NGT-21-002-080
NGT-80001

LUNAR OPERATIONS COMPANY

PRESENTS

LUNAR OPERATIONS COMPANY

A FINAL DESIGN REVIEW FOR A BOOTSTRAP LUNAR BASE

THE UNIVERSITY OF TEXAS AT AUSTIN

DECEMBER 4, 1987

(NASA-CR-184753) A BOOTSTRAP LUNAR BASE: PRELIMINARY DESIGN REVIEW 2 Final Report (Texas Univ.) 180 p CSCL 06K

N89-15807

Unclas
G3/54 0189638

A BOOTSTRAP LUNAR BASE

PRELIMINARY DESIGN REVIEW II
AND FINAL REPORT

In Response to:
RFP # ASE 274L FALL 1987

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November 25, 1987

EXECUTIVE OVERVIEW

A bootstrap lunar base is the gateway to manned solar system exploration. Fresh, idealistic minds must be brought in to explore new ideas and create new designs on the cutting edge of technology. With the aid of National Aeronautics and Space Administration (NASA) and Universities Space Research Association (USRA), Lunar Operations Company (LOCO) is incorporating innovative concepts in the design of a bootstrap lunar base.

To attack the technical problems of the project, the engineering division of LOCO is divided into three areas: fleet operations, lander designs, and lunar surface operations. The fleet operations group concentrated its efforts on a delta v study, deployment scenarios, concept feasibility for satellite communication/navigation systems, and fleet support vehicles. The lander design group designed a series of lander vehicles to support the development of the bootstrap lunar base and incorporated in the design the ability to transform some of the landers into required base components. Power plant, tinker toy, crane and habitat landers were designed. In addition, the Mechanical Engineering design team developed a lunar base entrance/elevator lander. The surface operations group was responsible for management of lunar resources such as oxygen, titanium, and aluminum, safety concerns such as solar flares and fire, base configuration, the sequence of base development, and habitation requirements.

Base development is proposed in three stages. The first stage will be constructed on the lunar surface, and will be covered with a radiation shield. The second stage will be underground, but will be buried under only 3-5 meters of regolith. The third stage will be buried further beneath the lunar surface and will be a more permanent base. This stage will be farther advanced than the bootstrap base considered by Lunar Operations Company; the thrust of LOCO is in designing the first and second stages of the base development.

LOCO believes that a bootstrap lunar base will prove the feasibility of future expansion into the solar system as well as serve as a proving ground for future expansion into the solar system. The base will be an outpost for the support of scientific research, exploitation of lunar resources, and demonstration of the human capacity for extraterrestrial expansion into the solar system.

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LIST OF ACRONYMS

CIM	Common Interlock Module
CS	Communication System
CW	Couchey-Wilshire
DME	Distance Measuring Equipment
ECLSS	Enviromental Control and Life Support System
EVA	Extra-Vehicular Activity
GN&C	Guidance Navigation and Control
GPS	Global Positioning System
HMF	Health Maintenance Facility
ILS	Instrument Landing System
LEM	Lunar Excursion Module
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LOCO	Lunar Operations Company
LO2	Liquid Oxygen
LOX	Liquid Oxygen
MA	Multiple Access
MMU	Manned Maneuvering Unit
NASA	National Aeronatics and Space Administration
NTO	Nitrogen Tetroxide
OMV	Orbital Maneuvering Vehicle
OTV	Orbital Transfer Vehicle
PAM	Payload Assist Module
PDR	Preliminary Design Review
RCS	Reaction Control System
REM	Roentgen Equivalent Man
RSTS	Regolith Support Truss Structure
SA	Single Access
SSCM	Space Station Common Module
STS	Shuttle Transportation System
TACAN	Tactical Air Navigation System
TDRSS	Tracking and Data Relay Satellite System
UDMH	Unsymmetric Dimethyl Hydrazine
USRA	Universities Space Research Association

1.0 General Summary

This document presents the second preliminary design for a Bootstrap Lunar Base by the Lunar Operations Company (LOCO) as outlined by RFP #274L Fall '87. An overview of the work completed through this phase of the project will be discussed as well the technical, management, and cost strategies to complete the program requirements.

1.1 Project Background

The development of a permanently manned space station in low earth orbit will enable NASA to realize its immediate goals of exploring and industrializing our local region of outer space as well as present many important options to the long-range direction of NASA's efforts in the post-space station era. The space station will not only serve as an orbiting science platform for Earth observation and for low-Earth orbit operations, but it will also function as a transportation node for interplanetary travel. This orbital gateway will be the key to missions to Mars, the asteroid belts, the inner planets and to the development of a permanent lunar base. Given these options, it is necessary for NASA to quickly establish the direction of the U.S. manned space program so that the required technologies can be implemented into the space station design. LOCO asserts that a return to the Moon for the establishment of a permanently manned lunar base should be the desirable long-range goal of the civilian space program. Once the feasibility of extraterrestrial colonization has been demonstrated in a lunar environment, the logical extension of that effort would then be a manned mission to Mars or to the asteroid belts.

A permanently manned lunar base will provide an outpost for the support of several objectives : scientific research of the moon and its environment, exploitation of lunar resources and demonstration of the human capacity for extraterestrial expansion into the solar system. The range of activities in scientific research of the moon include lunar geology, geophysics, astrophysics, materials science and astronomy. A base on the Moon will also provide a laboratory for the exploitation of lunar resources to aid in the industrialization and commercialization of space. The processing of liquid oxygen and the extraction of metals such as iron and titanium from lunar regolith and ilmenite give an economic incentive to lunar enterprises with their applications in large space structures. Most importantly, a lunar base will serve as a proving ground for planetary habitation. It will not only demonstrate the human ability to live and work productively in harsh environments but it will also demonstrate the feasibility of extraterrestrial resource exploitation. The principles of the successful development and operation of an autonomous lunar base can then be used in manned missions to other planets, specifically Mars.

An inherent problem to the development of a lunar base is the cost of delivering payload to the Moon. Estimates for the cost per pound have ranged from a few million to several million dollars, according to Ref. 1.1. Consequently, the basic objective in delivering and constructing a lunar base is to minimize the mass delivered to the Moon's surface and to maximize the utility of all payloads. This implies that in its first stage of development as a *bootstrap* lunar base, only the minimum essentials for base construction and operation will be delivered. Additions to support larger crews and heavier industry can then be added as the base matures in its development. Also implied is that all lander vehicles used to deliver payload and equipment to the lunar surface should be transformable into base elements, thus giving rise to the lander vehicle *transformer* concept. This design approach by LOCO will not only achieve the basic objective of minimizing costs but it will accomplish the ultimate goal of a proving ground for the human expansion into the solar system and beyond.

1.2 Design Overview

The Lunar Operations Company will design a bootstrap lunar base that stresses the transforming capabilities of its lander vehicles to aid in base construction. The design will also emphasize modularity and expandability in the base configuration to support the long-term goals of scientific research and profitable lunar resource exploitation. The bootstrap base will feature subsurface tunneling for radiation protection and pilot plants for the processing of liquid oxygen and for the extraction of metals and other materials.

1.2.1 Stages of Lunar Base Development

A bootstrap lunar base implies that the minimum payload needed to construct an operational base and accomplish its mission objectives will be delivered to the lunar surface. Also implied is that the landers used to deliver these payloads will be designed to transform into needed base components. To better place into perspective the concept of a bootstrap lunar base, LOCO has defined four phases of lunar base development : (1) minimum shielding during surface habitation with open ECLSS, (2) Increased shielding through covering habitation modules with regolith with a partially closed ECLSS and and pilot plant processing, (3) Expansion of the Phase 2 habitation and personnel with production and exportation of raw products, and (4) Maximum shielding through deep underground tunneling or tunneling into a crater wall with closed ECLSS, agriculture, and maximum production and exportation of raw and finished products. These phases are developed further in Figure 1.1 and are illustrated in Fig. 1.2.

In Phase 1, the lunar base crews must live in habitation modules above the surface upon arrival until trenches can be excavated for Phase 2. During Phase 1 operations, the lunar base crews will experience maximum exposure to radiation until better protection is provided with the Phase 2 base. To help decrease the radiation exposure the personnel receive during Phase 1, additional shielding using aluminum or water should be added to the habitation modules the Phase 1 crews will occupy. This phase will thus be carried

Figure 1.1 PHASES OF LUNAR BASE DEVELOPMENT

<u>Phase 1</u> -	**Habitation**	**: SSCM's on the lunar surface**
	Crew size	**: 6 to 8**
	ECLSS	**: Open or Partially Closed**

Initiate operation of Power Plant
Set up power distribution
Set up communications antennas
Excavate and Construct Phase 2 base
Begin construction of permanent landing pad
Carry out simple scientific experiments

<u>Phase 2</u> -	**Habitation**	**: SSCM's covered with regolith**
	Crew size	**: 8 to 12**
	ECLSS	**: Partially Closed**

Operate Pilot Processing Plant
Explore Moon for more resources
Carry out more complex scientific experiments
Complete construction of permanent landing pad
Expand Phase 2 with additional SSCM's

<u>Phase 3</u> -	**Habitation**	**: Expansion of Phase 2 SSCM's**
	Crew size	**: 50 - 100**
	ECLSS	**: Partially Closed**

Construct permanent processing plant facilities
Begin exportation of raw materials
Carry out large scale scientific experiments
Research manufacturing of products
Research Lunar Agriculture

<u>Phase 4</u> -	**Habitation**	**: Underground, Crater Wall, etc.**
	Crew size	**: 500+**
	ECLSS	**: Closed**

Carry out full production of LOX/Metals/Concrete
Manufacture and export finished products
Full scale Lunar Agriculture

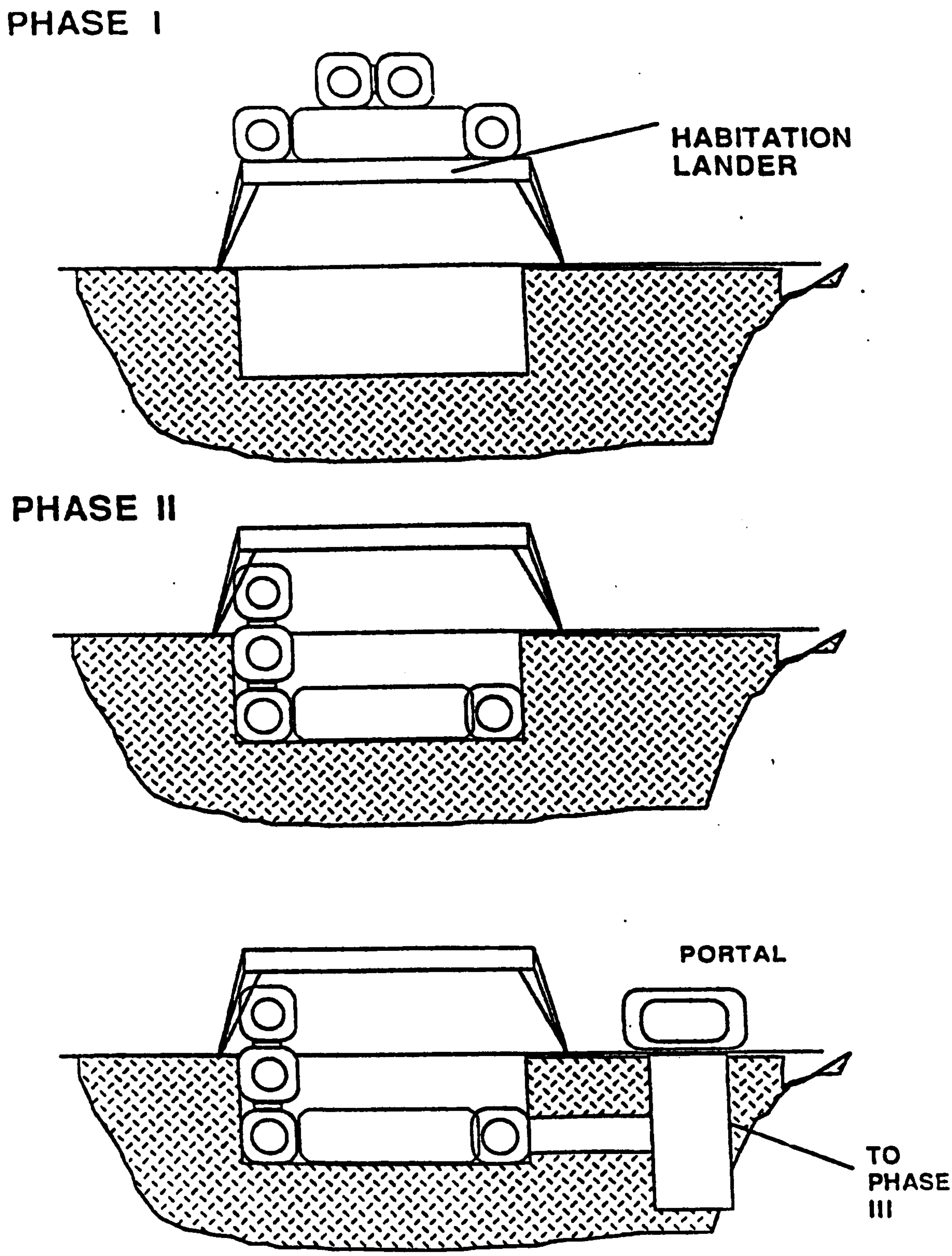

Figure 1. 2 Phases of Lunar Base Development

out with many crews spending only short periods on the moon before returning to Earth.

In Phase 2, the lunar base habitation modules are placed in the trenches such that they will be covered with 2.5 meters of lunar regolith to provide radiation protection. By burying the modules, some protection against meteorites will also be provided. During Phase 2, the crew will again be exposed to large amounts of radiation as construction of Phase 3 begins, but adequate shielding of the habitation modules will allow Phase 2 personnel to stay longer. Also, in Phase 2, the personnel will begin pilot plant operations to begin the extraction of LOX and metals from the lunar regolith. This will be a learning phase as new technologies are tested in the harsh lunar environment, but it is anticipated that these processes will soon be perfected and that the exploitation of lunar resources will not only be productive, but profitable, too. Phase 2 astronauts will also begin to carry out simple scientific experiments.

In Phase 3, the Phase 2 base is expanded with more SSCM's to accommodate larger crews and with the construction of larger processing plants. Larger crews will be needed to step up production of LOX and metals and to begin the construction of the permanent Phase 4 base. Obviously, the third phase of development will last a long time due to the time and effort needed to excavate the Phase 4 main entrance shaft and tunnels. Whether the Phase 4 base is located underground or inside the wall of a crater, this construction will be very labor intensive and will require advanced heavy machinery. It is hoped that the difficulty of this task might be reduced with the development of explosives technology for lunar applications.

Once the Phase 4 base has been excavated, larger crews will be brought down to occupy the base and complete its interior development. Large scale production of raw and finished products will then begin, soon to be followed by the development agriculture in lunar greenhouses. Eventually, the Phase 4 base will become an autonomous lunar society.

1.2.2 Design Focus

To accomplish its tasks for the design of a bootstrap lunar base, LOCO has focused its technical efforts into three areas : Surface Operations, Fleet Operations and Lander Design. The Surface Operations division will be responsible for the base configuration, the sequence of base development, the materials to be retrieved from the lunar surface and the methods to process them, the landing sites and procedures for handling emergencies and disasters.

The Fleet Operations division will focus its design efforts on providing the preliminary mission planning and fleet requirements throughout all phases of base development. Mission planning will include delta-v studies and scenario development. Another task of the Fleet Operations division will be determining the requirements of the lander fleet. This will be done by characterizing the numbers and types of vehicles and by estimating their masses and volumes. This will also include determining suitable communication and navigation systems for the lunar base and for the landers. The Lander Design division will carry out the point designs of a series lander vehicles to support the development of the bootstrap lunar base. These will include a power plant, a generic cargo module and a man-rated return vehicle. Reusability and transformability of the vehicles into base components will be emphasized with no waste of components.

1.2.3 Design Ground Rules and Assumptions

In its efforts to design a bootstrap lunar base, LOCO will use the following ground rules:

- Bootstrap Base will serve as a proving ground for future expansion into the solar system

- Bootstrap base will serve as the necessary and useful core of future post-bootstrap expansion

- Bootstrap base will feature subsurface tunneling for radiation shielding

- Early self-sufficiency through the processing of lunar regolith for volatiles and metals

- Lunar lander fleet to consist of both manned and unmanned vehicles
- All descent stages must be transformable and useable as elements in the bootstrap base
- Return stages for all lunar base personnel
- Initial power supplied by 10-20 Mwe nuclear reactor or several smaller 5 Mwe nuclear reactors
- Initial habitation will consist of a minimum number of space station common modules

In addition, the following assumptions have been made :

- The Space Station is a fully operational system
- Moonport, an orbiting lunar space station, is a fully operational system
- All payloads for the Bootstrap Base have been loaded on Moonport prior to its placement in low lunar orbit and are ready for deployment to the lunar surface
- A reliable transportation system will resupply the Bootstrap Base
- Earth-proven communication and navigation satellite technology can be readily exploited in a lunar environment
- Technology baseline of year 2005

1.3 Reference Mission Scenario

To guide the design efforts in the development of a bootstrap lunar base, a reference mission scenario has been constructed. This scenario represents the current direction of the lunar base mission and it will certainly change as the design evolves. The critical events in the reference mission scenario center around the construction of the bootstrap lunar base through Phase 2.

The lunar base fleet of landers will be deployed from Moonport (Ref. 1.2), shown in Fig. 1.3, which is in a posigrade, equatorial, circular , low lunar orbit. Upon arrival at the

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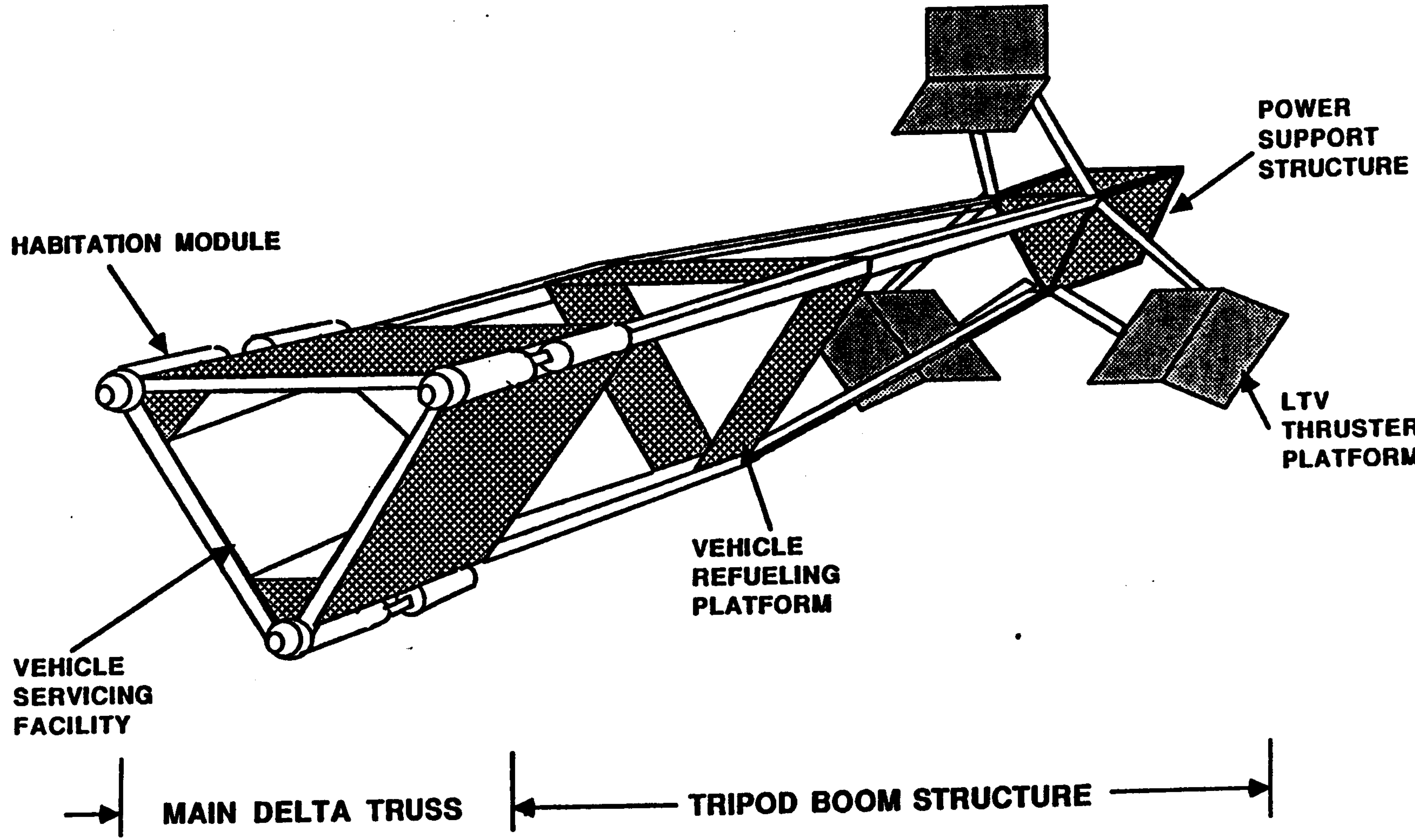


Figure 1.3. Moonport Configuration

(Courtesy Ref. 1.1)

lunar surface, Phase 1 begins. The first lander to come down will be a power plant and this will be delivered sub-critical to avoid permanently contaminating the site if an accident during landing should occur. Then the first Phase 1 crew will come down, soon followed by the habitation lander, the surface construction equipment, and the pilot plant equipment. The first Phase 1 crew will then be responsible for activating the power plant and distributing the power to the habitation modules, the surface habitation modules, and the pilot plant. Once the base has been powered up, then the trenching for Phase 2 begins. Initial estimates give 180 days for the time to dig the trenches for the Phase 2 base. This number was obtained by determining the volume of lunar soil to be trenched and then dividing it by a digging rate of 20 m^3 / day. A conservative error estimate of 33 % was then used to account for equipment maintenance and work slow downs due to crew rotations. Once the trenches have been completed, the Phase 1 habitation modules will be lowered into the trenches and covered by 2.5 meters of regolith, thus beginning the Phase 2 base. A second power plant will then be landed to provide primary power for the Phase 2 habitation modules while the first power plant provides full time power to the digging equipment and to the processing plant. It will also provide backup power to the Phase 2 base in case its dedicated power plant fails. Solar batteries or fuel cells will also be used for backup power. After the second power plant has been delivered, the first Phase 2 crew will come down to begin the pilot plant operations and to begin scientific exploration of the Moon. The sequence of major events described in this reference mission scenario is shown in Fig. 1.4. Estimates were made for the time to excavate the lunar regolith for covering the Phase 2 base by calculating the required volume of regolith to be removed and then dividing the volume by the volumetric digging rate. A figure of 20 m^3/day was given in the RFP for mining operations. It was decided to double this rate 40 m^3/day to estimate the capability of a surface digger during the excavation process. From Fig. 1.4 it is seen that the excavation process was estimated to take 51 days and that the foundation construction and module burying would take approximatley 30 days.

