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MALEO: MODULAR ASSEMBLY IN LOW EARTH ORBIT. A STRATEGY FOR AN IOC LUNAR BASE.

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Abstract
Modular Assembly in Low Earth Orbit(MALEO) is a new strategy for building an initial operational capability lunar habitation base. In this strategy, the modular lunar base components are brought up to Low Earth Orbit by the Space Transportation System/Heavy Lift Launch Vehicle fleet, and assembled there to form the complete lunar base. Modular propulsion systems are then used to transport the MALEO lunar base, complete and intact, all the way to the moon. Upon touchdown on the lunar surface, the MALEO lunar habitation base is operational. An exo-skeletal truss superstructure is employed in order to uniformly absorb and distribute the rocket engine thrusting forces incurred by the MALEO lunar base during translunar injection, lunar orbit insertion, and lunar surface touchdown. This conceptual paper discusses the components, configuration, and structural aspects of the MALEO lunar base. Advantages of the MALEO strategy over conventional strategies are pointed out. It is concluded that MALEO holds promise for lunar base deployment.
Keywords: Modular Assembly, Low Earth Orbit, Lunar Bases, Space Architecture, Truss Superstructure, Lunar Landing System(LLS), Space Station Freedom(SSF-1), Space Transportation System(STS).

1 Introduction

A phase 1 lunar habitiation base(LHB-1) is conceived as the first permanently manned facility on the lunar surface. The facility will provide a test bed for extended habitation, exploration, and scientific investigation.

It is considered somewhat analogous to a forward base camp in the Antarctic or on Mt. Everest. LHB-1 will also form the nucleus, if needed, for further expansion and experimentation, which might be necessary during the evolution of what might become the first fully self-sustained, permanently manned lunar colony. This lunar colony will support spacecraft operations in cislunar as well as interplanetary space by providing propellants and other material manufactured on the lunar surface. (NASA,1988)

The first priority in a phase 1 extended duration mission of this nature, is the provision of an assured safe haven for the astronaut crew which will alleviate astronaut anxiety associated with build-up operations, followed by a comfortable environment within the facility, which will enhance crew productivity.

2 Development of the MALEO Strategy

Space station-like modules are considered the major components which need to be assembled in order to form a phase 1 lunar habitation base(LHB-1) (Duke et al,1988). Conventional strategies suggest launching these modules separately from the Earth, landing them one at a time on the lunar surface, and assembling them there, using robots and astronauts, in extra-vehicular activity(EVA)(Alred et al,1989). Precursor missions are employed to land crew and assembly equipment. If Earth based robotic teleoperation is suggested for assembly operations, a rather complex cislunar satellite tele-communication network is required before automated assembly operations could commence [Figure 1].

At the 1988 inaugural summer session of the International Space University(ISU), held at MIT in Cambridge, Massachusetts, M.Thangavelu, a graduate student in Building Science from the University of Southern California(USC), proposed the idea of assembling the components of the lunar base in Low Earth Orbit. Modular Propulsion systems would then be employed to transport the entire base, complete and intact, directly to the lunar surface, for immediate occupation by the astronaut crew [Figure 2]. The strategy thereby avoids the cost and risk associated with manned extravehicular activity on the lunar surface, which had been proposed in several earlier concepts(Johnson, 1985). Thangavelu along with another ISU student, G.E. Dorrington from Cambridge University, presented the idea in a paper entitled " MALEO: Module Assembly in Low Earth Orbit. Strategy for Lunar Base Build-up" at the 39th Congress of the International Astronautical Federation, in October 1988, held in Bangalore, India(Thangavelu, 1988). M. Thangavelu continued to work upon this idea at USC. It became the focus of his masters thesis in Building Science(Thangavelu,1989).

Several ETO Launches
Several componentwise TLIs & LOIs
Several lunar landings
Assembly on lunar surface
Substantial precursor missions

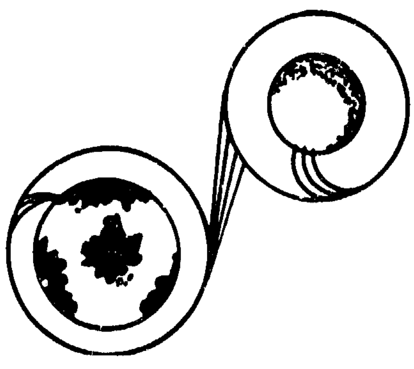

Figure 1.Lunar Surface Assembly

Several ETO Launches
Assembly in LEO
One or two TLIs and LOIs
One lunar landing
Minimum precursors

