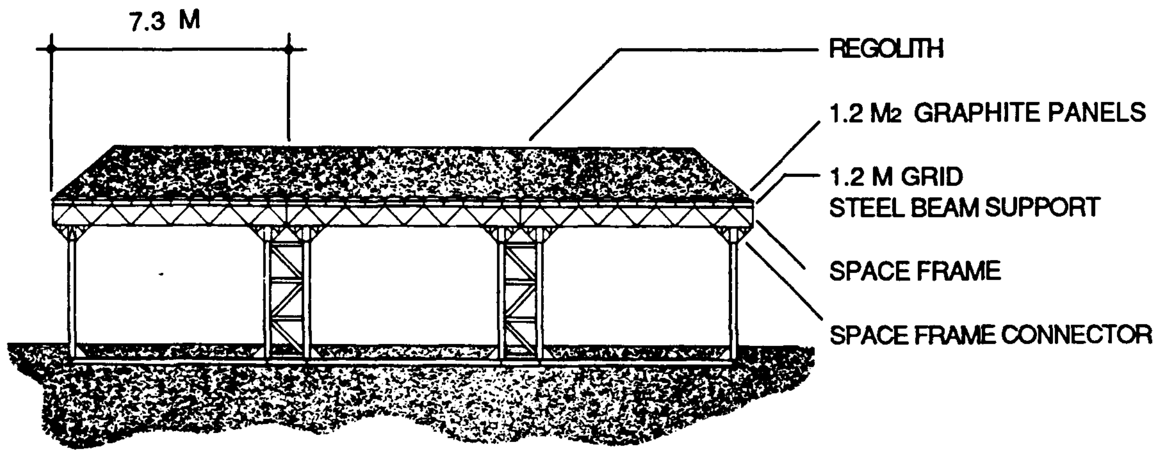

Figure 12. RSS Component

A 1.2 m grid of 30 cm x 30 cm steel beams above the space frame to support the 1.2 m x 1.2 m slightly arched composite graphite panels. Regolith would then be placed above the graphite panels at a depth of 4.4 m providing a force of 45,000 kg per 7.3 m x 14.6 m section of the RSS.

4.0 PROJECT DESCRIPTION

The deployment sequence for erection of the RSS would be the following:

Light grading of the site is performed by the MFV.

The steel tie beams panels are placed and welded together to form a floating foundation to support the columns.

Braced steel column structures are anchored to the foundation with pinned connections.

Space frame panels are then lifted into place on top of the columns by the MFV.

Regolith is then graded to cover the floating foundation to a 1m depth.

A 4.4m deep layer of regolith is finally delivered to the top surface of the space frame structure via a conveyor system.

The slightly arched composite graphite panels would provide a lightweight partition preventing the regolith from sifting through the RSS. Composite graphite panels were chosen over a Kevlar type structural fabric. Although Kevlar would withstand the load imposed on it by the regolith layer, the fabric would probably need to be delivered in large rolls and involve more labor intensive fastening to the steel lattice above the space frame. The composite graphite panels would be slightly arched to provide pretensioning and could be placed on the steel lattice such that the weight of the regolith would wedge the panels tighter into their support channels. The arched panels would probably not be significantly greater in weight than a Kevlar fabric, and would be transported in stacks to LEO.

4.0 PROJECT DESCRIPTION

The regolith is graded over the floating foundation to allow the modules to be positioned under the RSS by the MFV. Major disadvantages of the RSS are the heavy payload weight of steel components and the assembly time of the various panels in LEO. Pinned connections would also need to be designed to facilitate assembly on the lunar surface, although for a structure carrying these loads, the best type of connection would be a welded one, increasing assembly time considerably. For a structure such as this to become viable, assembly time and weight need to be decreased. This may be resolved by intensive structural analysis of component parts, design of quick connections, and the use of automated equipment.

4.9 CONCLUSION

An initial manned lunar outpost will have its equipment, support systems and base configuration derived by the mission activities to be supported by the outpost. Three systems have been studied that would allow for the assembly of such an outpost. A reusable Lunar Mobile Surface Transport System (LMSTS) would allow for transportation flexibility, doubling as a teleoperated lunar lander and a mobile surface trailer. A Multi-Functional Vehicle (MFV) would be used extensively for outpost assembly and the transport of the LMSTS. Finally, a Regolith Support System (RSS) would provide modular, above surface support for regolith to protect the outpost from the harsh radiation of the lunar environment.

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