DAYS		EVENT
0	-	Moonport in lunar equatorial orbit
1	-	Deploy power plant
1	-	Deploy first Phase 1 crew
1	-	Deploy Habitation ---> Phase 1 base
2	-	Initiate operation of power plant
2	-	Deploy Surface Construction equipment
3	-	Begin excavation for Phase 2 base
6	-	Begin construction of landing pad
53	-	Complete excavation for Phase 2 base
54	-	Construct Base
85	-	Bury Phase 1 ---> Phase 2 base
100	-	Complete construction of landing pad
115	-	Deploy first Phase 2 crew
116	-	Deploy Pilot Plant equipment
117	-	Begin Pilot Plant operations
120	-	Begin scientific experiments

Fig. 1.4 Sequence of Major Events

LOCO will carry its design efforts through the development of a Phase 2 base since that mission actually requires bootstrapping. A Phase 3 or Phase 4 base is an enormous undertaking and, thus, LOCO will only attempt to define requirements for these phases (such as closing the life support system, introducing lunar agriculture, full water recycling, and full waste recycling).

1.4 TECHNICAL OVERVIEW REFERENCES

1.1 Personal Communication with Dr. Wallace T. Fowler, Professor at The University of Texas at Austin, Department of Aerospace Engineering, Austin, TX 78712.

1.2 Space Port Systems, *Moonport : Transportation Node in Lunar Orbit*, The University of Texas at Austin, May 3, 1987.

2.0 FLEET OPERATIONS

The following describes the research, analysis, and design information developed by the Fleet Operations division up to Preliminary Design Review 2. This division provides preliminary mission planning and fleet vehicle support and requirements for all phases of Lunar Base construction.

2.1 Preliminary Mission Planning

The preliminary mission planning to be considered in this design effort includes the development of scenarios for the deployment of the lunar landing fleet and for the return of lunar base personnel to Moonport. A ΔV analysis for these scenarios has been conducted to estimate the fuel requirements to accomplish the mission. A time of flight analysis has also been carried out to account for emergencies when a minimum transfer time is needed, such as in rescue operations.

2.1.1 Deployment Scenarios

The two basic scenarios to be used in deploying the bootstrap lunar base fleet from Moonport to the lunar surface involve either unmanned sorties for cargo delivery or manned sorties for personnel delivery. Figure 2.1 illustrates the deployment scenario. In an unmanned sortie, the vehicle will be undocked from Moonport using an OMV before beginning its descent . This will ensure that the deorbit burn by the lander engines will neither damage Moonport nor injure any personnel who might be doing EVA. The unmanned cargo vehicle will rely on an automated control and navigation system to deliver it to the proximity of the lunar landing site. When in suitable range, the navigation system will switch from star tracking to triangulation using ILS beacons for position and velocity information to more accurately guide the craft to its intended target. Once landed, those

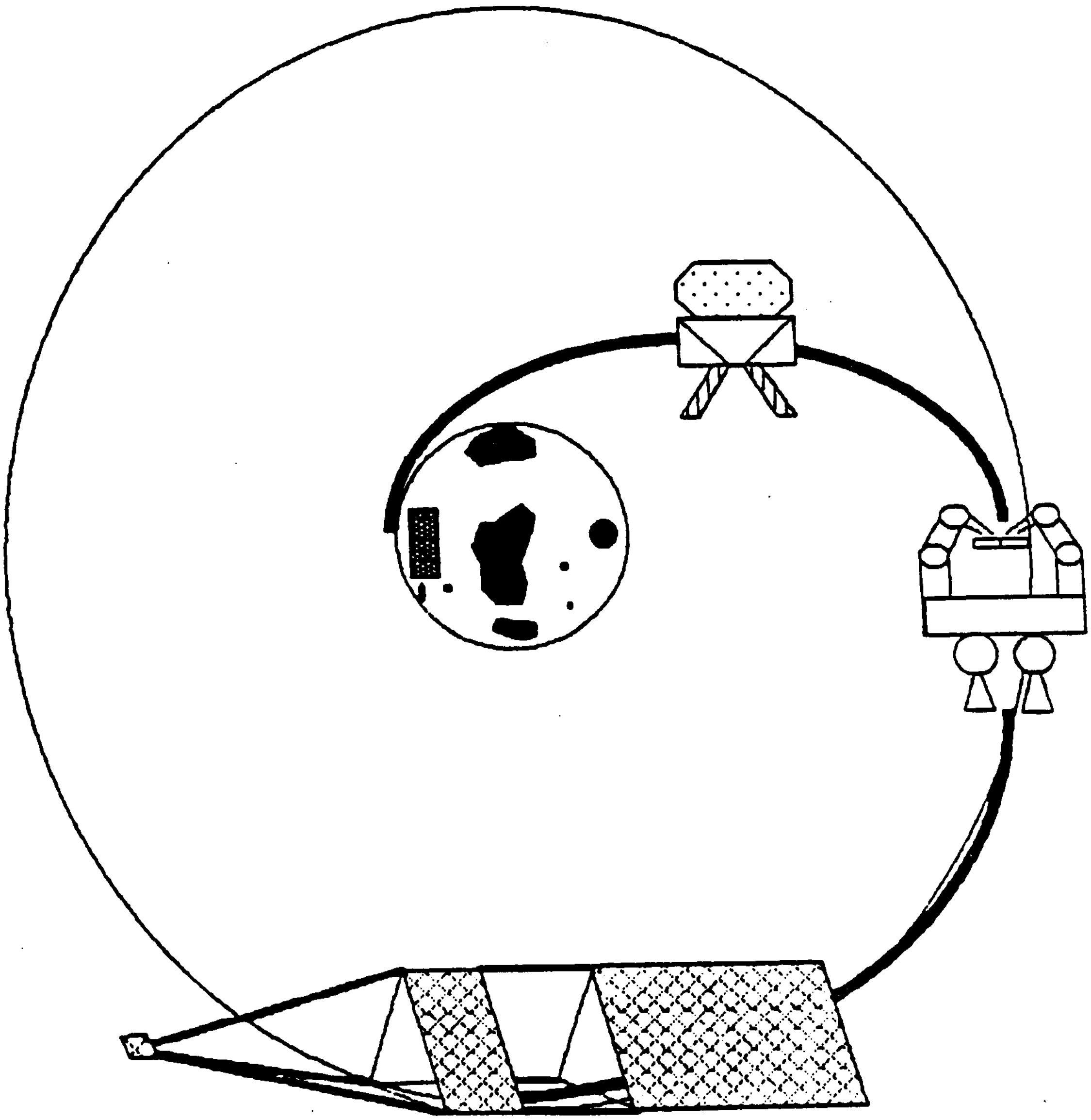


Fig. 2.1 Deployment Scenario

vehicles which were intended to transform into base elements will be then be dismantled accordingly. Manned sorties will proceed almost in the same manner. Personnel vehicles will also use OMV's to undock from Moonport and they will also rely on automated control and navigation systems for guidance during the descent. However, with personnel aboard it is necessary that a manual override be available so that the vehicle can be piloted by one of the crew should the automated system fail or should unexpected obstacles such as boulders block the vehicles' flight path. Furthermore, the personnel vehicle will be reusable so none of its components will be used as base elements.

2.1.1.1 Minimum Delta V Descent to Lunar Surface

Because one of the driving considerations for a bootstrap base is minimizing the mass needed to accomplish the mission, the method of transfer to be used for most fleet vehicle deployments will be a Hohmann trajectory (Ref. 2.1). Initial calculations for a Hohmann transfer from Moonport to a vacuum perigee on the lunar surface give a total Δ V of approximately 1.725 km/sec. To account for the fuel needed for attitude adjustment and hovering, this number was increased by 15% to give a net Δ V of approximately 1.988 km/sec. This figure compares well to the descent Δ V used in the Apollo 16 mission of 2.0 km/sec. For engines using liquid oxygen / liquid hydrogen for fuel, this corresponds to a required mass ratio of $M_0 / M_f = 1.52$. While the Hohmann transfer gives the minimum Δ V to get to the lunar surface, the time of flight for this transfer is 56.5 minutes, and in emergency situations a minimum time of flight will be the main concern.

2.1.1.2 Minimum Time of Flight Descent to Lunar Surface

The need for a minimum time of flight descent to the lunar surface becomes extremely important in the event of emergencies, such as a cave-in during construction of the bootstrap base. In this case, it is necessary that Moonport astronauts be able to quickly descend to the lunar surface to carry out rescue operations. In addition, a catastrophic failure of Moonport's nuclear reactor might require a fast evacuation to seek safety at the bootstrap base. To approximate a minimum time of flight transfer, calculations were made by determining the Δ V needed to completely stop the descent vehicle's orbital velocity and the Δ V needed to then bring the craft to a soft landing as it free falls from Moonport's orbit. Since there is no atmospheric drag, the time of flight can then be easily found using the equations of motion for a particle in free fall. These calculations are given in Appendix B, and they show that for this type of maneuver a time of flight of 2.38 minutes can be obtained for a Δ V of 2.536 km/sec, after it had been adjusted for attitude control and hovering. This gives a 95% decrease in the time of flight over a Hohmann transfer for only a 28% increase in total Δ V.

2.1.1.3 Lambert Targeting to Lunar Surface

Calculations of the synodic period between Moonport and the lunar surface, given in the Hohmann transfer calculations in Appendix A, show that launch opportunities from Moonport to the lunar surface and vice versa open up approximately every 2 hours for a specific scenario. This means that required phase angle between Moonport and the bootstrap base for the Hohmann transfer and for the minimum time of flight transfer is available every 2 hours, which in emergency operations might not be acceptable. Consequently, a Lambert targeting program (Ref. 2.2) was used to analyze the Δ V required for various times of fligh and transfer angles. This was done to simulate descents from Moonport to the bootstrap base, as the angle of separation between the base and Moonport at the time of launch varied from 30° to 330°, and is depicted in Fig. 2.2. Thus, when an emergency is encountered,

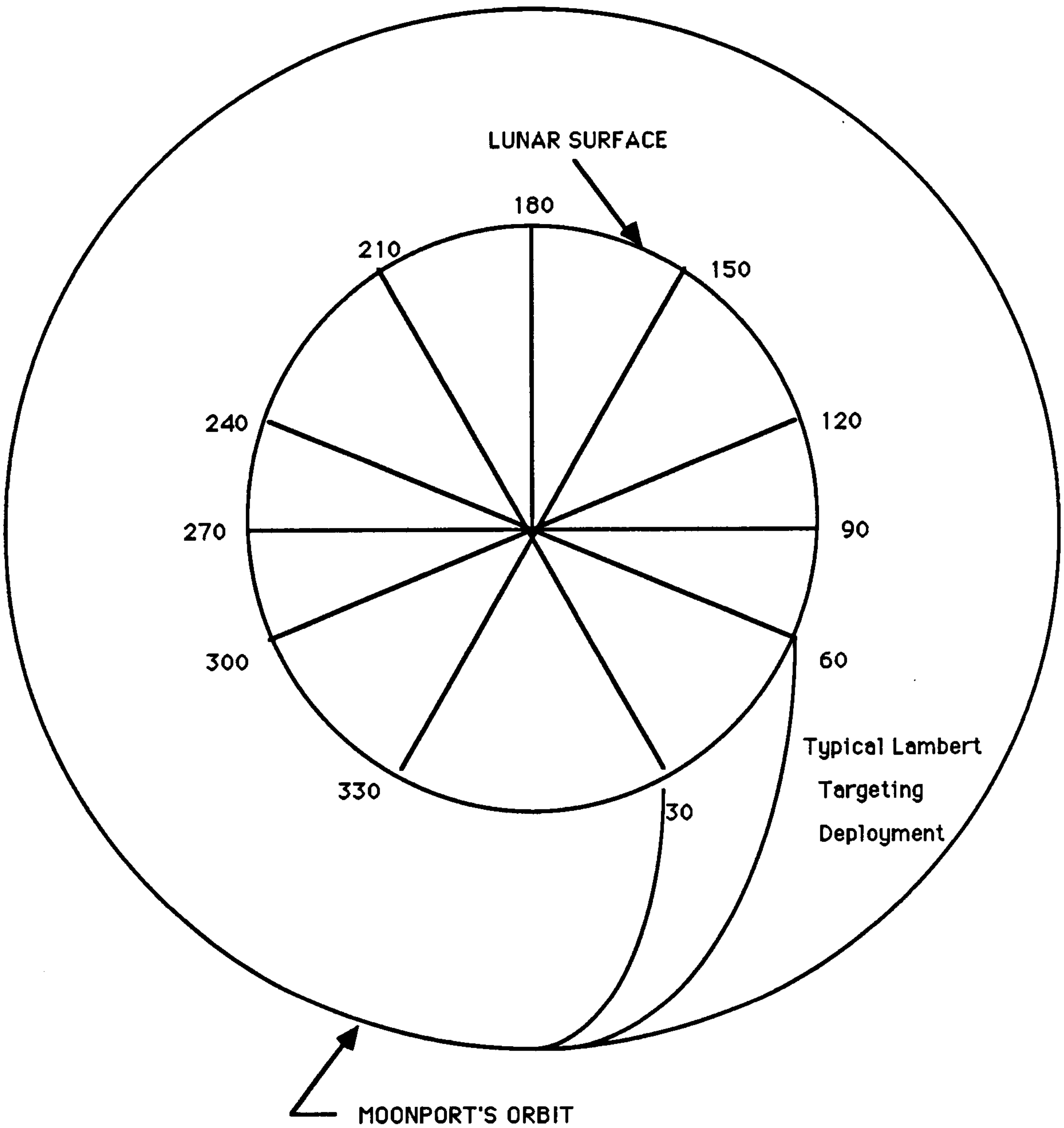


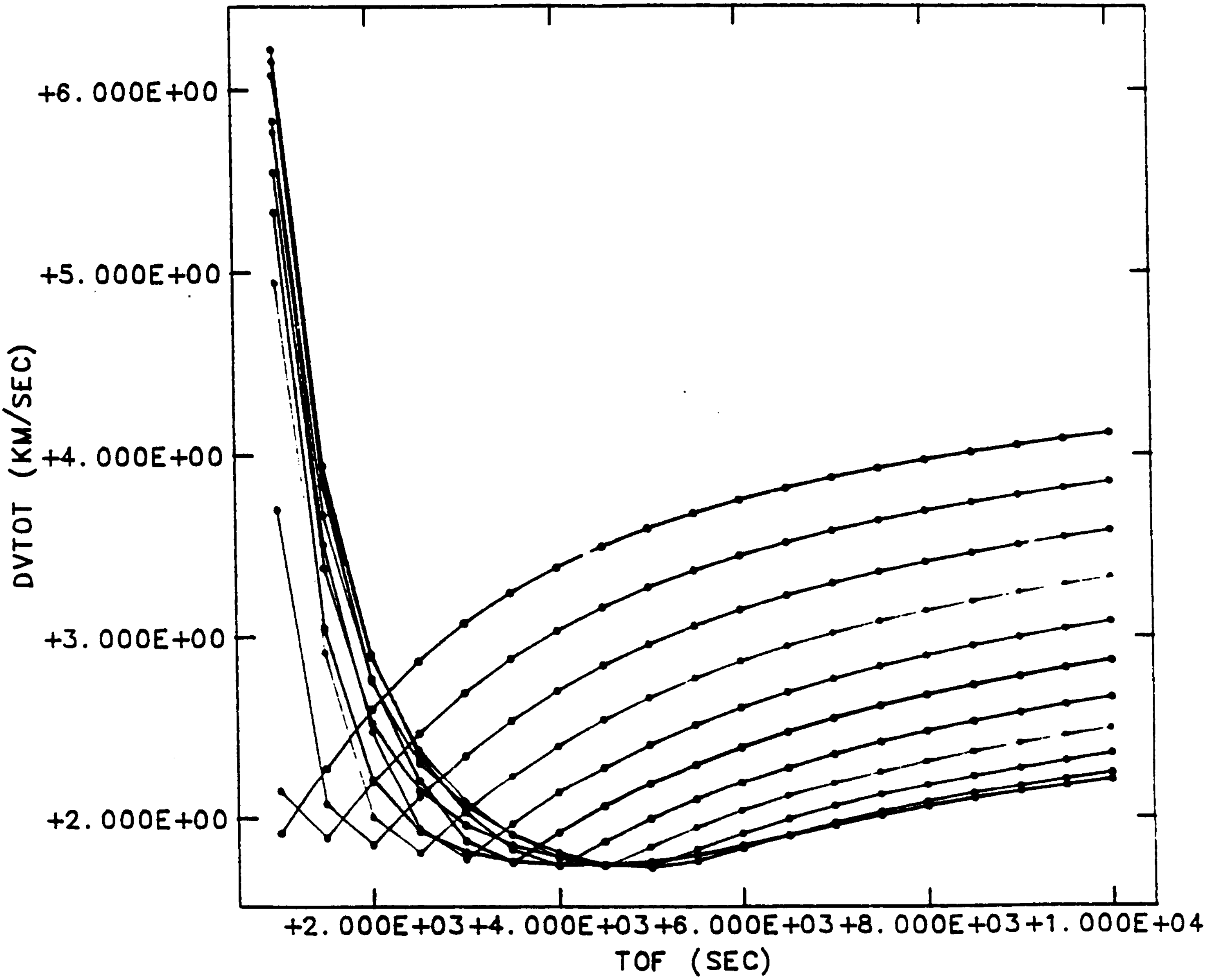
Figure 2.2 Lambert Targeting Scenarios

Lambert targeting can be used to reach the lunar surface regardless of the phasing between Moonport and the bootstrap base. The required Δ V's for times of flight from 1000 to 10000 seconds for each angle of separation are listed in Table 2.1 and are plotted in Fig. 2.3. It is observed that for a single angle of separation, the Δ V is very large for short times of flight , but then increases after reaching a minimum Δ V comparable to that of the Hohmann transfer discussed in section 2.1.1.1. It is also observed that for a particular time of flight, the Δ V decreases as the angle of separation increases.

TABLE 2.1 Lambert Targeting Total Delta V vs. Time of Flight

TOF	TOTAL DELTA V (KM/SEC)										
(SEC)	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
1000.0	2.095	2.432	4.076	5.391	6.257	6.659	6.719	6.552	6.272	5.959	5.711
1500.0	2.456	2.114	2.353	3.233	3.851	4.182	4.285	4.195	3.969	3.641	3.261
2000.0	2.794	2.414	2.094	2.275	2.768	3.063	3.192	3.164	3.010	2.748	2.388
2500.0	3.070	2.689	2.355	2.061	2.202	2.474	2.621	2.637	2.547	2.364	2.103
3000.0	3.291	2.922	2.587	2.288	2.029	2.131	2.290	2.339	2.177	2.004	1.989
3500.0	3.470	3.115	2.786	2.488	2.226	2.011	2.082	2.154	2.148	2.076	1.969
4000.0	3.618	3.276	2.953	2.659	2.398	2.180	1.992	2.033	2.054	2.017	1.962
4500.0	3.742	3.411	3.096	2.806	2.547	2.329	2.132	1.989	1.993	1.984	1.972
5000.0	3.846	3.526	3.218	2.932	2.675	2.458	2.260	2.103	1.995	1.977	2.000
5500.0	3.937	3.626	3.324	3.042	2.787	2.570	2.372	2.213	2.088	2.019	2.045
6000.0	4.015	3.712	3.416	3.138	2.886	2.669	2.470	2.310	2.182	2.094	2.102
6500.0	4.084	3.788	3.498	3.223	2.972	2.757	2.557	2.396	2.265	2.172	2.164
7000.0	4.146	3.855	3.570	3.299	3.049	2.834	2.634	2.472	2.339	2.243	2.224
7500.0	4.200	3.915	3.634	3.366	3.119	2.904	2.704	2.540	2.406	2.307	2.282
8000.0	4.249	3.969	3.692	3.427	3.181	2.967	2.766	2.601	2.466	2.365	2.335
8500.0	4.294	4.018	3.744	3.481	3.237	3.023	2.822	2.656	2.520	2.417	2.383
9000.0	4.334	4.062	3.792	3.531	3.288	3.075	2.874	2.707	2.569	2.465	2.428
9500.0	4.371	4.103	3.835	3.577	3.335	3.122	2.921	2.753	2.613	2.508	2.469
10000.0	4.405	4.140	3.875	3.619	3.378	3.166	2.964	2.795	2.655	2.548	2.506

FIGURE 2.3 DELTA V VS. TOF



2.1.2 Return Scenarios

In the bootstrap phase of the lunar base, only personnel will be returned to Moonport as Phase 1 and 2 work crews get rotated out periodically. This topic is covered more in depth in Section 4.5. Since the quantities of LOX and metals produced by the pilot plant will not be sufficient for exportation, return of raw materials to Moonport will not occur until Phase 3 of the base. As a result, the return scenarios considered in this report will deal only with the return of personnel using minimum time of flight and minimum ΔV transfers. In these scenarios, personnel vehicles will lift off from the bootstrap base to the orbit of Moonport where they will then rendezvous and dock with an OMV to shuttle it to the vehicle bay Moonport. The personnel vehicles will rely on automated control and navigation systems for guidance during the ascent, as well as the rendezvous and docking. However, with personnel aboard, it is necessary that a manual override be available so that the vehicle can be piloted by one of the crew should the automated system fail. These scenarios are illustrated in Fig. 2.4.

2.1.2.1 Minimum Delta V Ascent to Moonport

The minimum ΔV ascent to Moonport has been approximated by simply reversing the process of the Hohmann transfer descent. This analysis is justified by the argument that, for an spacecraft, a take-off and a landing are essentially the same process except that thrust reversing is also employed in a landing to help slow down the spacecraft. Thus, the ΔV required for such an ascent is 1.988 km/sec, which compares well with the ascent ΔV for the lunar module in the Apollo 16 mission of 1.867 km/sec.