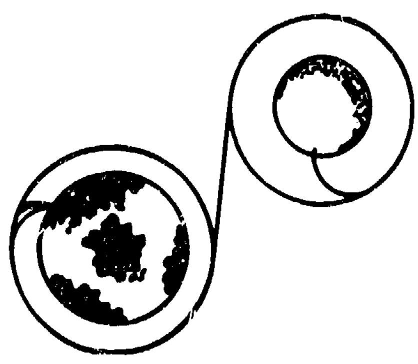

Figure 2. The MALEO Strategy

ETO - Earth to Orbit, TLI - Translunar Injection, LOI - Lunar Orbit Insertion

3 Configuration of the Lunar Habitation Base-1(LHB-1)

Several configurations are possible for the design of LHB-1, and two or more modules might be employed, as required by the mission objective[Figure 3]. In the past, horizontal and vertical configurations have been proposed for lunar habitation bases(Johnson,1985). In the MALEO strategy, the horizontal configuration was preferred to the vertical one for the following reasons.

1. Commonality with space station Freedom enhances design and engineering economy.
2. Commonality enhances crew adaptation and productivity.
3. Better and larger work spaces for extended duration missions, which minimizes circulation spaces.
4. Wider footprint for better landing stability.
5. Ease of expansion during evolution by attaching additional horizontal modules.

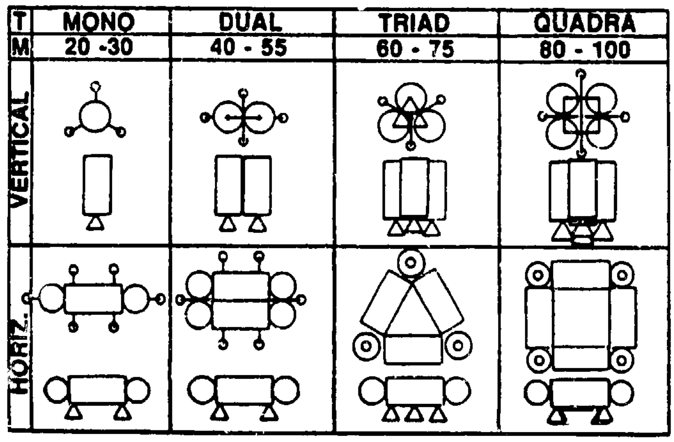

Figure 3. Schematic Lunar Base Module Configuration Study

Using space station-like modules as a base line, it may be possible to contain all the necessary systems required for the phase 1 LHB-1, for a crew of four astronauts / mission specialists, in three modules and three nodes. They would be interconnected in a triangular closed loop configuration which will facilitate dual egress for the astronaut crew. This triangular configuration also enhances structural stiffness by virtue of its geometry. This configuration is less susceptible to twisting moments than other optimal configurations and hence would transmit the least bending moments to the connecting joints of LHB-1 in the event of a lunar landing on uneven terrain.

4 The components of the Lunar Habitation Base-1(LHB-1)

The major components of LHB-1 are the three modules and three nodes. They constitute the manned core of LHB-1 and are described below [Figure 4]

1. The habitation module houses the four astronauts/mission specialists, and contains crew sleeping quarters, a gymnasium/recreation facility, and a galley.

2. The sanitation/hygiene node is conveniently located adjacent to the habitation module and besides those functions will also house water recycling and solid waste management systems.
3. The laboratory module is also adjacent to the sanitation / hygiene node. This module is equipped with interchangeable racks which are partially outfitted, so that modifications and new setups are possible, as the base evolves.
4. The primary EVA node is the airlock which is used for all of the extra-base activity. It contains the EVA suits, and equipment to prevent regolith back-tracking and contamination.
5. The power and logistics module contains the power generation, storage, and regulation equipment. The module contains solar power panels which are deployed externally, can accomodate a nuclear power source that could be deployed externally.
6. The ECLSS node is also the command center of LHB-1 and is designed so that the base may be extended by attaching additional modules, if necessary.