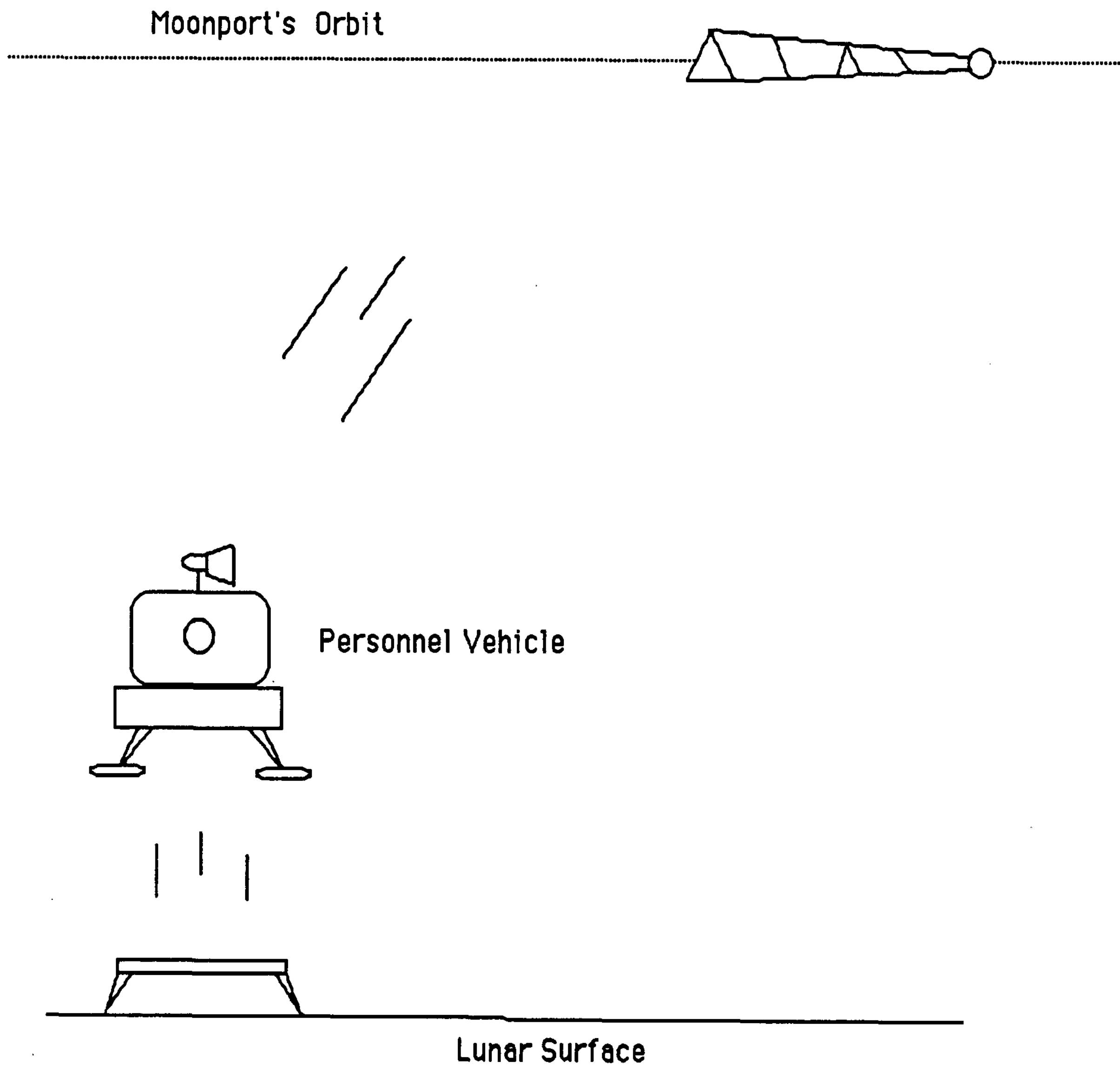


Figure 2.4 Personnel Return Scenario

2.1.2.2 Minimum Time of Flight Ascent to Moonport

To determine a rough estimate of the minimum time of flight ascent from the bootstrap base to Moonport, a FORTRAN program for a lunar ascent trajectory was obtained from Ref. 2.3 that optimizes the time of flight for an ascent from the lunar surface to an orbit of 100 km. The source code for this program is found in Appendix B. Restrictions of this program include a flat moon model and constant gravity. The obtained results give a time of flight of 16.3 minutes, as compared to a time of flight of almost 56 minutes for the ascent of the lunar module in the Apollo 16 mission. Calculations for the corresponding Δ V, found in Appendix A, give 3.355 km/sec, which is 1.78 times the Δ V for the ascent in the Apollo 16 mission.

2.2 Communication and Navigation Systems

The deployment of the bootstrap base and its expansion into a permanent base will require accurate, reliable communication and navigation systems. As a result, a study of feasible communication and navigation systems has been carried out for the deployment, construction, and occupation of a lunar base.

2.2.1 Communication Systems

This sub-division investigates feasible communication systems for all aspects of the bootstrap lunar base development such as deployment, construction, and permanent occupation. It is assumed that the communication system that is finally chosen should provide continuous communication between Moonport, the landers, the bootstrap base, and finally be expandable for the permanent base. Included with this information is a general communication system (CS) schematic, as represented in Figure 2.5, which describes in detail all the CS components for a general communication set-up.

2.2.1.1 Communication System Satellite

The CS satellite that is being considered is a TDRSS-type communication satellite. The general services provided by TDRSS, as stated in Reference 2.5, include forward link data (command) to the user spacecraft, return link data (telemetry) from the user spacecraft, and range and doppler tracking for any spacecraft. TDRSS is simply a communication service, it is not explicitly concerned with the contents of the data transferred, therefore, its primary purpose is the reception, frequency translation and amplification of data. Up to 32 simultaneous multiple access (MA) users can be tracked and provided with command and support telemetry (to 50 Kbit/s) service. To increase system reliability a number of functions have been removed from the satellite and placed in a ground terminal package, at the Lunar

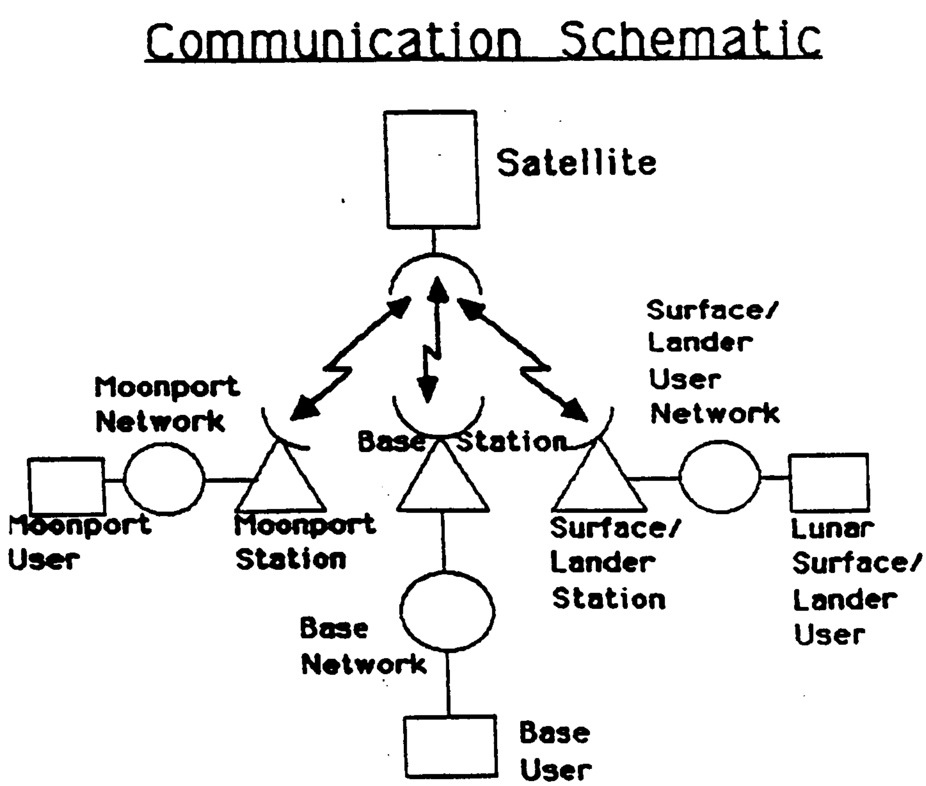


Fig. 2.5 General Communication Schematic

base. These functions include: mode and redundancy control of satellite communications equipment, gain and power level control of all channels, antenna pointing, K-band autotrack and acquisition search, and other functions not adversely affected by transmission delay.

The following is a list of key features as provided by TDRSS from Reference 2.5 :

1) Shaped high efficiency 4.9-m-diameter antennas to ensure link performance margins for single access (SA) forward and return services.

2) A multiple-access design provides ≥ 1-dB link margins with 6 of 30 elements failed in the return channel and 4 of 12 elements failed in the forward channel.

3) A two for one (or greater) redundancy in all active circuits (except for limited parts of the MA system) virtually eliminates single point failures.

4) A high level of redundancy for critical components such as the down link transmitter (only two of six downlink 27-Watt traveling-ware tube amplifier transmitters are used at any one time).

5) Independent gain adjustments in all return channels ensure optimum downlink power utilization to minimize interference.

6) Ground-implemented antenna pointing and frequency control minimize spacecraft complexity.

The TDRSS telecommunications system consists of the electronic equipment and associated antennas required for the repeater relay link between the user spacecraft/satellites and the ground terminal. A general block diagram of the TDRSS electronic equipment and the antenna configuration are included in Figure 2.6 and 2.7, respectively.

2.2.1.2 Bootstrap Base Communication

In order to deploy the bootstrap lunar base, some type of initial CS needs to be implemented which can be expanded and which would prevent or reduce any communication blackout. One of the CS configurations that is being considered includes two stationary communication satellites located at the L4 and L5 libration points. These satellites could then be expanded for an eventual constellation of six satellites which include the two stationary satellites.

The L4 and L5 points are approximately 65000 km from the Moon on the same orbit. TDRSS, as mentioned in Reference 2.5, has a conical angle coverage of 26 degrees, therefore, by simple geometry the beam widths of the two satellites would easily cover the Lunar surface as shown on Figure 2.8. This would enable spacecraft to communicate with each other as long as their lunar altitude is below approximately 13000 km. Other options for the Boot strap phase would be to use three satellites at 1000 km altitude or even two satellites at the same altitude and phasing with Moonport. As mentioned earlier, TDRSS can transfer forward and return link data by receiving the signal, and applying frequency translation and amplification. It cannot process the data nor provide tracking information in the boot strap configuration.

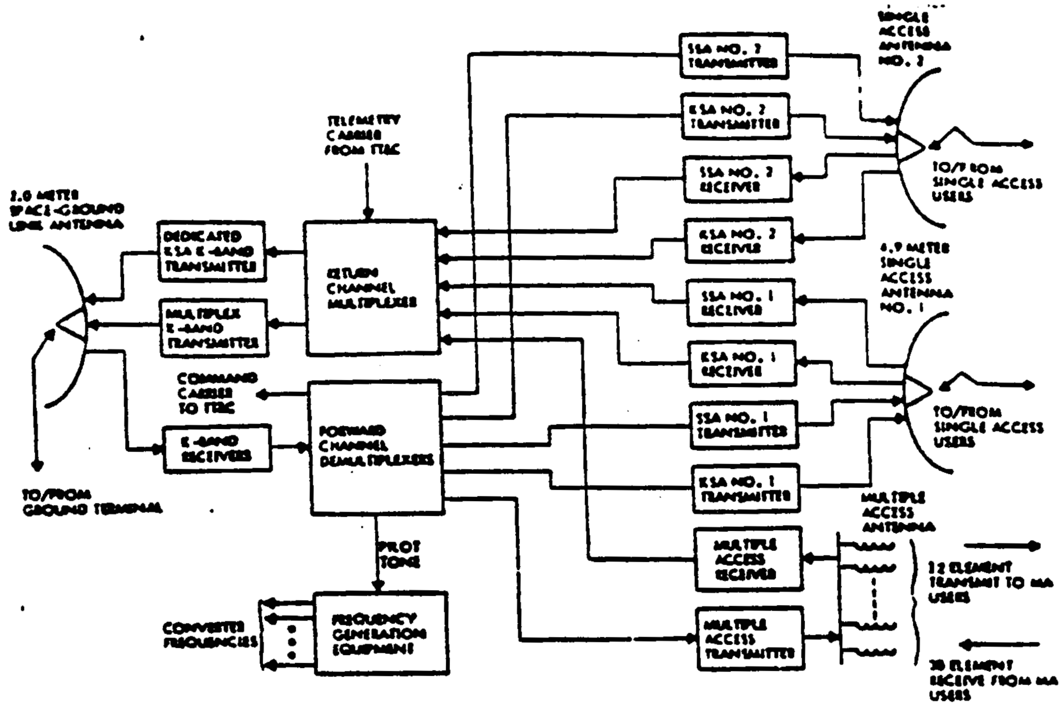
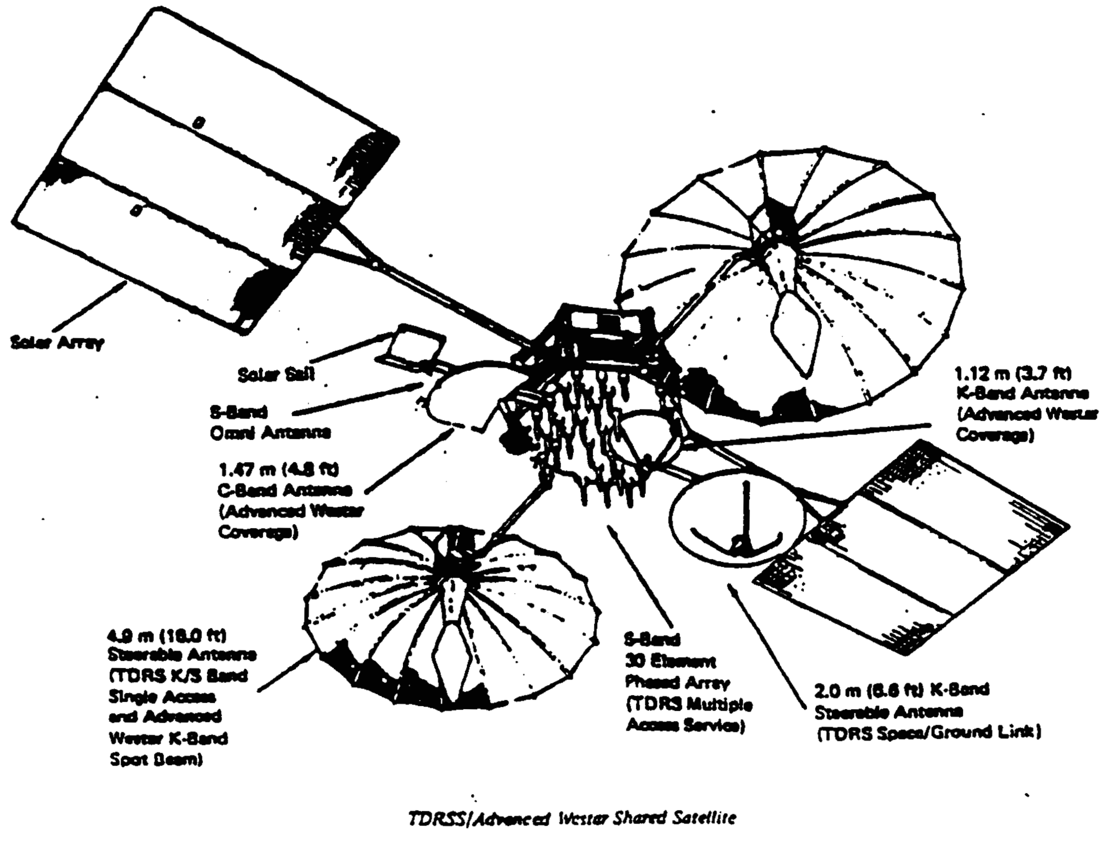


Fig. 4. Payload subsytem: functional block diagram.

Fig. 2.6 TDRSS System Block Diagram (Courtesy of Ref. 2.5)



TDRSS/Advanced Westar Shared Satellite

Fig. 2.7 TDRSS Antenna Configuration (Courtesy of Ref. 2.4)

TDRSS satellites at L4 and L5

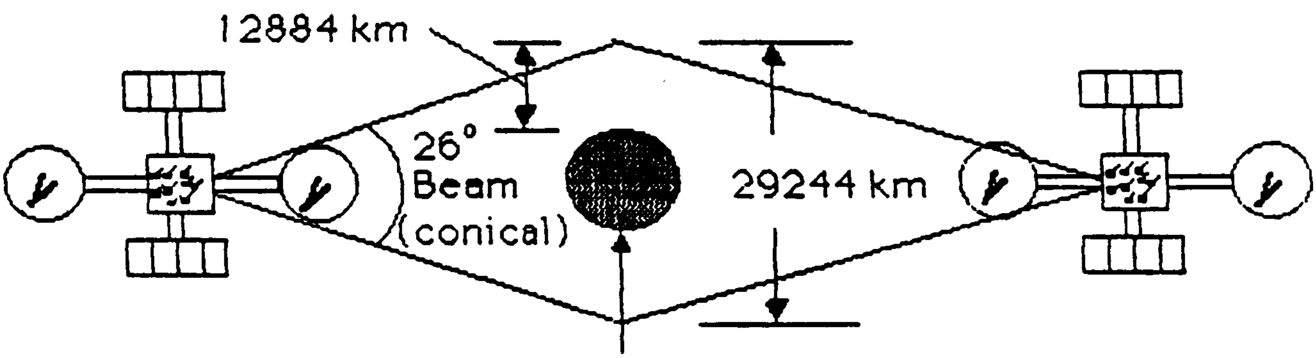


Fig. 2.8 Possible Initial Communication Satellite Configuration

2.2.1.3 Permanent Lunar Base Communication

When TDRSS is used in conjunction with two operational geostationary satellites and a single ground facility, it is able to service user spacecraft in Earth orbit between the altitudes of 200 km and 12000 km. For permanent Lunar operations the two stationary satellites could be located at the L4 and L5 libration points, and the ground facilities would be the Lunar base itself. A constellation of four satellites around the Moon would also be used in accordance with the preliminary configuration analysis provided by Reference 2.3, which states that a satellite at an altitude of 1000 km will illuminate approximately 40 percent of a Lunar hemisphere at any one time. This configuration provides three functional communication satellites and one spare for redundancy.

2.2.1.4 Lander Communication System

The communication systems to be carried by all vehicles in orbit or on the surface and any personnel on the lunar surface should be derived from the Apollo and Space Shuttle Transportation System (STS) equipment. From comparing the two communication systems, and the information available from Reference **2.1**, the communication system which should be used would include:

- highly reliable systems (redundancy),
- low cost systems and support equipment,
- narrower beams for greater gain,
- and C-band communications links.

2.2.2 Navigation Systems

This section will briefly discuss navigation systems which have been investigated. The navigation system to be used on the fleet vehicles will be derived from the Apollo landers and current STS equipment. Modifications will be made, however, to include technological advancements as well as several additional new systems. It is assumed that the navigation system that is finally chosen should provide proximity navigation in orbit and on the surface for the boot strap base and be expandable and provide continuous navigation between Moonport, the landers, and the permanent base.

2.2.2.1 Bootstrap Base Navigation Systems

The bootstrap base navigation systems should require the least amount of support equipment; because of this, the deployment of a Global Positioning type tracking system (GPS) for this phase is not perceived to be required. The systems which will be required, however, will include all proximity operation type equipment for navigation in the vicinity of Moonport and its support vehicles and most importantly for navigation to the surface of the Moon. The following will describe several systems which can be used for the applications mentioned above.

2.2.2.1.1 Instrument Landing System

The Instrument Landing System (ILS) is a precision approach system designed to place an aircraft in a position to land under lower ceiling and visibility conditions than is possible when using other facilities. It provides extremely accurate alignment and descent information during approach and landing.

The ILS uses ground radio transmitters which emit direction localizer (course) and glide slope signals. The onboard receiving equipment translates the signals into visual presentations of the position of the user in relation to the approach path. Other required equipment includes marker beacons, compass locators (homing beacons), and Distance Measuring Equipment (DME). The entire system is represented on Figure 2.9 (Ref. 2.8).

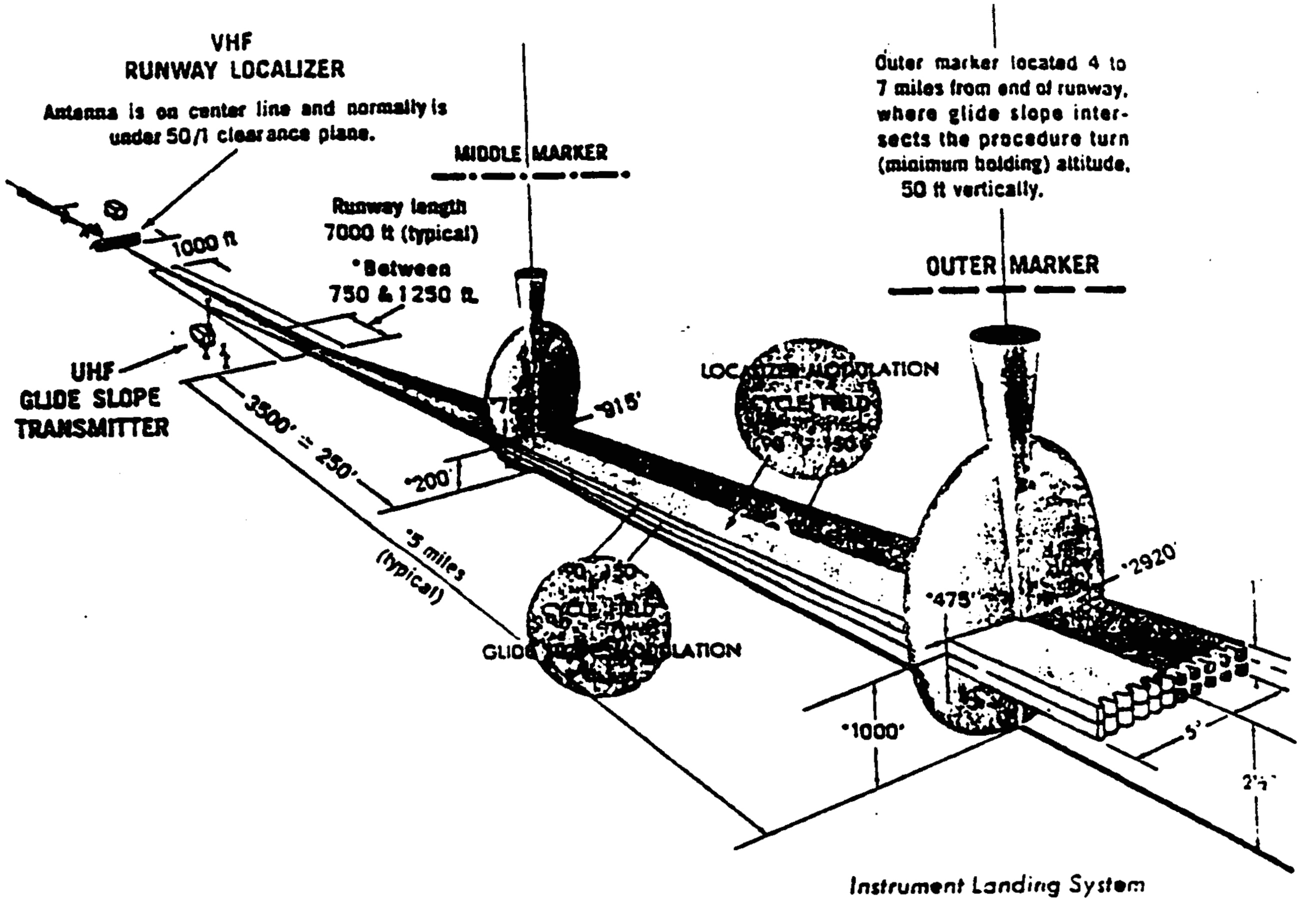


Fig 2.9 Instrument Landing System Representation (Courtesy of Ref. 2.8)

ILS Ground Equipment

The following includes the ground equipment that is required in order to have an operating ILS.

Localizer transmitters are installed approximately 1000 feet beyond, and 300 feet to the side of the far end of the runway center line. Figure. 2.10 shows the equipment set-up for the transmitter components. The transmitter emits two signals on opposite sides of the extended runway center line to provide azimuth information.. The signals overlap along the runway center line which forms the course.

Localizer transmitters will supply usable signals for a distance of at least 25 miles (approximately 22 nautical miles), in a section 10 degrees either side of the course line at an altitude of 1000 feet above the terrain. Also available is signal reception at a distance of approximately 40 miles (35 nautical miles) at 5000 feet, and at 80 miles (70 nautical miles) at 10000 feet (Ref. 2.8).

Glide slope transmitters are installed between 750 and 1250 feet down the runway from the approach end. The site is normally displaced 400 to 600 feet from the center line of the runway. Figure 2.11 shows the glide slope transmitter equipment. This transmitter radiates two signals which overlap to form a glide slope and provide guidance in a vertical plane. The power in this transmitter is sufficient to produce a usable signal 10 to 15 miles from its location in an 8 degree sector either side of the localizer course line at an altitude of 1000 feet above the terrain or the glide slope interception altitude, whichever is lower (Ref. 2.8).

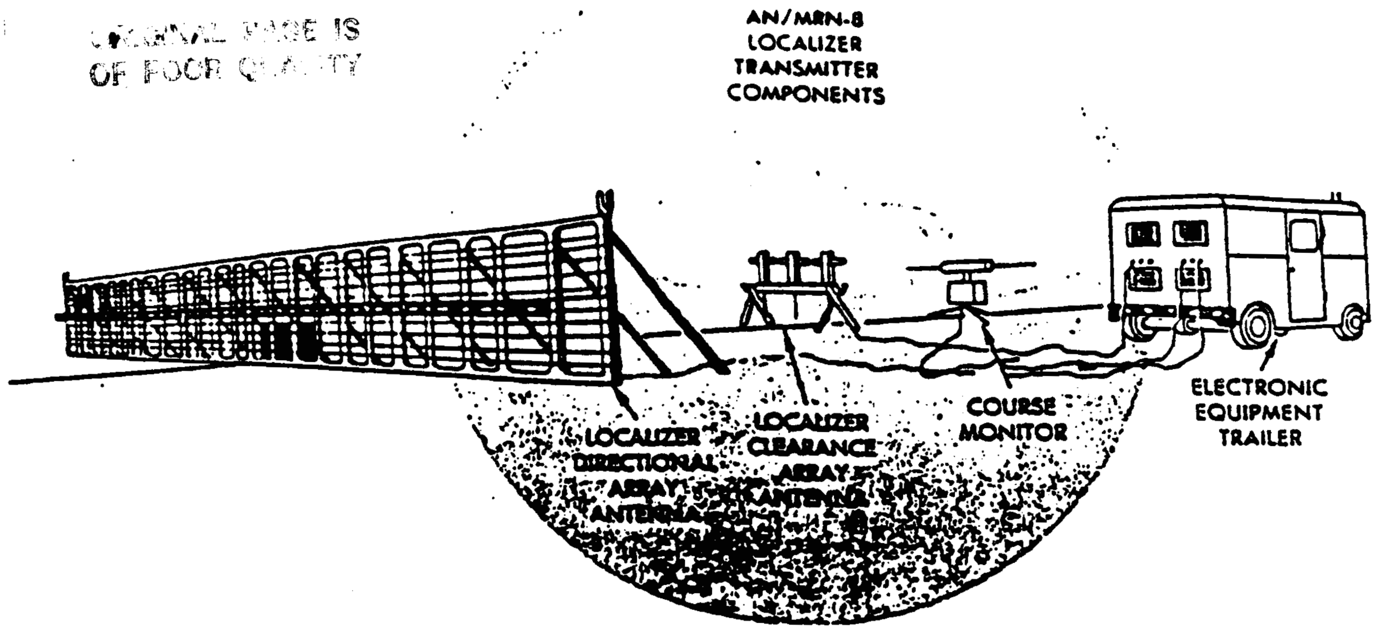


Fig. 2.10 Localizer Transmitter Components
(Courtesy of Ref. 2.8)

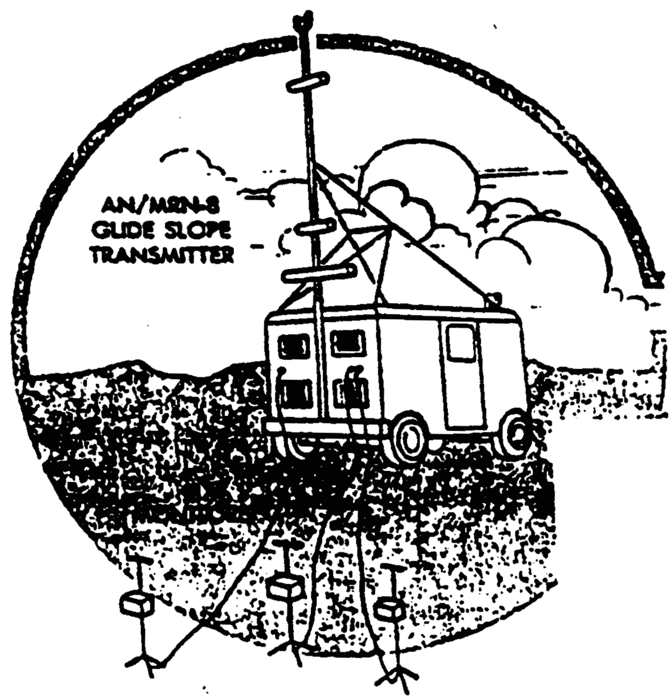


Fig. 2.11 Glide Slope Transmitter Components
(Courtesy of Ref. 2.8)

Marker Beacons are used in conjunction with ILS equipment to present definite fix and range information. Two marker beacons are normally installed on the approach course. The outer marker is located to intersect the glide slope within ± 50 feet of the published procedu turn altitude, and is usually between 4 and 7 miles from the approach end of the ILS runway. The middle marker's location will vary according to local terrain features and the glide slope angle, but will normally be from one-half to three-fourths of a mile from the approach end of the runway (Ref. 2.8).

2.2.2.1.2 Tactical Air Navigation System

The Tactical Air Navigation (TACAN) system is a short-range navigation system which supplies continuous, accurate, slant-range distance and bearing information. TACAN provides up to 126 position corridors to, or from, the TACAN facility. An integral part of TACAN is the Distance Measuring Equipment (DME) which furnishes continuous slant-range information from the TACAN facility, and enables the user to know his location at all times. The DME has an accuracy on the order of ± 600 feet, plus two tenths percent o the distance being measured.

TACAN's position information is presented in two dimensions - distance and direction from a single point, which is provided by a multichannel airborne receiver-transmitter. The same radio signals transmitted over a selected channel convey both distance and bearing information. This system has a maximum range of approximately 196 nautical miles (Ref. 2.8).

<u>TACAN Scenario</u> - A spacecraft's transmitter starts the integration process by sending out the distance interrogation pulse signal at a low-pulse repetition frequency. These signals are detected by the receiver of the ground beacon. The ground beacon then triggers its transmitter which sends out the distance reply pulse signal (Ref. 2.8). This scenario is represented in

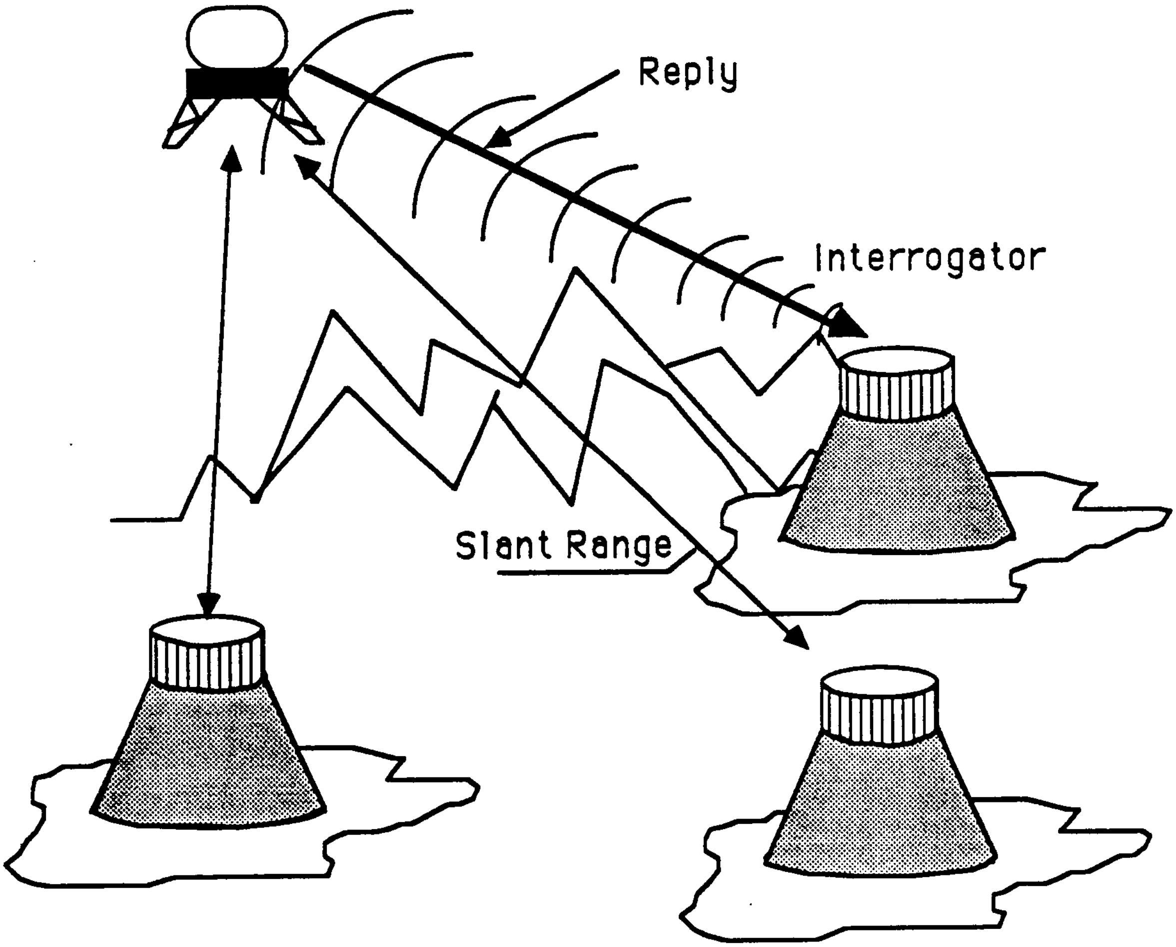


Figure 2.12 TACAN Scenario and range representation.

(Courtesy of Ref. 2.8)

2.2.2.1.3 Laser Ranging Systems

Laser ranging systems for spacecraft applications are currently being studied. These systems are made up of a laser(s) and receiving plate(s) on the vehicle which bounce a signal off any object or surface. The return signal is then processed and the amount of time to receive the signal determines its distance. This system could also be used for all proximity operations and for altitude determination on lander descents and ascents.

2.2.2.2 Permanent Lunar Base Navigation Systems

Because of the tracking capability of TDRSS, the communication system which was proposed above, which included four satellites in 1000 km orbit and and two satellites at the L4 and L5 librations points, could also be used for navigation. This configuration along with the Moon base support system enables all the landers to be tracked.

2.2.3 System Advantages

Communication System Satellite :

The costs and complication of TDRSS could be reduced because of the fact that the vehicles on and around the Moon may not require so many communication subsystems. Another option is to upgrade existing less expensive communication satellites to match current technological communication advancements.

Bootstrap Base Communication :

Rather than using two satellites at L4 and L5, three satellites in 1000 km orbits could be used, or even two satellites and appropriate phasing with Moonport. This allows the user to have communication capabilities only for certain amounts of time depending on their position.

Permanent Base Communication :

By using the six satellite configuration, at no time are any landers, personnel on the surface, or the Moonport users blacked out. This system can be reduced by using satellites that only have communication capabilities and that are only in lunar orbit.

Lander Communication :

From comparing the previous Apollo and STS communication systems, and the information available from Ref. 2.1, the lander communication system which should be used would include:

- highly reliable systems (redundancy)
- low cost systems and support equipment
- higher frequency bands above the K-band
- switched and/or scanned beam antennas,
- forward and return processors,
- inter-satellite relay from 54 to 64 GHz,
- narrower beams for greater gain,
- S-band multiple access equipment for antenna locking in conjunction with a K-band autotracker,
- and finally C-band communications links.

Bootstrap Navigation :

ILS -

The ILS is a good system because it provides the user with a visual fix of his position relative to the ideal glide slope location. It does not, however allow the user to deviate from the glide path without losing the signal. This system would be useful if : the equipment could be reduced in number and size; the effective transmitting area was increased to many directions instead of one; the required area could be reduced; and if the entire system was mobile.

TACAN -

Presently, the TACAN system provides bearing and distance information for navigation and nonprecision approaches for landing. Some modification of the system for spacecraft landing procedures is required. A simple solution would be to use three TACAN systems, for triangulation, adjusted to one inertial frame. Thus, if the area around the bootstrap base is on the reference plane, a lander can be maneuvered to an "exact" position. Also, the TACAN system is small enough, as compared to ILS, that it could be mobile.

Another option would be to use a single TACAN system with a beacon for close proximity navigation, or some other TACAN-beacon combination.

Laser Ranging -

Laser ranging can be used for both altitude and on orbit applications which makes this system very versatile. With technology advancements, the laser ranger could eventually be used to automatically control proximity operations for docking procedures. On the surface, it could be used to land ,with extreme accuracy, sensitive payloads such as nuclear power plants.

Permanent Base Navigation :

The proposed system includes six TDRSS satellites and base support systems. A reduction in the number of satellites may limit the tracking capability of the system. This system is designed from current TDRSS tracking specifications, therefore the technology base and proving ground have already been established. Since this system simply expands one of the proposed bootstrap base configurations, it is considered to be desirable for usage. Another attribute of this system is its ability to double as a communication system.

2.2.4 System Disadvantages

Communication System Satellite :

The cost of the TDRSS system is the principle concern with deploying it. For Earth applications the total system cost of TDRSS, in 1987 dollars, which takes into account all development, deployment and support costs, is 800 million dollars over a period of ten years. Each TDRSS unit has a cost of approximately 80 million 1987 dollars. Another possible problem with this satellite lies in its complicated systems; this drives repair time up which may in turn raise EVA time as well as retrieval costs.

Bootstrap Base Communication :

The major problem with putting two satellites into the L4 and L5 positions is the energy required for placement from the Earth or even Moonport. From Moonport CW targeting schemes would have to be calculated and checked against the orbital transfer vehicle's specifications. For this configuration, and the three satellite constellation as well as the two satellite constellation with Moonport phasing configurations, the principle problem lies in that there is no redundancy and therefore the system is susceptible to single point failures.

Permanent Base Communication :

Again, the energy cost mentioned above is a major problem. Also, the overall price and technology for installing a communication system of this magnitude (which must include all the components in Figure 2.5) requires further research and study.

Lander Communication :

The items that are of principle concern include the switched and/or scanned beam antennas, and the S-band multiple access equipment for antenna locking in conjunction with a K-band autotracker. The technology to be able to develop these systems is a projected space technology by Ref. 2.7 for bootstrap lunar base applications.

Boot Strap Navigation :

ILS -

From the information listed above, it is apparent that the ILS is a support equipment laden system. For the bootstrap base this presents a problem in that as little equipment as possible would be preferred. Another problem which is apparent is the fact that the ILS requires a large area to operate correctly as shown on Figure 2.9 .

TACAN -

The principle restriction with the TACAN system is that it can provide bearing and distance information only to line of sight objects. Also, at low altitudes, the distance at which a station can be received is reduced. At great distances, the slant range is regarded as horizontal distance, thus, no altitude information is available.

Laser Ranging -

As mentioned above, studies are currently being conducted on laser ranging systems. The principle problem with using lasers is in their power requirements. Currently, lasers require substantial energy sources which, for our applications, would hamper the payload capacity of the landers. Another problem which could occur is in stabilization of the laser system for accurate assessment of the distance.

Permanent Base Navigation :

This phase of the base would use systems that would have been operating since boot strap deployment therefore problems could occur in using outdated systems. Also, to replace this system may be more expensive than choosing a reduced capability system. Finally, since both communication and navigation systems are on the same satellite, failure by any satellite could break down this systems effectiveness.

2.3 Lunar Landing Fleet Vehicle Support

The Fleet Support Division is in charge of providing servicing and maintenance for all fleet vehicles and for docking and undocking vehicles with Moonport. The three main vehicles that will be used by the Fleet Operations Division are OMV's, MMU's, and PAM's. The following sections will explain the purpose of each vehicle and the reason why each one is critical to deploying the Bootstrap Lunar Base.

2.3.1 Orbital Maneuvering Vehicle

The Orbital Maneuvering Vehicle (OMV) is an unmanned space vehicle that acts as a space ferry for transferring cargo to different points in the same orbit. It will be particularly useful in transferring spacecraft to and from Moonport. By doing this, the spacecraft being transferred will be able to conserve fuel that would have been used for docking with or leaving Moonport. The OMV will serve two general purposes in deploying the Bootstrap Lunar Base; the first will be to transfer the landers from Moonport hangars to a point away from Moonport in the same orbit. The main reason for this is to protect Moonport facilities and personnel from the deorbit rocket thrust of the landers. The OMV will also be used to bring spacecraft containing astronauts returning from the moon back to Moonport. The second purpose of the OMV is to take Payload Assist Modules (PAM's) a safe distance away from Moonport where they can also fire their engines. OMV's use hydrazine or NTO/MMH as their propellant and have two mechanical arms to aid in docking with the landers.

2.3.2 Manned Maneuvering Unit

Manned Maneuvering Units (MMU) are one-man self contained jet packs that snap on to the astronaut's life support system. The MMU is particularly useful because it allows the astronaut to maneuver without the hindrance of an attached tether during EVA's. MMU's will be extremely beneficial by allowing the astronaut to do repair work outside of Moonport.

They will also be used for astronauts to conduct periodic inspections of Moonport facilities for any pressure leaks due to small meteorites. The MMU uses high pressure nitrogen (GN_2) for propellant and is propelled via 24 thrusters that are located in groups of three at the eight corners of the unit (See Ref.2.9). Figure 2.13 is a general schematic of the MMU. The vehicle is hand controlled; the left hand controls translational motion, while the right hand controls rotational motion. The MMU weighs 204.12 kg and has a maximum EVA time of eight hours. This time is due strictly to the period the battery will stay charged. Space Shuttle EVA experience with the MMU has shown that the MMU will run out of fuel much sooner than the maximum EVA time allotted for the battery to stay charged. Figure 2.14 shows the space station MMU's option of either being manned or controlled by a robot. The robot will be controlled by an astronaut via voice link and will be able to assist the astronaut in performing tasks by getting tools for the astronaut and holding a light or TV camera to aid the astronaut while he works.