MALEO LHB-1 MASS SUMMARY

HABITATION MODULE	15-17.5	MT
LABORATORY MODULE	15-17.5	MT
POWER/LOGISTICS MODULE	15-17.5	MT
PRIMARY EVA NODE	5- 7	MT
AIR REVITALIZATION NODE	5- 7	MT
SANITATION/HYGIENE NODE	5- 7	MT
TRUSS SUPERSTRUCTURE	6	MT
LANDING SHOCKS/AIRBAGS	4	MT
SOLAR ARRAYS/COMM.ANT.	3	MT
LUNAR ROVER X 2	2	MT
MISCELLANEOUS	10	MT
TOTAL -	100	MT

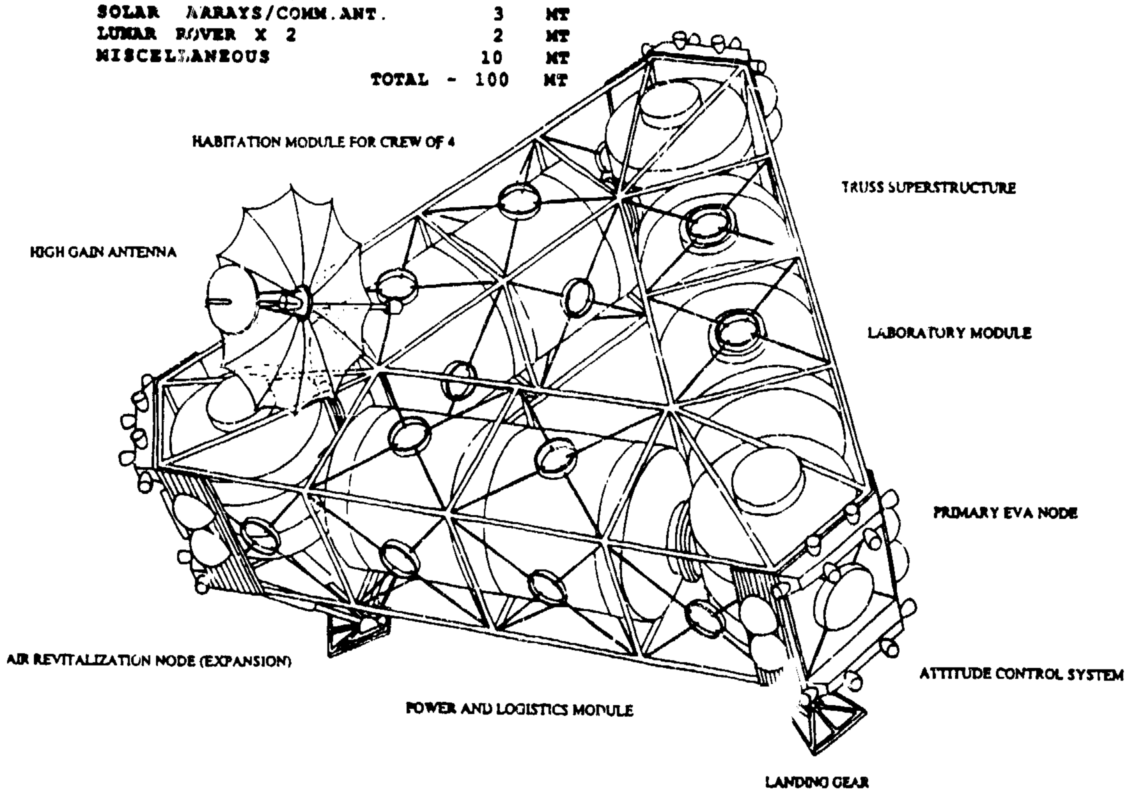

Figure 4. Components of a 3 Module Lunar Habitation Base and LHB-1 Mass Summary

The components which integrate the modules together as a complete spacecraft are the following:

1. The truss superstructure has three functions. It is the structure employed to support the thrust structure of the modular orbital transfer vehicle(mOTV) and to distribute the forces transmitted from the mOTV uniformly through the entire LHB-1 during TLI, LOI and lunar landing. It also offers the primary attachment points for the attitude control system pallet(ACSP), the landing gear/airbag system and the storage pockets.
2. The landing gear/airbag deployment system is designed to absorb the shock on impact and may be conventional lunar excursion module type absorbers or controlled gas escape airbags or a hybrid system.
3. The three attitude control propulsion pallets are assembled and fuelled on Earth, brought up to LEO by the STS, attached to the three corners of the LHB-1 after the truss superstructure has been built around the modules, and they stabilize the attitude of the spacecraft during transit and landing operations.
4. The storage racks may be configured as required and are placed symmetrically about the MALEO truss superstructure in order to maintain the thrust structure symmetry and balance. They contain the rovers, the solar panels, and other EVA equipment, which are essential for the effective initial operational capability(IOC) of LHB-1.

5 The Modular Orbital Transfer Vehicle(mOTV)

The mOTV is used to transport the MALEO lunar base, complete and intact, to the prescribed lunar parking orbit. The mOTV provides the required delta V for TLI, LOI, and midcourse impulse and correction manuevers. Two current or near term options are available for the design of the mOTV propulsion system. They are Chemical Cryogenic Propulsion and Nuclear Electric Propulsion.