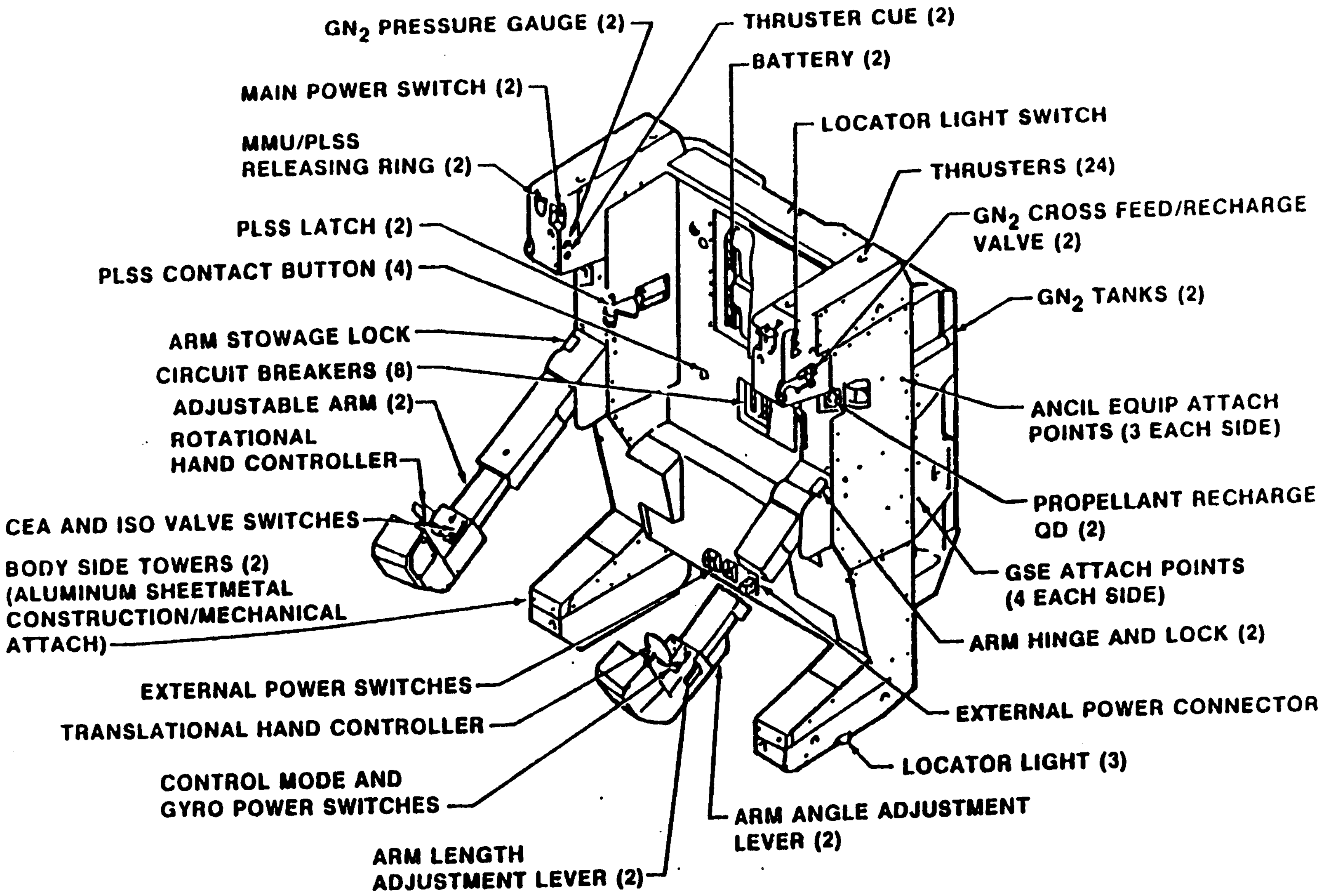


Figure 2.13. MMU Features

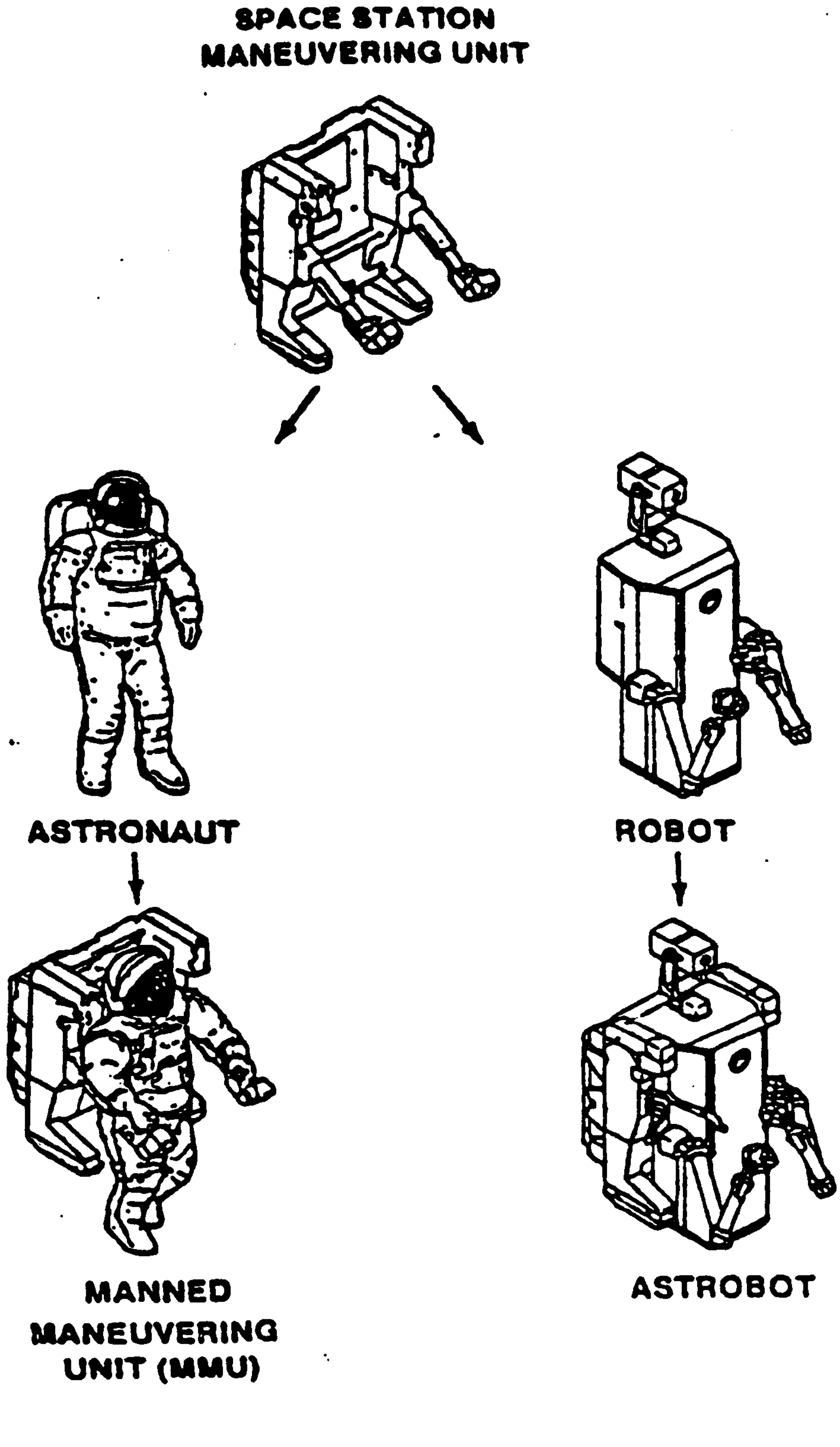


Figure 2.14. Space Station MMU Options

2.3.3 Payload Assist Module

LOCO will use Payload Assist Modules (PAM) to boost the communication and navigation satellites into higher orbits. The satellites will be stored in Moonport hangars attached to the PAM's. Moonport's mobile remote manipulator system (MRMS) (See Ref. 2.10) will be used to remove the satellites from the hangars and attach them to OMV's. The OMV will then transfer the satellite and PAM to a different point in the same orbit at a safe distance from Moonport where the PAM can fire its rocket engine to climb to a higher orbit. Since PAM's are nonretrievable, they will stay in their higher orbits after separating from their payloads. Figure 2.15 shows the initial and final orbit of the satellites along with the Hohmann Transfer orbit and the calculated delta v's. The initial orbit is Moonport's orbit at a distance of 1838 km from the moon's surface and the final orbit is 1000 km higher. Figure 2.16 shows the two PAM's (see Ref. 2.11) used to perform the required task. Star 15 was used for the perigee burn to give a delta v of 0.153 km/sec, while Star 6B was used for the apogee burn to give a delta v of 0.138 km/sec. Table 2.1 is a listing of the vehicle specifications. Although OTV's were originally to be used for deploying the satellites, LOCO decided to use PAM's instead because they are cheaper and weigh less than OTV's while being able to perform the same task. The advantage of the OTV is that it has the capability of retrieving the satellite for repairs if the satellite gets damaged or malfunctions.

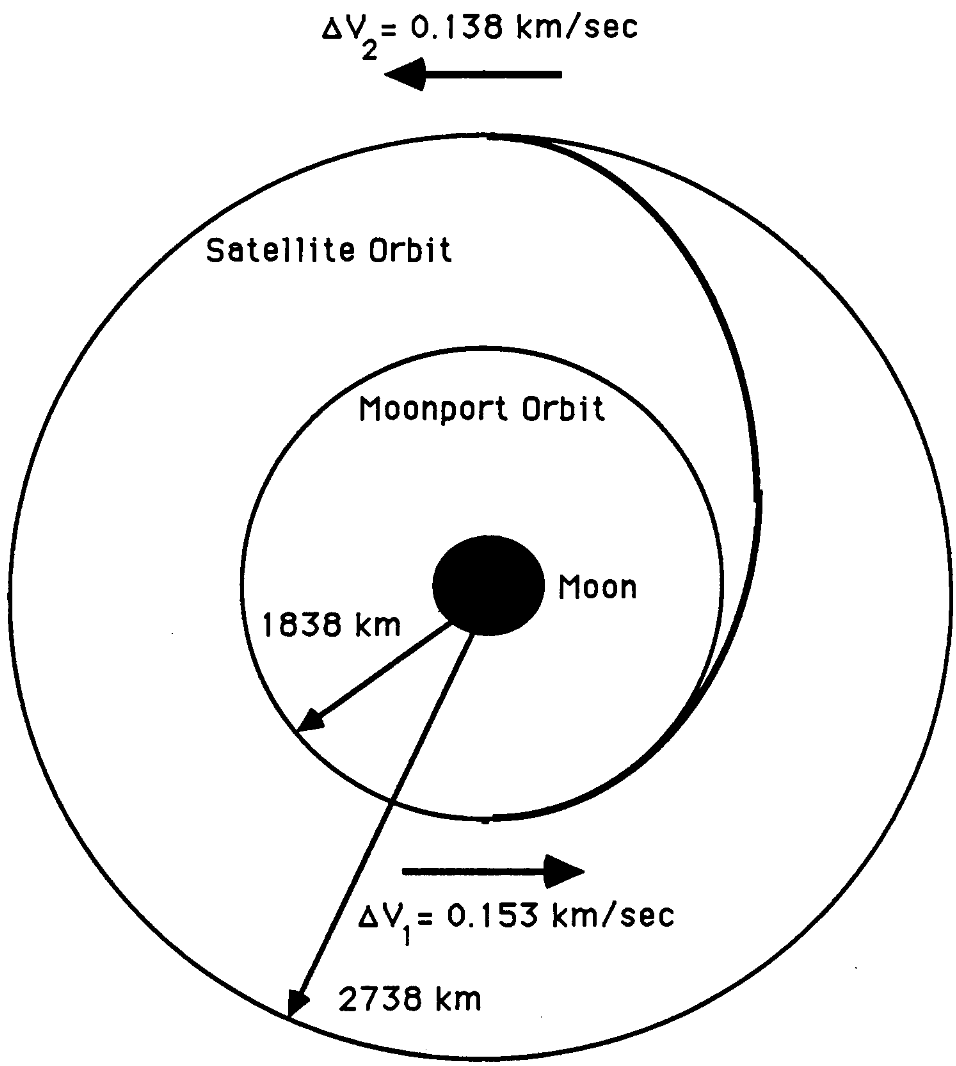
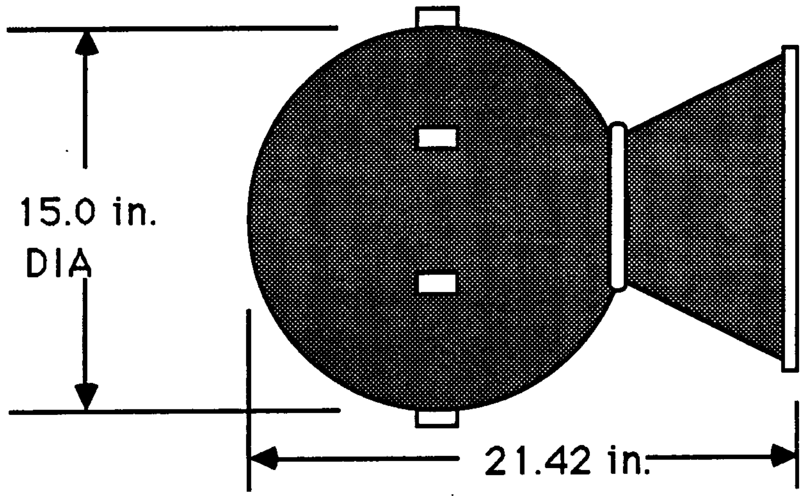
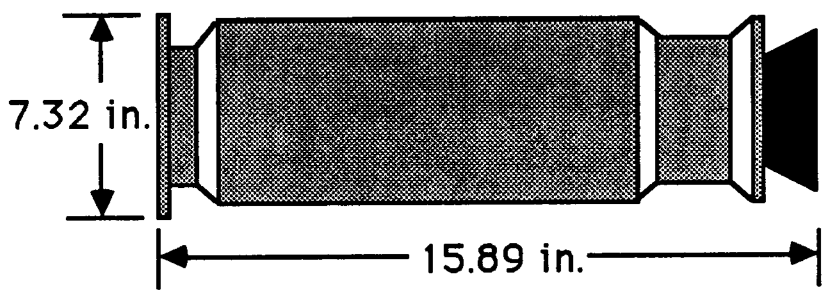


Fig. 2.15 Delta v's



STAR 15



STAR 6B

Figure 2.16 Payload Assist Modules

Table 2.2 PAM Specifications

Vehicle	Star 6B	Star 15
Weight (lbm)	22.62	107.5
Isp (sec)	273.0	228.0
Propellant (lbm)	13.5	9.5
Maximum (lbf)	634.0	5,450.0

2.4 Fleet Operations References

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3.0 Lander Design

Lander Divisions I and II were tasked with designing a fleet of transformable Lunar Landers to support a Bootstrap Lunar Base. To this end, conceptual designs were developed which stress reusability, modularity, and maximum utility of every payload. Initial ideas have been combined and refined and a set of mass, thrust, and dimensional specifications have been developed. The developed designs include a dedicated Power Plant Lander , a Habitation Lander, Crane Lander, a Two Stage Personnel Transport, and a Generic Truss Element Lander. Additional conceptual designs which require further study are located in Appendix A. Following the lander descriptions is a brief discussion of the preliminary Δ V studies which produced the lander specifications, as well as a tabular presentation of this data.

A third lander division was comprised of members of the Mechanical Engineering Department's design class. This group designed a lunar lander which transforms into a portal and elevator system for an underground lunar base. Results of their design effort can be found in Reference 3.4.

3.1 Power Plant Reactor Lander

The power needs of the lunar base were determined to be in the range of 5 to 8 MWe . Only two such power systems came close to meeting the requirements. One system uses a gas cooled reactor developed by the University of Washington [Ref. 3.1], and the other uses a liquid metal cooled reactor developed by Texas A&M University [Ref. 3.2]. A decision matrix was formed (Table 3.1) to help determine which reactor and power system would best serve the needs of the base, and it was decided that the gas cooled reactor should be used for the lunar base.

Table 3.1 - Decision Matrix

REQUIREMENTS	GASED COOLED	LIQUID METAL COOLED
POWER OUTPUT	2	1
EFFICIENCY	1	2
CRITCALITY LEVELS	1	2
RADIATION OUTPUT	1	2
NEUTRON PROTECTION REQUIRED	1	2
RADIATION TO GENERATORS	2	1
LUNAR ENVIROMENT ADAPTIBILTY	1	2
MASS OF REACTOR AND COOLANT	1	2
TOTAL	10	14

LOWEST NUMBER IS BEST

The gas cooled reactor is a 10 MWe input 4 MWe output fuel pin reactor using 90% rich U as the fuel which has a life expectancy of 10 years. Helium gas will be used as a coolant for the reactor and as the medium to generate power from the turbines and assembly. The turbines and assembly will be landed separately from the reactor in order to provide a relatively radiation free environment for repairs to the turbines and assembly. The power system needs to be a two loop system in order to prevent the radioactive gas cooling the reactor, from contaminating the turbines and assembly (generator). This will mean a loss in efficiency and the actual power output will fall below 4 MWe. A side view of the reactor lander is shown in Fig. 3.1. and a top view is shown in Fig. 3.2.

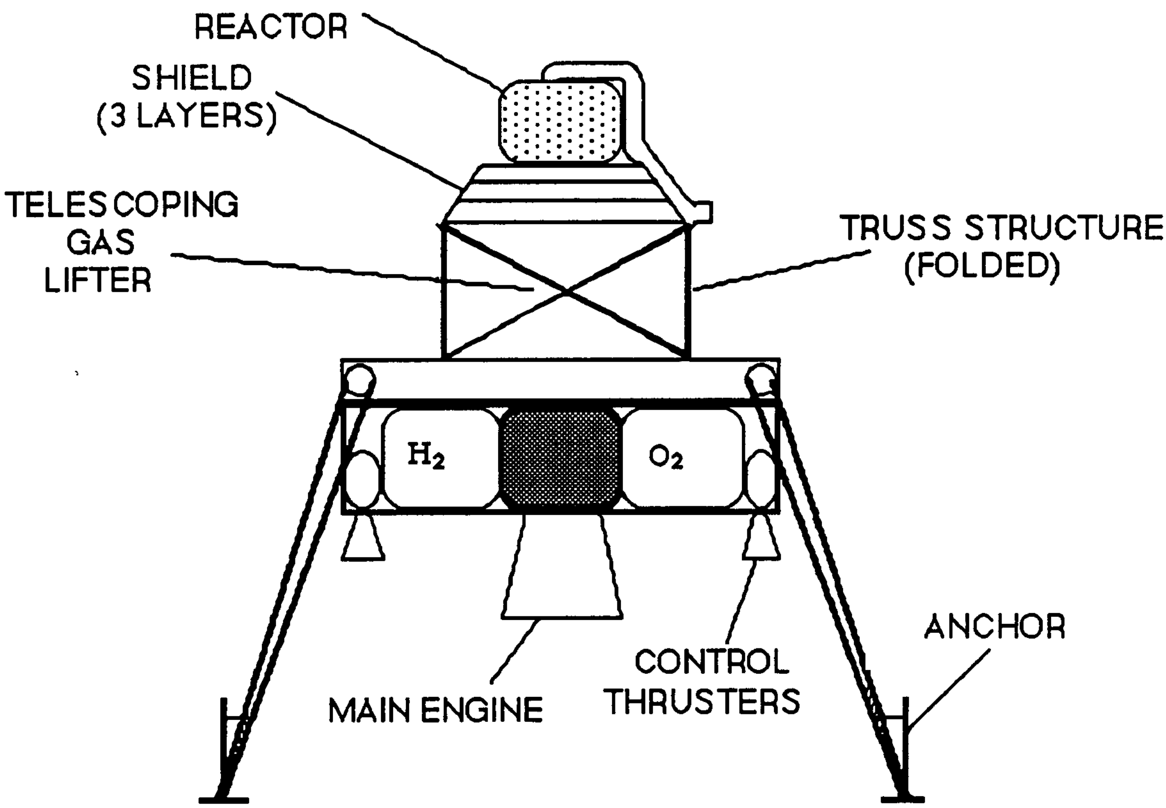


Fig. 3.1 Power Plant View 1

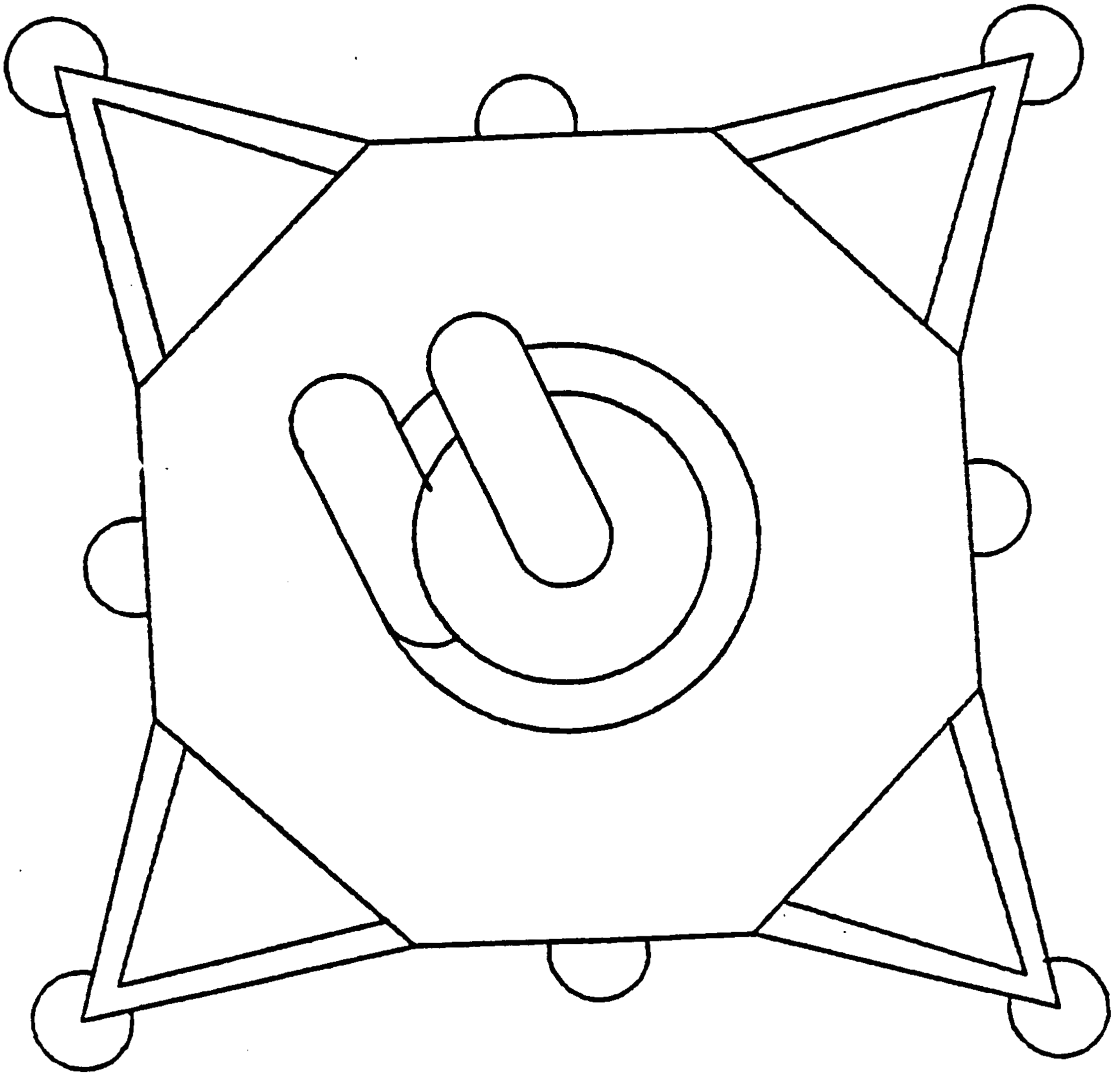


Figure 3.2 Power Plant View #3

The reactor is to be landed inside of a crater while the generator assembly, pumps, and heat transfer unit between the primary and secondary loops are placed outside of the crater in order to use the crater wall as additional shielding. The distance between the reactor and the generator should be 200 m. The pipes carrying the helium in each loop should be able to handle a pressure of 750 psia. This configuration is illustrated in Fig. 3.3.