6 The Lunar Landing System(LLS)

The LLS is used to de-orbit and softland the MALEO LHB-1 on the lunar surface. Chemical cryogenic propulsion is favored for the descent and landing operation. Advanced RL-10 rocket engine technology would be applicable for the development of the LLS.

7 The MALEO Assembly and Deployment of LHB-1

At least four options exist for the MALEO Assembly of LHB-1.
They are:

1. Free Space Assembly using the STS as the work platform.
2. Free Space Assembly using the STS as the primary assembly platform with assistance from Space Station Freedom(SSF-1).
3. MALEO LHB-1 Assembly attached to Space Station Freedom(SSF-1).
4. MALEO Assembly connected to the manned core of SSF-1.

The fourth option utilizes the SSF-1 infrastructure most effectively by providing the assembly facilities and crew required for the MALEO assembly and operation of LHB-1.

Two options are possible for the deployment of MALEO LHB-1. They are :

1. Single phase direct lunar landing option
2. Two phase Lunar Orbit Rendezvous(LOR) option

In the simplest MALEO single phase direct lunar landing option, the Lunar Habitation Base(LHB-1) and the Lunar Landing System(LLS) are integrated in LEO and the entire assembly is directly delivered to the lunar surface.The operation is expected to take a few days from TLI to touchdown on the lunar surface. This option favours a fully cryogenic mOTV propulsion system.

In the two phase option, the LHB-1 is first transported to a lunar parking orbit(LPO) by the mOTV. In the second phase, the lunar landing system is transported by a similar mOTV to dock with the LHB-1 in LPO. After the LHB-1 and the LLS are securely interconnected in lunar orbit, the LHB-1+LLS descent and touchdown on the lunar surface as in the first option. The two phase LOR option effectively reduces the TLI mass of the MALEO operation in half and might be advantageous for cryogenic propellant management during the MALEO operation. This option is particularly suited for the slower electric mOTV orbital transfer, where cryogenic propellant boil-off might be a prime concern. Manned EVA is required in lunar orbit.

The following sequence of illustrations help to visualize the MALEO strategy 2 phase option for the deployment of the lunar habitation base.