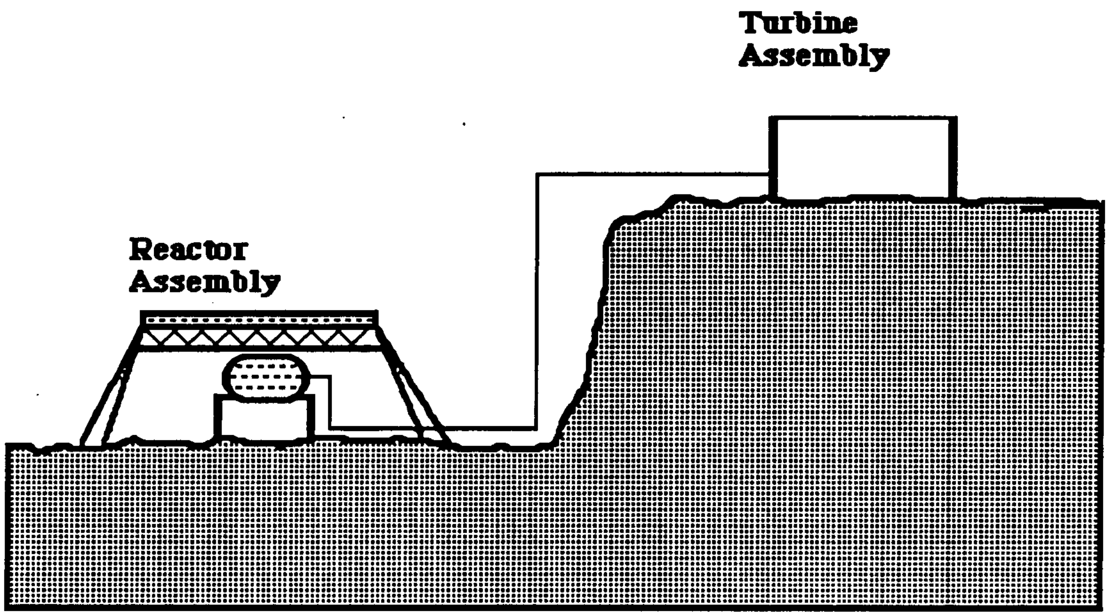


Figure 3.3 Reactor and Turbine Configuration

Upon landing, the reactor will be lowered to the surface or below the surface, as suggested by the Texas A&M study, using a hoisting mechanism incorporated into the lander. This scenario differs with the concept of the University of Washington study that the reactor must be raised at least 15.5 m above the lunar surface to handle the neutron backscattering. By keeping the reactor on the ground, less structural mass must be used for supporting the reactor, which translates into a lighter, less complex lander. Increased safety and reliability is added by eliminating the potential threat of having the reactor fall and cause a critical reaction. In this configuration, a dynamic controller will be employed to compensate for nuetron backscattering due to the lunar regolith.

The lander is to carry the reactor, shield, and short starting pipes for connecting the primary loop. The dry mass of the entire lander plus engines is estimated to be 52,000 kg. The lander has 1 main engine which is gimbaled and 4 control thruster engines, also gimbaled, and each having an estimated thrust of 30% of the main engine. This is a safety measure so that, if the main engine fails, the other engines can still produce enough thrust to carry out the mission. The engines are all to be placed in an engine block along with all the fuel. This is to allow an easier engine disassembly after landing. The nozzle of the main engine should have a dust clearance of 3 m. The landing gear should be designed to insure this and it should not be attached to the engine block, but above it, and connected to the main platform of the lander. The landing gear should also be retractable in order to make room for storage on Moonport. The landing gear should also have some sort of drill anchoring device in order to keep the reactor secure and prevent tipping.

3.2 Crane Lander

Also proposed is a Crane Lander which will remove the payloads from other landers and, later, aid in construction of the permanent Lunar Base. The crane will have compact legs which fold for storage and transportation. It will arrive at the lunar surface, at which time its engines and RCS clusters will be removed . Depending on the range of maneuverability of the crane arm, it may or may not carry a payload in addition to its own control-module payload. As indicated by Fig. 3.4, once on the surface, its legs will unfold and deploy to provide the necessary lifting leverage. Modes of transportation might include ordinary wheels or flexible walking legs. It is estimated that this lander will be required to lift an average payload of approximately 18,000 kg. (Fig. 3.5) The Crane Lander allows for simplification of all other Lander designs since they no longer need to consider payload deployment.

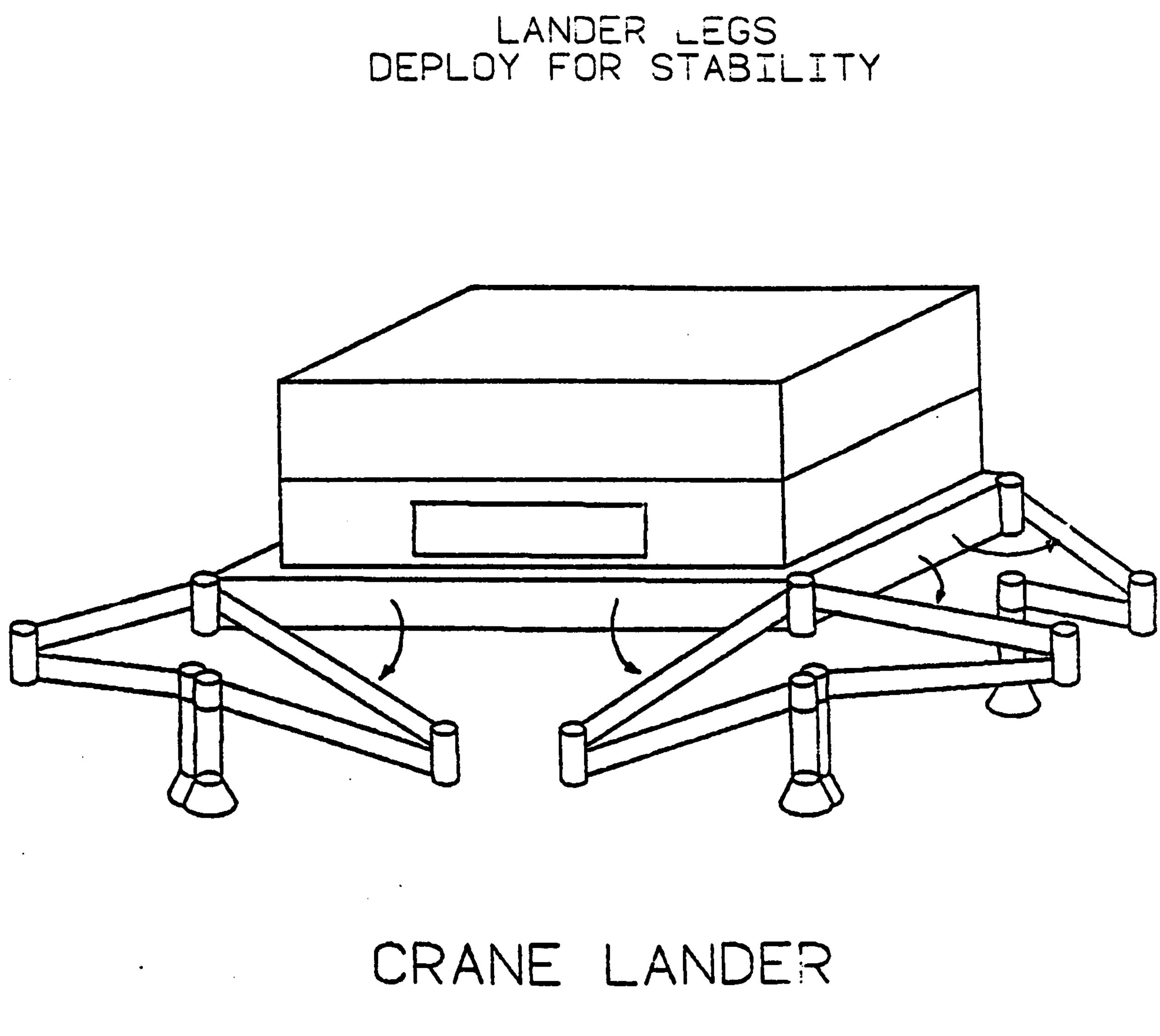


Figure 3.4. Transforming Crane Lander

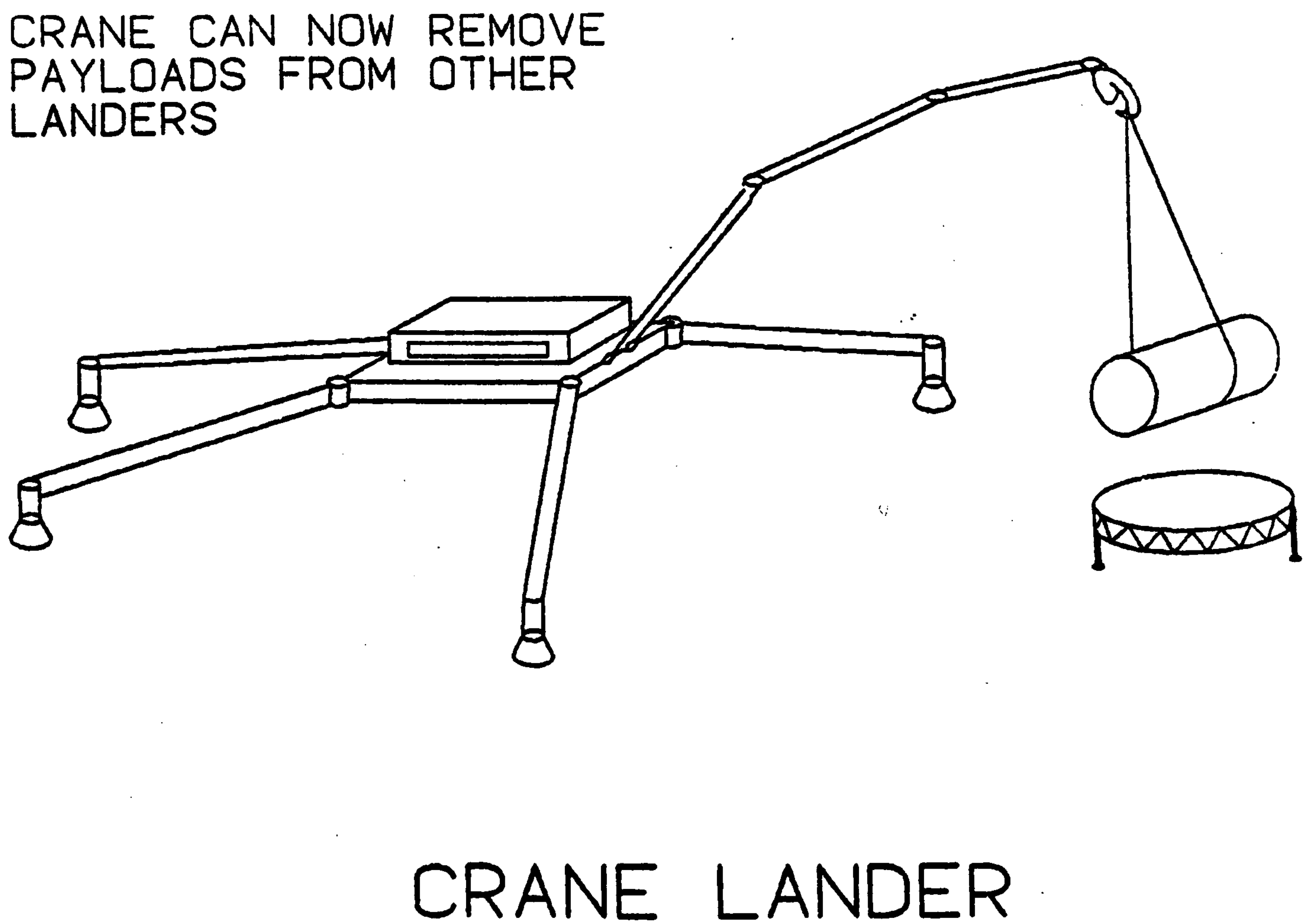


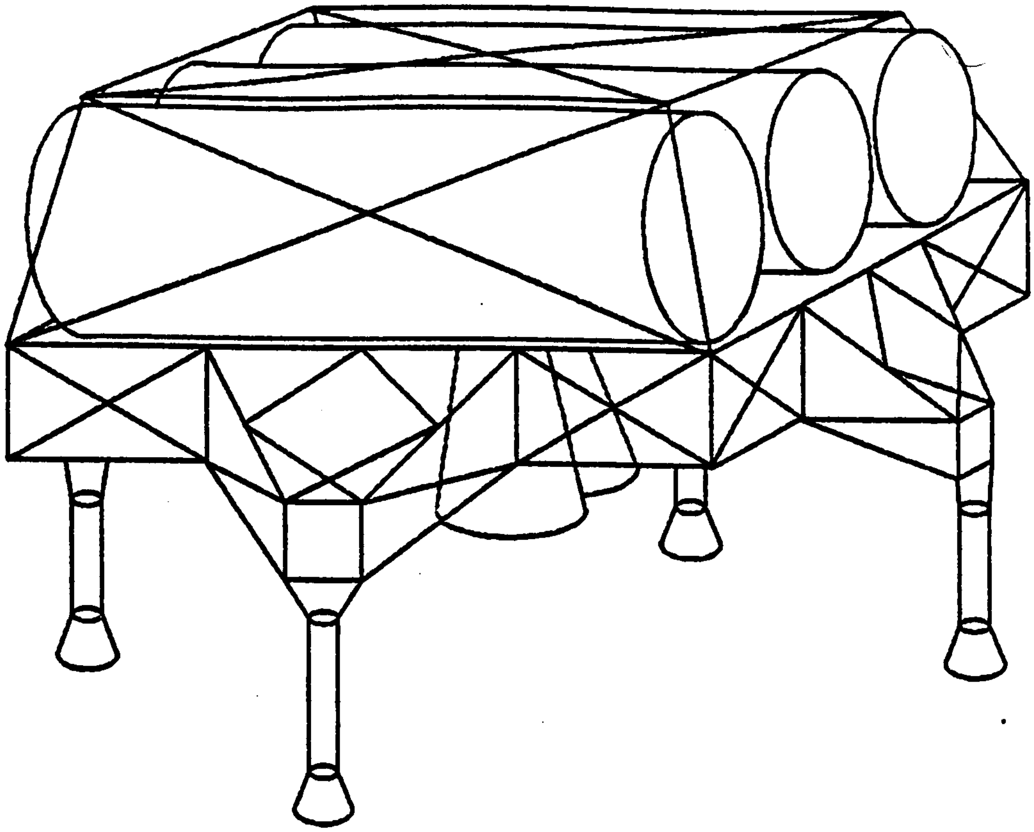
Figure 3.5. Transformed Crane Lander

3.3 Generic Truss Element Lander (G.T.E.L.) or 'Tinker Toy' Lander

A generic truss element lander is being considered. It will function as an all-purpose payload transporter which can be easily scaled according to the desired payload. As suggested by its name, this lander will consist of basic load-bearing truss elements connected by interlocking universal-type joints. The lander will be transformable by a disassembly process, and the truss elements will be used for necessary base components such as wall supports, machinery parts, or furniture. Because of this feature, the G.T.E.L. is also being referred to as a 'Tinker Toy' Lander. This design has the advantage of being extremely versatile and easy to reconfigure. The truss element lander could be used as an alternative to the Habitation Lander (discussed later), or for the placement of additional habitation modules. It is also anticipated that a Tinker Toy Lander will be used for deployment of the power plant turbines and compressors.

3.3.1 G.T.E.L.: Habitation Modules

As a transport for the Space Station Common Modules, the generic truss element lander would be scaled approximately to the dimensions indicated in Table 3.3. It would arrive on the lunar surface as shown in Fig. 3.6. The habitation modules would then be removed by the Crane Lander and the lander components would be scavenged and reconfigured as module and regolith supports as indicated in Fig. 3.7.



HABITATION MODULES ON 'TINKER TOY' LANDER: INITIAL CONFIGURATION

Figure 3.6. Landing Tinker Toy Lander #1

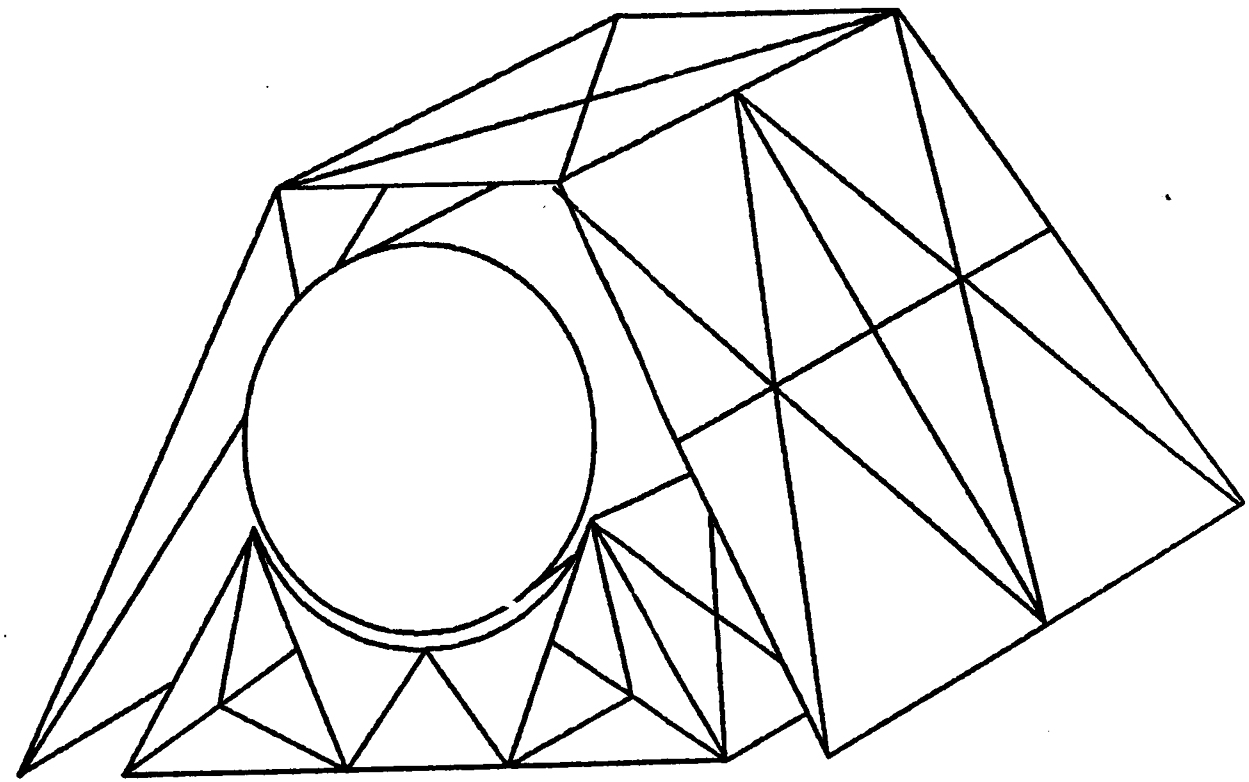


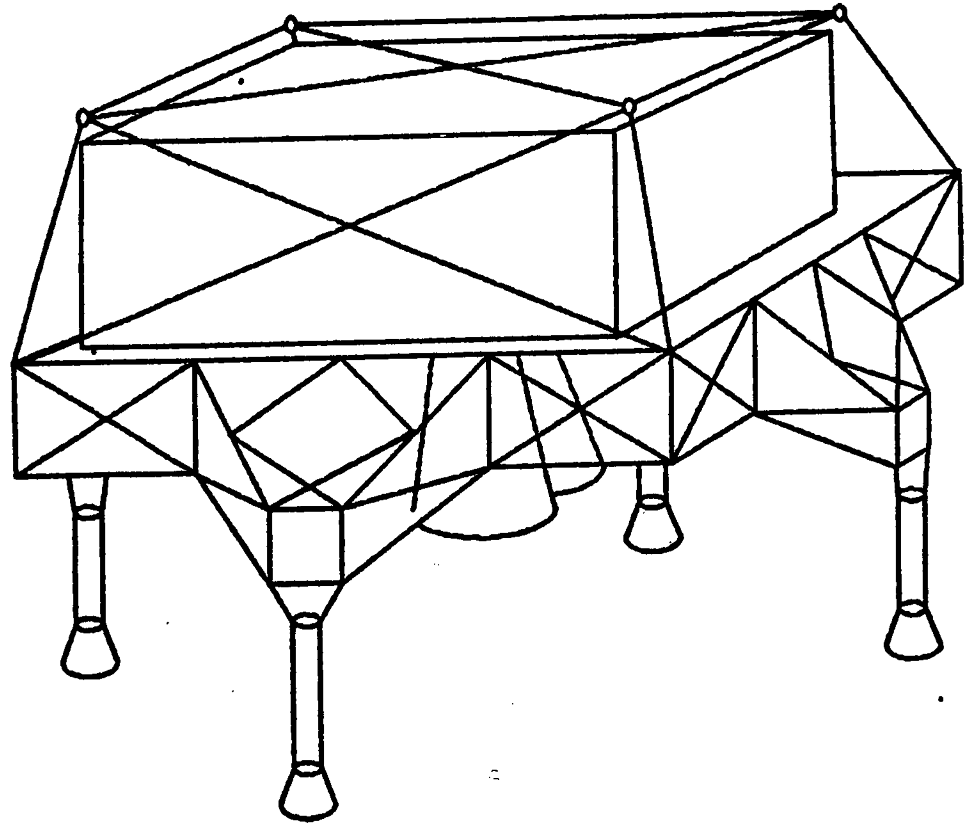
Figure 3.7. Transformed Tinker Toy Lander #1

3.3.2 G.T.E.L.: Power Plant Compressors/ Turbines

As mentioned in the discussion of the power plant design, it has been decided that the compressors and turbines should be landed away from the reactor core to provide for ease of maintenance and to lessen the chances of radioactive contamination to astronaut workers repairing the equipment. These power plant components would be brought down on a scaled Tinker Toy Lander as shown in Fig. 3.8 with the specifications indicated in Table 3.3. Once on the lunar surface, the engines and RCS clusters would be removed through either an automated, or if this proves to be unnecessarily difficult, a manned process. Next, mesh regolith supports would unfold and enclose the lander (Fig. 3.9). These supports would then be covered with the 2 to 4 meters of regolith required to provide radiation protection. As indicated by the open section view of Fig. 3.10, this would provide a low-radiation work area under the lander.

TABLE 3.3:
Lander Specifications

LANDER	DIMEN-SIONS (m)	VOLUME (m^3)	MASS W/O PROP (kg)	TOTAL MASS (kg)	THRUST REQ'D (N)
Power Plant (Telsc.)	11.7 x 8 x 8	750	52,500	98,175	158,209
Habi-tation Lander	13 x 13 x 5	845	66,780	124,879	201,242
Crane Lander	lgs: 15 core: 3 x 3 x 5	45	15,000	28,050	45,203
Person-nel Trnspt	3.5 x 3.5 x 3.5	43	2100	3,927	6,328
G.T.E.L. Hab. Modules	13 x 14 x 5	910	23,400	43,758	70,516
G.T.E.L. Comp/ Turb.	5 x 5 x 5	125	182,000	340,340	548,457



POWER PLANT TURBINES AND COMPRESSORS
ON 'TINKER TOY' LANDER:
INITIAL CONFIGURAION

Figure 3.8. Landing Tinker Toy Lander #2

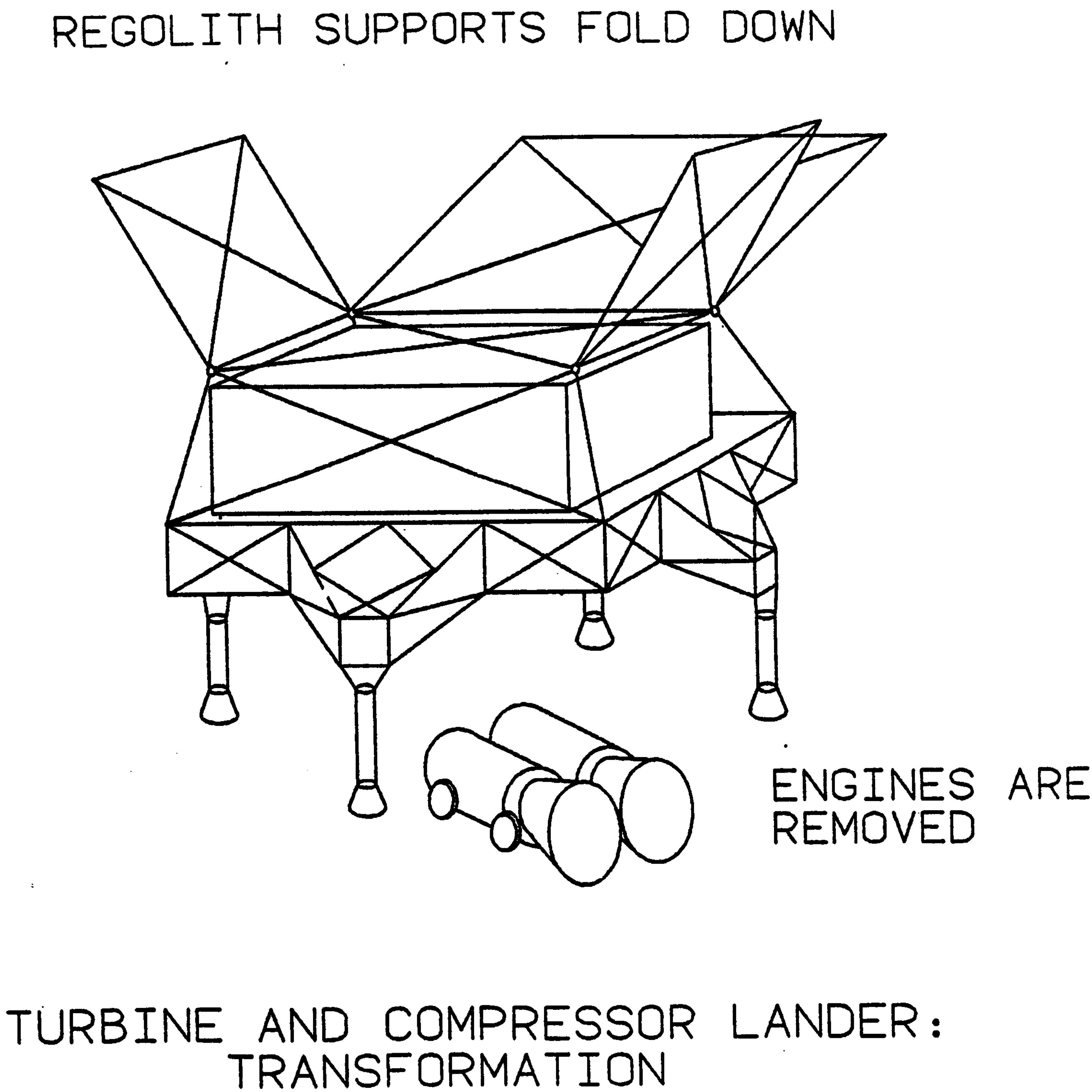


Figure 3.9. Transforming Tinker Toy Lander #2

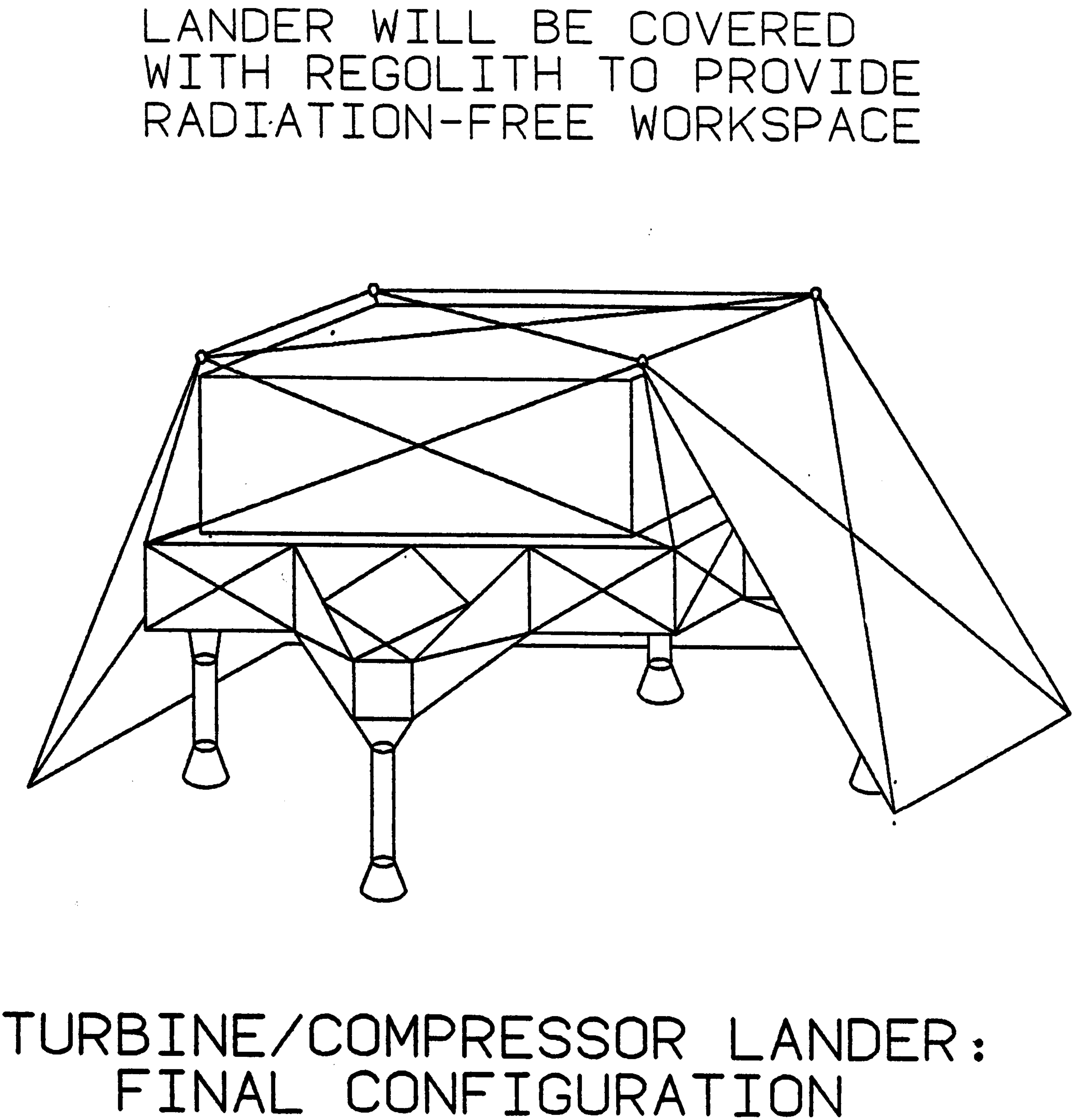


Figure 3.10. Transformed Tinker Toy Lander #2

3.4 Habitation Lander

The primary purpose of the habitation lander is to transport the habitation modules to the lunar surface during Phase I of the Lunar Base development. The lander will carry the first four habitation modules and the two interconnection modules that are needed to provide quarters for the astronauts. Since all four modules will be brought down at one time, a high reliability and confidence of all systems is required.

During Phase 1, the lander will land as shown in Figs. 3.11,3.12, 3.13, and 3.14, and using an anchoring and leveling system which is housed in the landing gear it will provide the needed support base for the modules. The astronauts will operate out of the modules in the landing configuration, and a flexible and pressurizable tubing will be used to connect the upper two modules to each other and to the lower modules. The two interconnecting modules will be lowered to the lunar surface by the crane lander and will be stacked on each other to provide access to and from the lunar surface.

When the base advances to Phase 2, the habitation modules will be lowered into a trench in the lunar surface. This will be done using a crane and winch system that is part of the lander. The top of the module will be buried two to four meters beneath the surface. Since the regolith may not provide an adequate foundation, the lander will continue to support the modules.

First, the lower two habitation modules will be lowered into the trench using the winch system. The cables used to lower the modules will then become supporting cables which will keep the modules level. After this is preformed, the two interconnection modules will be positioned using the crane, and then, their support cables will be connected

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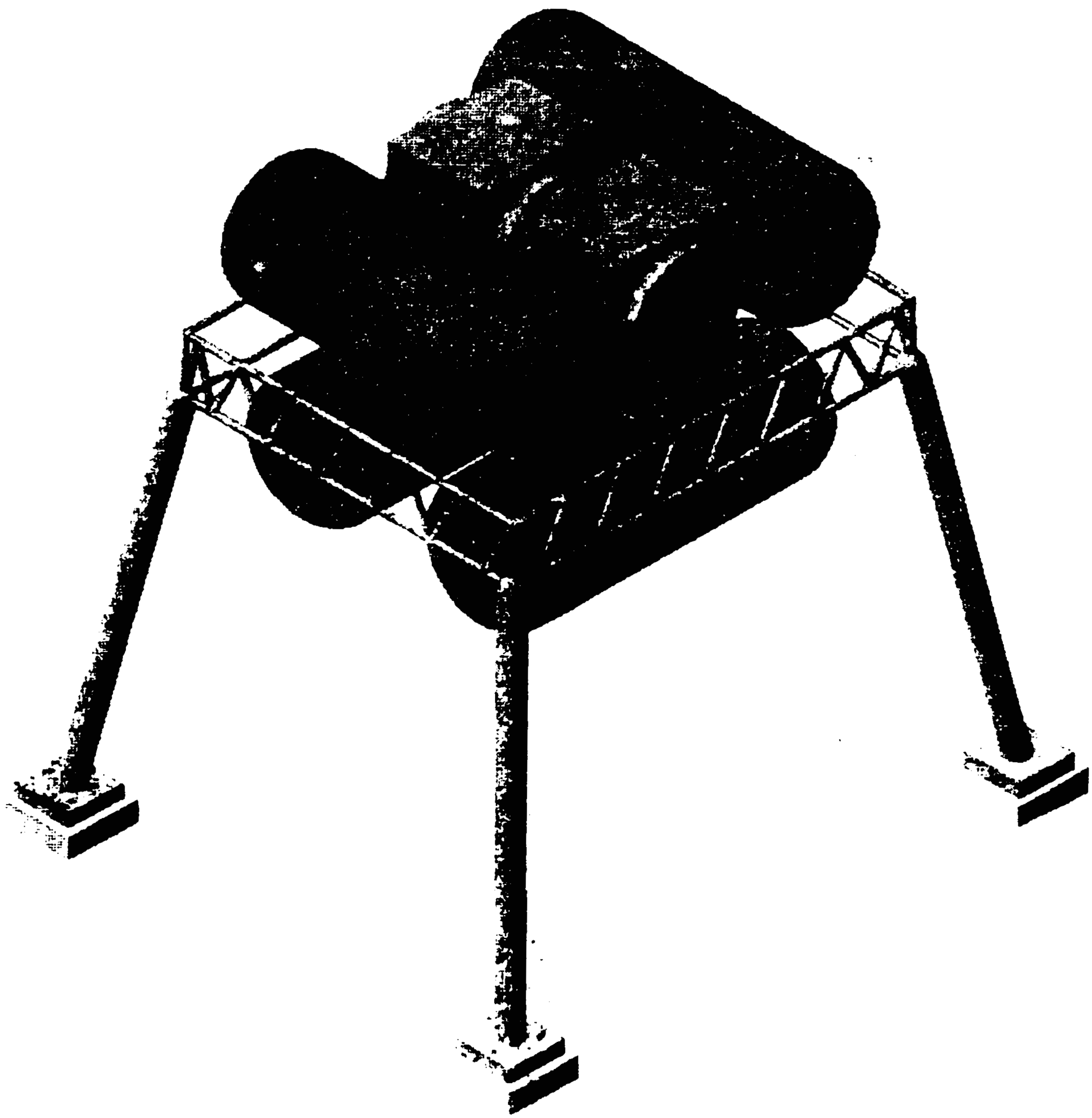

Figure 3.11. Habitation Lander View #1

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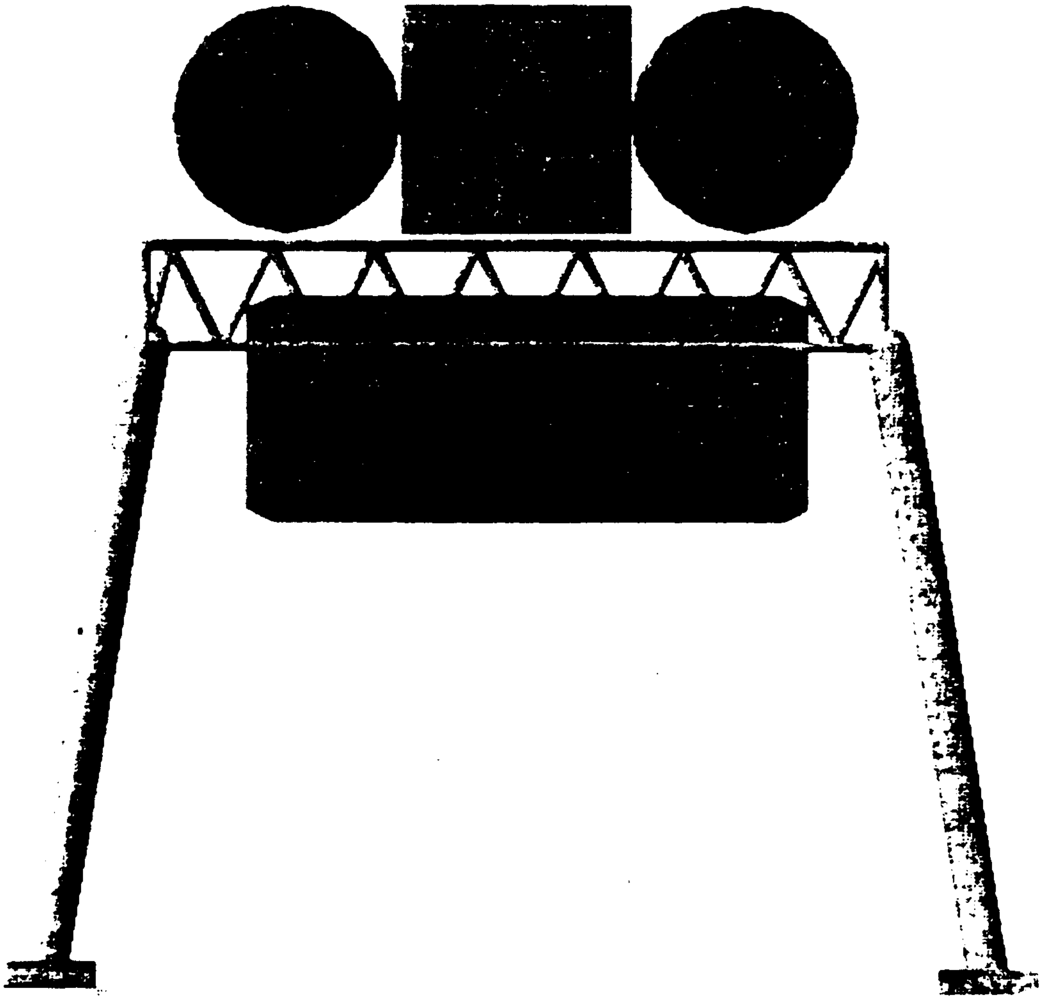

Figure 3.12. Habitation Lander View #2

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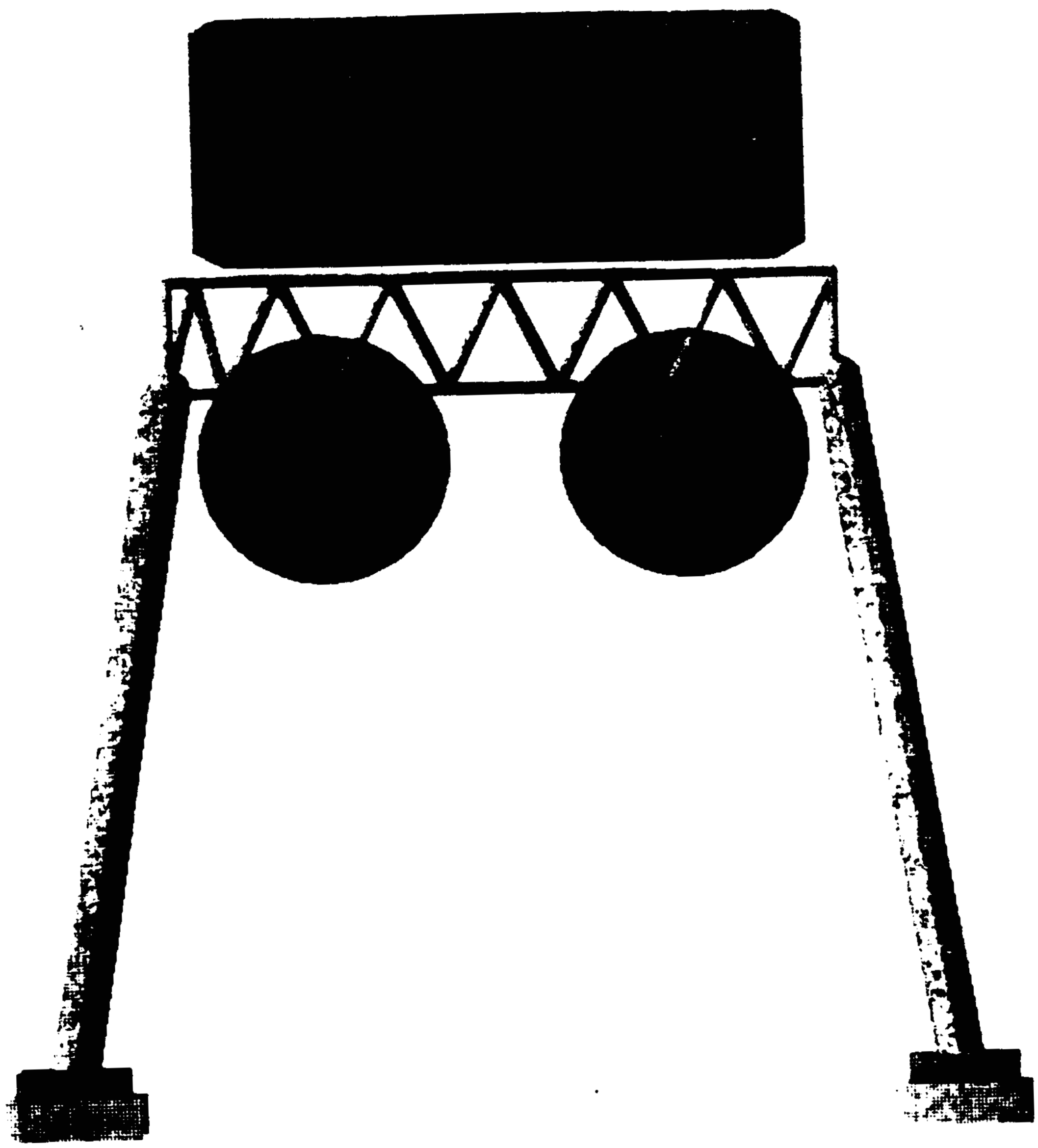

Figure 3.13. Habitation Lander View #3

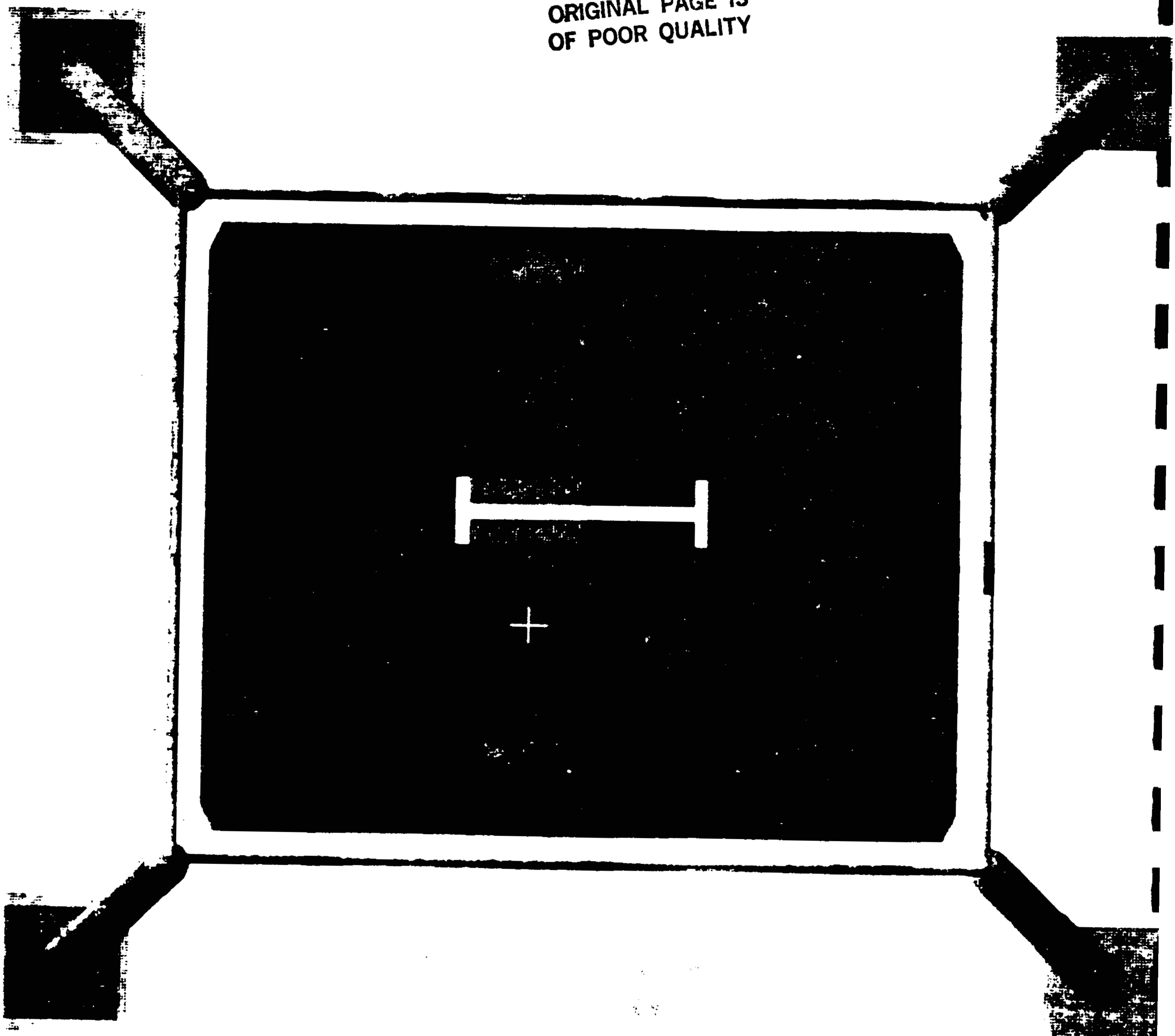

Figure 3.14. Habitation Lander View #4

onto the lander. The final stage of deployment involves lowering the upper two modules. First, the crane slightly lifts a module off of the truss structure, and then, it swings the module over the side and into place. The same procedure is followed for the final module.