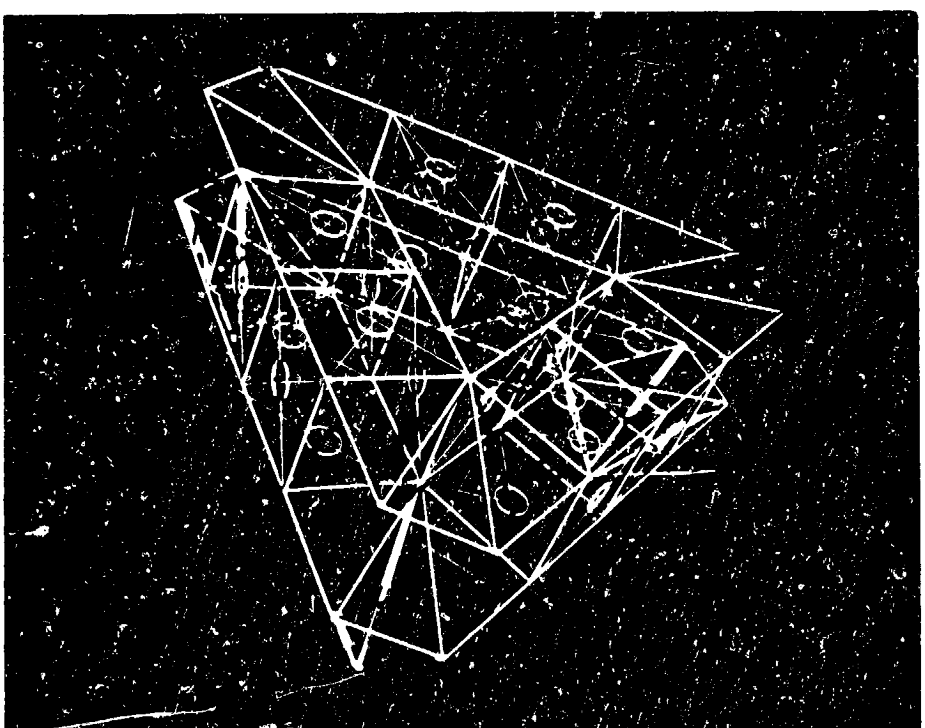

Figure 5. MALEO LHB-1 Truss Superstructure

Figure 6. MALEO LHB-1 Module Assembly

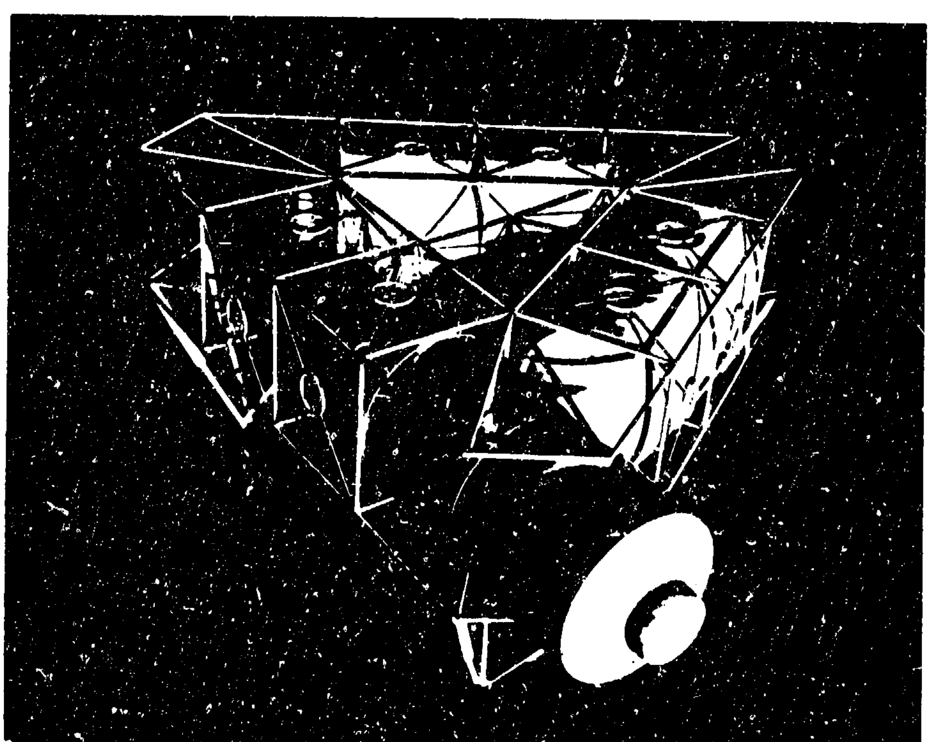

Figure 7. MALEO LHB-1 Module Insertion

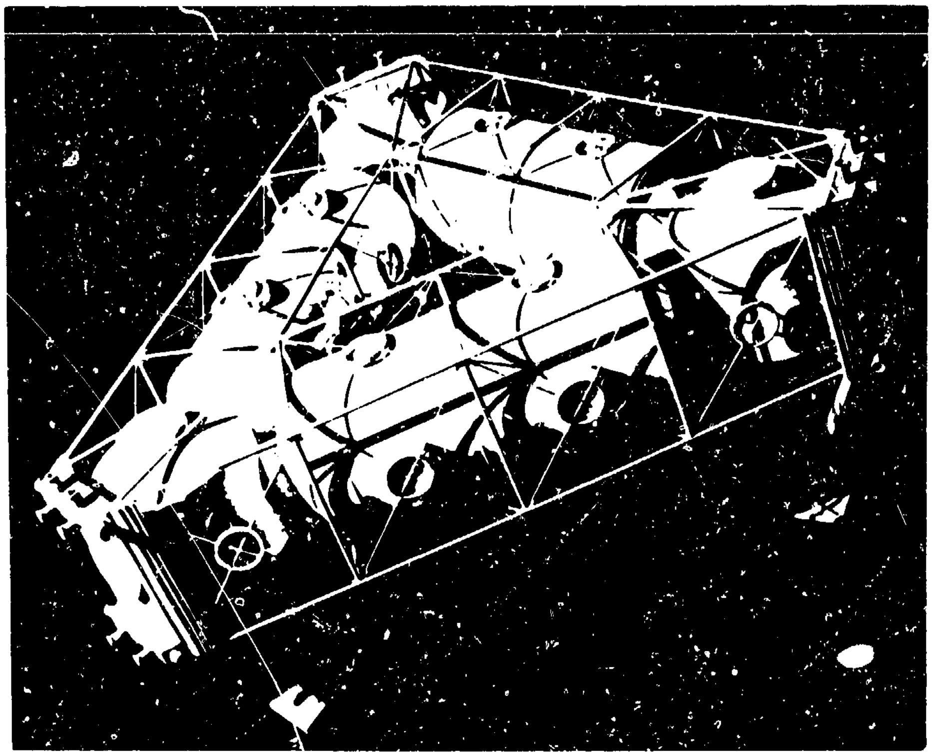

Figure 8. MALEO LHB-1 Assembly Complete

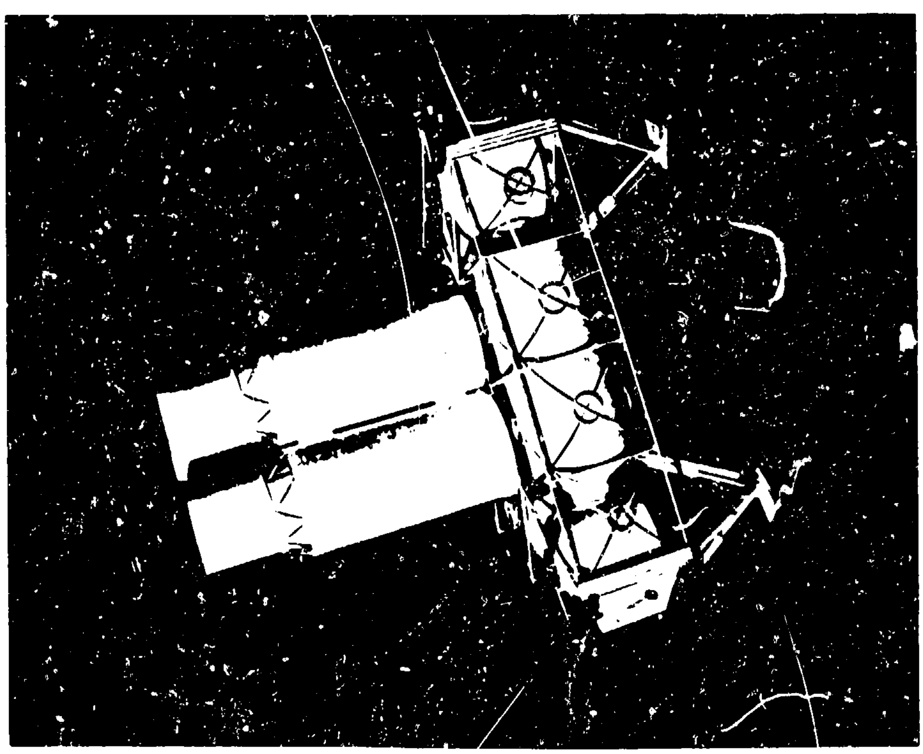

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Figure 9. Phase 1 LHB-1/mOTV Translunar Injection

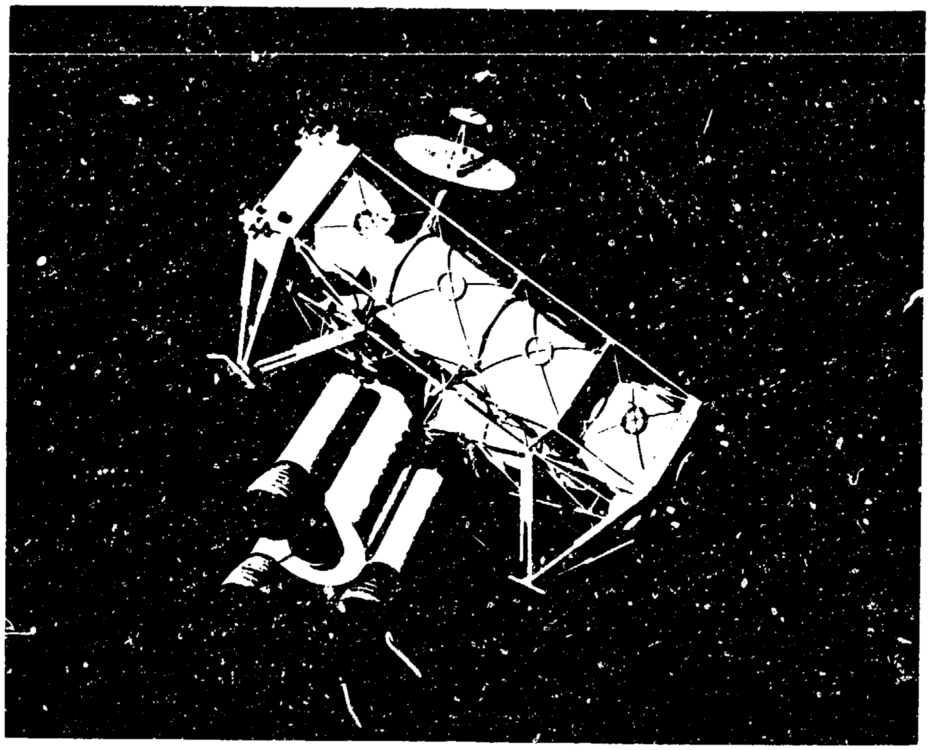

Figure 10. LLS/LHB-1 Lunar Orbit Rendezvous(LOR)

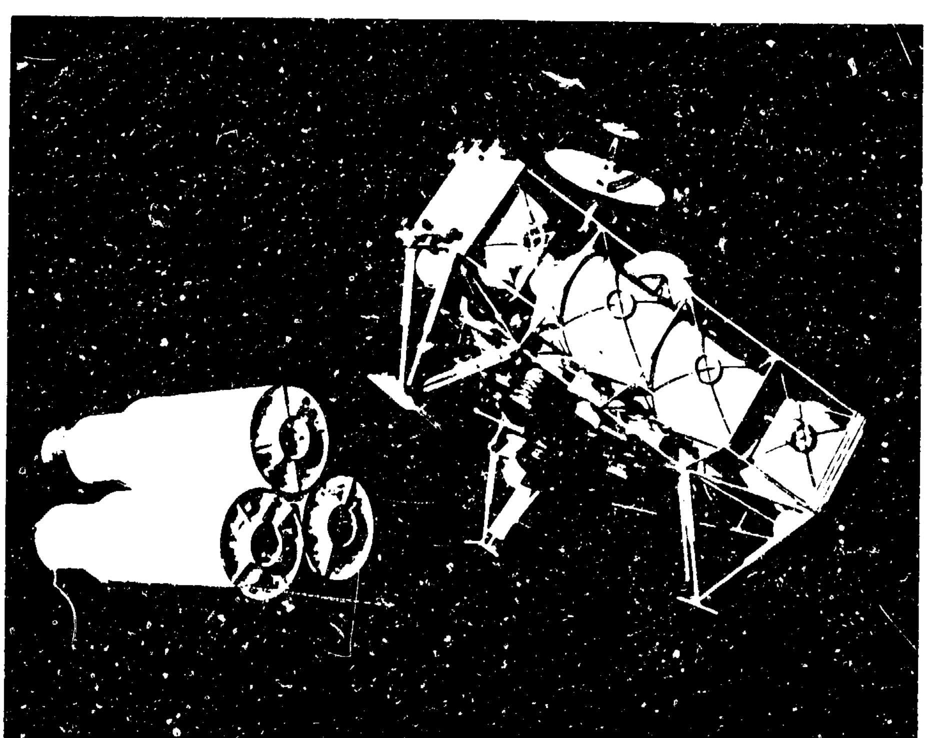

Figure 11. LLS/LHB-1 De-orbit and Desc nt (expended mOTVin background)

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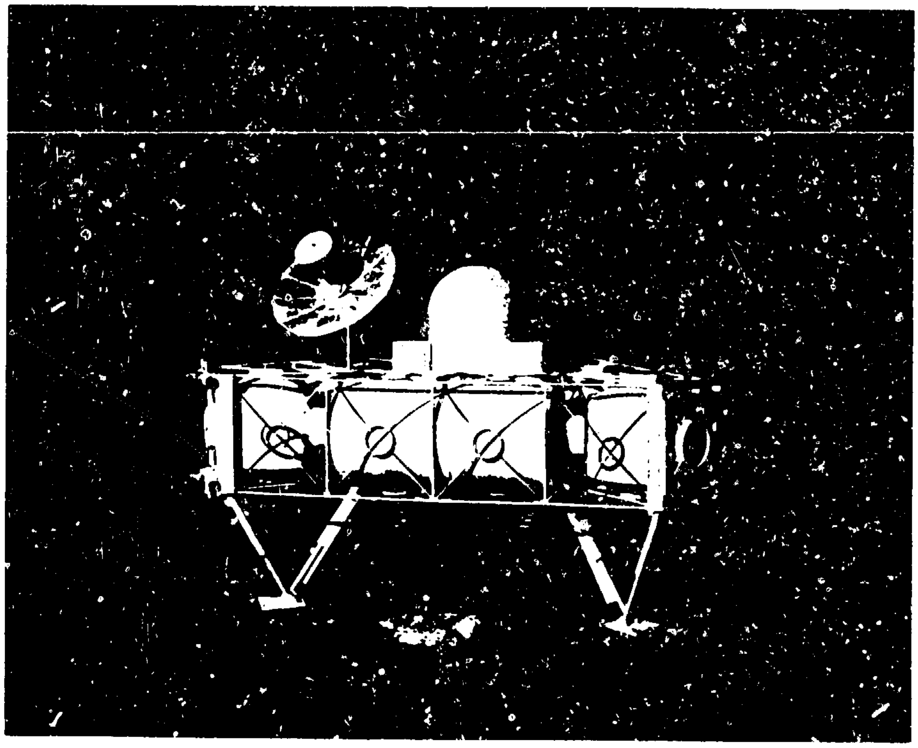

Figure 12. MALEO LHB-1/LLS Lunar Surface Touchdown

8 LHB-1 Structural System

From the operations listed above in sequence, it is evident that the truss superstructure of the LHB-1 and the complementing structures of the lunar landing system(LLS) and the modular orbital transfer vehicle need to be highly efficient, light weight and reliable. Historically, spacecraft have used few, if any, members in tension(Cohen,1987).

Inherently stiff tension members are suggested in the MALEO truss superstructure pretensioning system in order to conserve mass, minimize structural deflection, and to distribute the thrusting forces optimally among the truss members(Schierle,1990). The configuration is structurally strengthened by suspending the LHB-1 modules within a truss superstructure so that LHB-1 will be able to uniformly absorb the stresses induced on it during translunar injection(TLI), lunar orbit insertion(LOI), and lunar surface touchdown. The thrust structure, which includes the truss superstructure,the lunar landing system and modular orbital transfer vehicle interconnections, are selected so that the forces are applied symmetrically about the truss superstructure. The mOTV and the LLS share the same thrusting points on the truss superstructure. The truss superstructure is designed to facilitate quick and easy EVA assembly in LEO. An erectable/deployable philosophy is employed so that the structure is partially assembled even before launch to LEO. This philosophy is applied again upon lunar surface touchdown, after which much of the truss superstructure is disassembled and used for other building purposes on the lunar surface.

Though a stressed skin module configuration could be designed to take the stresses arising from TLI and LOI, which are estimated to be about 2g maximum, module safety and other factors dictated that a separate truss superstructure be employed for the thrusting load distribution.

9 Advantages of the MALEO Strategy

If space station derived modules are to be employed in the construction of a phase 1 lunar base, then the MALEO strategy offers the following advantages:

1. The safer LEO radiation environment for EVA, is also less risky and more economical than EVA on the lunar surface(Bufkin et al., 1986).
2. Spares and replacements are easily and more economically flown to LEO or borrowed from the LEO SSF-1 infrastructure.
3. The clean LEO assembly environment avoids dealing with the lunar soil which has undesirable abrasive and cohesive properties. Regolith has interfered with manned EVA systems in the past(Weaver,1988). During phase 1 build-up, paucity of man and equipment demands high reliability, and MALEO avoids the initial lunar surface assembly operations entirely.
4. In the event of an assembly accident, a crew rescue is more feasible from LEO using the assured crew return capability(ACRC) of SSF-1, than from the lunar surface.
7. The inheritability and commonality with Space Station Freedom (SSF-1) hardware enhances cost / unit economy as well as spares and replacement units for both the MALEO as well as the SSF-1 program.
6. LEO offers SSF-1 assisted assembly and the possibility of Earth-based real-time telerobotic assembly operations.
8. Avoids the risk of the repeated Earth to Orbit(ETO) launchings, TLIs, LOIs and lunar landings associated with the typical componentwise sequential build-up prescribed by the assembly on lunar surface strategy.
9. The LHB-1 is safely configured for habitation upon touchdown. Conventional strategies involving lunar surface assembly cannot offer a comparably safe environment during base build-up without additional investment.
10. In this primary extended duration mission, the MALEO LHB-1 offers an assured and substantial safe haven at IOC, which will help to diminish anxiety and enhance productivity among the astronaut crew.

10 The Disadvantages

1. The risk of losing the entire LHB-1 in the event of an accident during the transportation and landing demands high reliability.
2. Prefabricated MALEO base strategy deprives the assembly crew of the initial experience of learning to work on the lunar surface.
3. MALEO is a large manned spacecraft. All the MALEO systems, the LHB-1, the LLS, and the mOTV needs to be studied, their dynamic characteristics examined, and their limitiations confirmed.

11 Conclusion

The importance of highly reliable structural systems for the truss superstructure of the LHB-1, the lunar landing system, and the modular orbital transfer vehicle, are clearly evident for the success of such a mission. The vibration and resonance characteristics of such a large structure during lunar descent and a heavy impact or unsymmetric touchdown on the lunar surface, are being studied. Advances in structural materials and on-orbit assembly techniques acquired while assembling and operating SSF-1 will enhance this strategy. If a decision is made for the rapid deployment of a lunar base about the year 2000, the MALEO strategy holds promise and needs detailed engineering and systems analyses along with other strategies.

12 Acknowledgements

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