The leveling system on the lander provides sensors on all of the modules as well. These sensors will provide the necessary information to the crane and winch system to make any adjustments needed to maintain the modules in a level position at all times.

After the Phase 2 habitation module deployment, the lander will support a pressurized shirt sleeves 'garage'. It uses a combination of aluminum and regolith to provide the needed radiation protection. Two options exist for the deployment of the 'garage': a bellows concept and a box concept. The bellows are folded against the bottom of the lander and made of a composite; rigid slats connected by a Kevlar fabric. The BOX technique deploys the four walls which are then welded to provide an airtight seal. A cargo bay door is incorporated into one of the walls allowing for large equipment.

3.5 Two-Stage Personnel Transport

The purpose of the personnel transport is to quickly and efficiently transport base inhabitants to and from Moonport. This lander, which is based on existing technology, is designed to act as a man-rated ascent/descent vehicle and as an emergency escape vehicle for both bases.

In order to serve as a man-rated transport, the lander must be designed for a high degree of reliability. In addition, the descent stage will be reused during the later phases of the lunar base and so must maintain this reliability through many starts and stops.

The configuration of the transport is governed by the need for an efficient yet adaptable craft. Fig. 3.15, an initial design, indicates how the following requirements may be met.

- descent stage serves as base for the ascent stage
- minimum fuel required for ascent because descent stage is left behind
- crew pod can be linked directly to habitation module with movable airlock
- descent stages can be linked together and returned to orbit on a cargo vehicle
- descent stages can be used for a variety of cargo payloads
- computer controlled so that it may be flown manned or unmanned

Initially, the lander was designed to provide transportation for a pilot and three personnel. To accomplish this, the total lander volume would be approximately 35 m^3 with a total mass of 2750 kg. This would provide a payload capacity of 400 kg.

Propulsion for the craft would be a throttleable, gimbaled rocket motor using the NTO/50% UDMH fuel. Control would be provided by RCS clusters in conjunction with the gimbaled rocket motor. The descent stage would have collapsable or removable legs and a universal latching mechanism so that it can be linked with other stages and returned to Moonport as a cargo payload.

The main disadvantage of the two stage transport is that the number of descents is limited until a cargo return capability is achieved at the lunar base. As soon as this is accomplished, the descent stages can be refueled and returned to orbit. Another limitation is that the lander would provide very little UV or meteorite protection. While this would pose relatively little danger for transport between bases, it would be a significant factor in an extended stay.

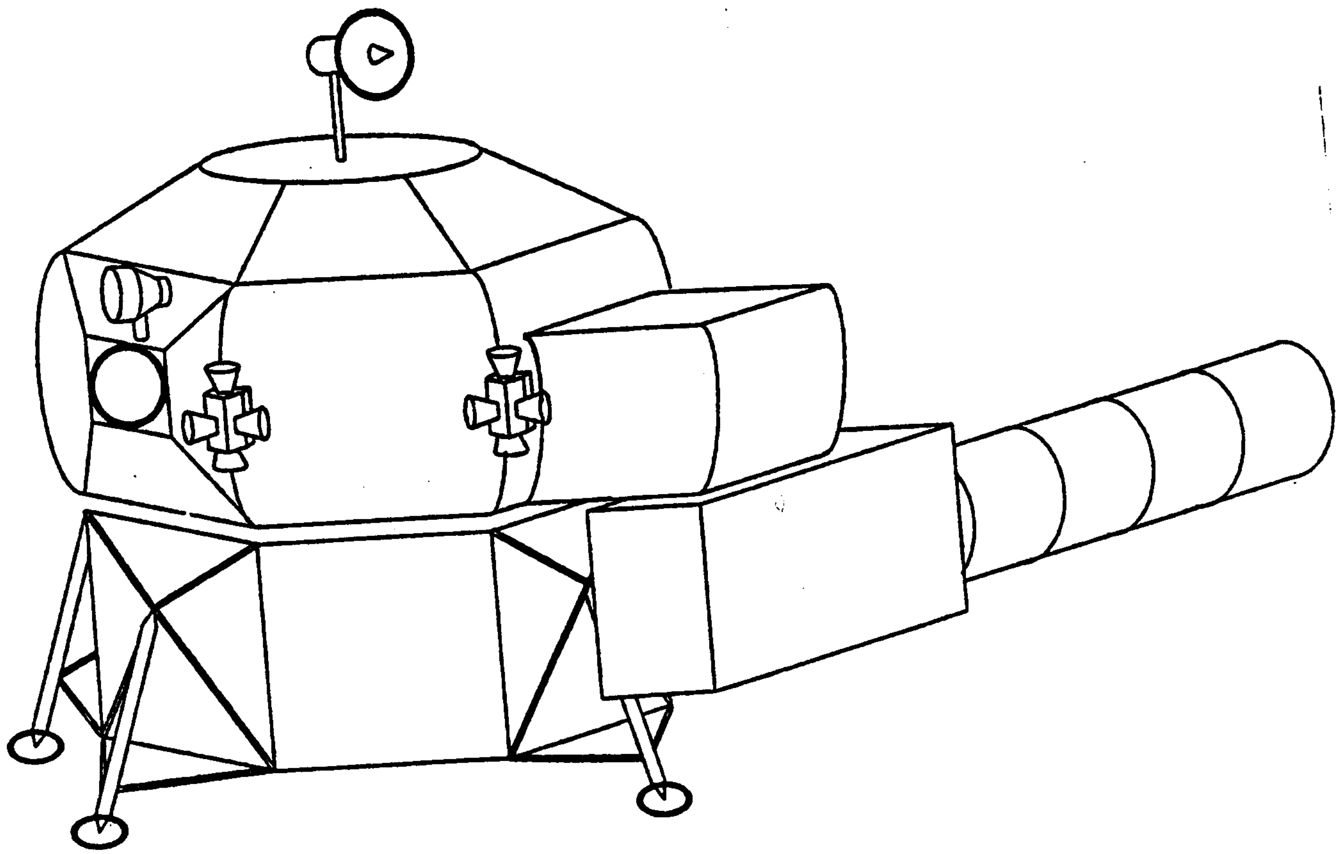

Figure 3.15. Two-Stage Personnel Transport Lander

3.6 Delta V Studies as Related to Lander Specifications

Using the mass of the Habitation Lander as an example, Appendix A shows the preliminary analysis of lander masses and required thrust. These equations show a propellant mass of 19,246.23 kg for LO2/LH2 and 31,015.72 kg for NTO / 50% UDMH. This, of course, indicates that it requires 38% more propellant (by mass) if NTO/50% UDMH is used rather than LO2/LH2. Given the propellant mass and density, a volume can be calculated from:

Volume = Massprop / Densityprop

where : density of NTO / 50% UDMH = 1100 (kg/m3)

density of LO2 / LH2 = 270 (kg/m3)

This volume can then be combined with an estimate of that of the lander to obtain a value for the total lander volume.

The lander thrust to weight ratios were determined using Apollo LEM as a baseline:

Thrust (LEM) = 1,050 - 10,500 lb (with an average value of 5,775 lb)

Weight (LEM on moon) = 5,000 lb

Thrust average / Weight = 2.1

Finally, the thrust and specific impulse can be used to determine the mass flow rate from :

Thrust = Isp * g * m

Specifications for each lander were calculated based on the procedure outlined above and are indicated in Table 3.3 on page 75.

3.7 Lander Integration with Moonport

The Bootstrap Lunar Base scenario under consideration utilizes the proposed Moonport (see Ref. 3.5) to transport all base components, including landers and payloads, to low lunar orbit. Since the landers have an estimated combined volume of 2,900 m^3 and mass of 350,000 kg (considering, for the moment, only one of each type of lander), it seems impractical to anticipate such a large cargo storage bay in Moonport which will function solely as a lander storage area. An alternative method is to attach the landers to the Moonport truss structure as suggested in the Moonport report. (See Fig 3.16) This would reduce the internal storage volume required of Moonport but would also require careful placement of the landers and analysis of the changing inertia properties of Moonport as the landers are removed.

3.8 Lander Evaluation

Table 3.4 shows a qualitative comparison of the landers presented in this report.

TABLE 3.4
Qualitative Evaluation

Lander	Description	Purpose	Advantage	Disadvantage
Power Plant (Telsc.)	Reactor Raised	Protects Reactor	Stability Small Volume	New Technology in Telescoping Pipes
Habi-tation Lander	Truss-like Lander	Deploys Habitation Modules	Deploys Ready-to-Live-in Volumes	High Reliability Required
Crane Lander	Folding lgs Wheels/	To remove payloads other lndrs	Simplifies design of payload itself	Might function better as walking lgs
Person-nel Trnspt	Two-Stage Ascent/Descent Vehicle (manned)	Transportation to/from Moonport	Efficient, Uses Existing Technology	Limited Number of Descents
G.T.E.L. Hab.	Tinker Toy scaled for SSCM	Transport prelim hab. modules	Transforms to support & cover modules	Need crane for hab. module Modules removal
G.T.E.L. Comp/ Turb.	Tinker Toy scaled for power plnt components	Deploy turb/comp & transform into low rad. environment	Simple design; transforms into wkspace	Still some radiation; very high mass

3.9 Lander References

3.1 University of Washington. *Report on Lunar Nuclear Power Plant..* Published by The University of Washington, 1986.

3.2 Texas A+M University. *Report on a Lunar Nuclear Power Plant..* Published by Texas A+M University, 1986.

3.3 Mendell, W. W. (Ed.). *Lunar Bases and Space Activities of the 21st Century.* Houston: Lunar and Planetary Institute, 1985.

3.4 Arriqucci,.F., Nothrop,E. , York, D., Designs of a Lunar Lander Transformable into a Portal for an Underground Lunar Base. Published by The University of Texas at Austin, November 16, 1987.

3.5 Space Port Systems. *Moonport: Transportation Node in Lunar Orbit.* Published by The University of Texas at Austin, May, 1987.

4.0 Surface Operations

The surface operations division will be responsible for decisions related to the construction and development of the lunar base. This includes concerns of placement with respect to the rest of the lunar facilities as well as safety, habitation and mining operations.

4.1 Safety Concerns

Safety is a major concern of the bootstrap lunar base. Cosmic radiation and solar flares are of major concern, as are fire, loss of pressure, power failure, computer failure, and impact from debris. Safety requirements must be determined and emergency procedures must be developed to ensure safety of personnel as well as safety of the base.

4.1.1 Base Safety Requirements

Radiation is the main thrust of the safety discussion for the bootstrap lunar base. Radiation can cause life-threatening cancers, malignancies, and leukemias as well as cataracts, infertility, tumor induction, and the defective development of fetuses. The lunar base is designed to minimize radiation levels, preferably keeping the radiation level below 5.0 rem/year (the maximum allowable dosage for radiation workers) [Ref 4.1].

Moonport will serve as a safe haven until a suitable habitation area is prepared for the lunar base. The safe haven will be stocked with food, water, and emergency equipment. An additional safe haven on the lunar surface will be required until the base is covered with radiation shielding. This radiation shielding must be three to five meters thick to protect personnel from the excessive radiation from solar flares. "Garages" with solar radiation protection will protect workers on the surface as well as give them some freedom of movement. Remote emergency shelters stocked with food, water and emergency equipment will serve as safe havens for personnel working away from the base.

Fire and its associated smoke are life-threatening problems that could easily occur on the Bootstrap Base. Fire extinguishers should be located in each section of the base. Airlocks will serve as fire walls, and module walls should be covered with fire retardant material. Emergency escape tunnels will be installed and readily accessible to each section of the base.

Contamination of the lunar base from several sources is possible. Airlocks will prevent spread of habitation contamination to some extent. Power plants should be located a sufficient distance from the base to lessen problems of possible radiation leakage.

Power is a necessary component of the Bootstrap Base. Power will be supplied by several nuclear reactors, so that if one reactor goes out, power linkages can switch to alternate power plants. Single-point failure is to be avoided.

There will be airlocks at each section of the base, so that loss of pressure in one area will not put the entire base in jeopardy. Repair materials should be available so that leaks may be repaired before severe pressure loss occurs. Most leaks will not be severe should take several hours to put the pressure in critical condition, so that repairs should be made easily without disrupting daily activities. There should be backup computers at an alternate site to avoid single-point failure.

The base is scheduled to be autonomous, so that communication breaks for several hours should not impair the base activities. A backup communication system should be considered in case repairs cannot be made in a few hours.

It is unlikely that debris will land in the area of the base. The regolith used for solar flare protection should be sufficient to provide protection from small, slow moving objects.

4.1.2 Emergency Scenarios

Several potential emergency scenarios must be developed for the Bootstrap Lunar Base in order to provide adequate preparation for the crew in case of emergency. The situations included in this report include solar flares, fire, sudden loss of pressure, EVA injury to an astronaut, and critical damage to Moonport and the Bootstrap Base.

Solar flares pose an interesting problem on the base. During the construction phase of the base, there will be no Bootstrap Base structures capable of providing adequate solar flare shielding on the moon. Therefore, personnel will need to go to a safe haven on the lunar surface (if it has been constructed) or to Moonport during a flare. During the occupation phase of the Bootstrap Base, solar flare protection will be available at the base itself. This protection will be better than can be provided on Moonport, so it is suggested that Moonport personnel evacuate to the Bootstrap Base until the flare has dissipated.

Fire in a Space Station Command Module has the potential to destroy the entire base. Therefore, special measures must be taken to insure containment of any fire as well as the safety of all personnel. If a fire occurs, personnel should be evacuated immediately, no matter how small the fire. Smoke is the greatest fear in a closed environment such as the Bootstrap Base, and care should be taken that smoke is not spread to additional modules. The air ducts should be closed as soon as possible to curtail the spread of smoke. Next, the fire should be extinguished. The easiest way to do this on the moon is to open the SSCM to the surface so that all oxygen can escape. Without oxygen, the fire will die. Once the fire is extinguished, the SSCM should be repressurized. Repair crews should then repair the damage to the SSCM so that the module can be functional as soon as possible.

Sudden, severe loss of pressure is another possible life-threatening problem on the Bootstrap Lunar Base. It is anticipated that most pressure losses would be minor, and that personnel could function normally while the leak is being repaired. However, it is quite possible that a severe leak will force the evacuation of all personnel from the involved SSCM. Repair crews in pressurized suits should repair the damage and repressurize the module when feasible so that normal functioning can resume.

In the event that an astronaut is injured during Extra-Vehicular Activity, the injured astronaut could not be transported immediately to the Bootstrap Base because of pressurization problems. Therefore, it is suggested that there be two astronauts on the surface whenever any EVA activity is required. The second astronaut can provide a preliminary diagnosis of the injury and provide temporary aid to the injured astronaut while the two wait to be transported to a first aid station. If the astronaut has a severe injury, he will need the hospital facilities of Moonport. The second astronaut can pilot the escape vehicle to the facilities. However, if the injury is minor, the astronaut can get aid at the Bootstrap Base, and the second astronaut can stay with him until the two can reach medical help.

If Moonport is critically damaged, the personnel need to escape to the Bootstrap Base. A repair crew will be sent to Moonport to assess the damage and, if possible, repair it. Similarly, if the Bootstrap Base is critically damaged, the base personnel need to evacuate to Moonport. Repairs will be made to the base, if possible. Once the base has been repaired and thoroughly examined, the personnel may return to the site.

4.2 Base Construction Overview

The bootstrap base, landing pad, and permanent base can be constructed using conventional techniques, as on Earth, and construction equipment adapted for use on the lunar surface. The layout was designed on the basis of simplicity, ease of access, and expandability. The Bootstrap Lunar Base will be located either above, partially below, or just below the surface. An initial bootstrap base located deep below the surface would not be feasible, because it would not be possible to establish the initial base quickly due to the extensive and time consuming construction efforts required. The initial bootstrap base personnel could oversee the construction of a larger permanent base that could be located far below the surface should that be desired.

4.2.1 Construction Equipment

Various types of construction equipment will be needed to produce the bootstrap base. Since typical Earth construction equipment would prove useless on the lunar surface, special equipment will have to be developed. At this time, only the necessary type of equipment can be specified along with its Earth counterpart as shown in Table 4.1.

4.2.2 Foundation Preparation

The bootstrap base will require a foundation that will provide a strong , stable support for the modules. This foundation should be prepared from lunar soil, that is, the surface should be prepared and supplemented to form the foundation. This foundation should be constructed utilizing minimum amount of equipment to reduce the amount of overall equipment delivered.

Most methods for foundation construction used on Earth depend on large amounts of mass to compact the ground, but with the reduced gravity on the Moon , these methods would prove futile. Three methods found suitable for possible lunar applications are piling, dynamic consolidation, and vibrocompaction. Piling consist of driving metallic piles into the ground which compact and strengthen the soil and provide additional support. Dynamic consolidation is the process by which the ground is compacted through repeated impacts by a large mass. Vibrocompaction is a method of compacting soil by applying a vibrating load. Its effect is increased if vibrated at the soils natural frequency. Of the three techniques

Table 4.1 Construction Equipment

Moon Equipment	Earth Equivalent
Excavating Equipment	Backhoe, Trencher
Regolith Transport	Dump Truck
Regolith Mover	Bulldozer,Scraper
Crane Lander	Crane
Pile Driver	Pile Driver
Conveyor Belt /Regolith Transport	Conveyor Belt/Soil Transport
Heavy Load Transport Vehicle	Truck
Jack Hammer	Jack Hammer
Regolith Compactor	Soil Compactor

presented, piling seems the most suitable alternative for the bootstrap base. It can be accomplished with a fair amount of ease and a minimal amount of equipment and, unlike the others, it is not so dependent on mass. Also, piles can be incorporated into the regolith support structure, further facilitating base construction [Ref. 4.11].

4.2.3 Base Construction

Many proven construction methods which have been perfected on the earth may be applied to lunar construction. Some examples of these methods are: controlled trajectory blasting, foundation preparation, and simple load bearing structures. As this enables one to have a greater degree of confidence in procedures, proven techniques will be applied whenever feasible.

The first requirement of the base is that it have radiation shielding. This may be accomplished in several different ways: (1) above ground construction, (2) below ground construction, and (3) partially below ground construction and shown in Figures 4.1 (a) through 4.1(c). Table 4.2 shows a Decision Matrix which was developed to determine the scenario most preferred. One should note that a lower point value is better, and that the weighting factors are the same for all considerations except for safety-which had a weighting factor of two. The Decision Matrix shows that the partially buried scenario is the best choice.

The second consideration is the necessity of a Regolith Support Truss Structure (RSTS), as shown in Figure 4.2. It would be possible to simply make the modules stronger, and pile the regolith directly onto the modules. But as Table 4.3 shows, the required mass module to support the regolith would be approximately 18000 kg. In contrast, the combined mass of a module and the truss elements would be approximately 3000 kg. This significant savings in mass required the use of a RSTS system. The RSTS system is conceptualized as a collapsible system as shown in Figure 4.3 with many of the truss elements coming from the transformable Tinker Toy Landers, thereby taking advantage of the mass already delivered to the moon.

A third consideration is the requirement of cradles to hold the modules in place. This will prevent point loads from being applied at the bottoms of the modules and also maintain the integrity of the base.

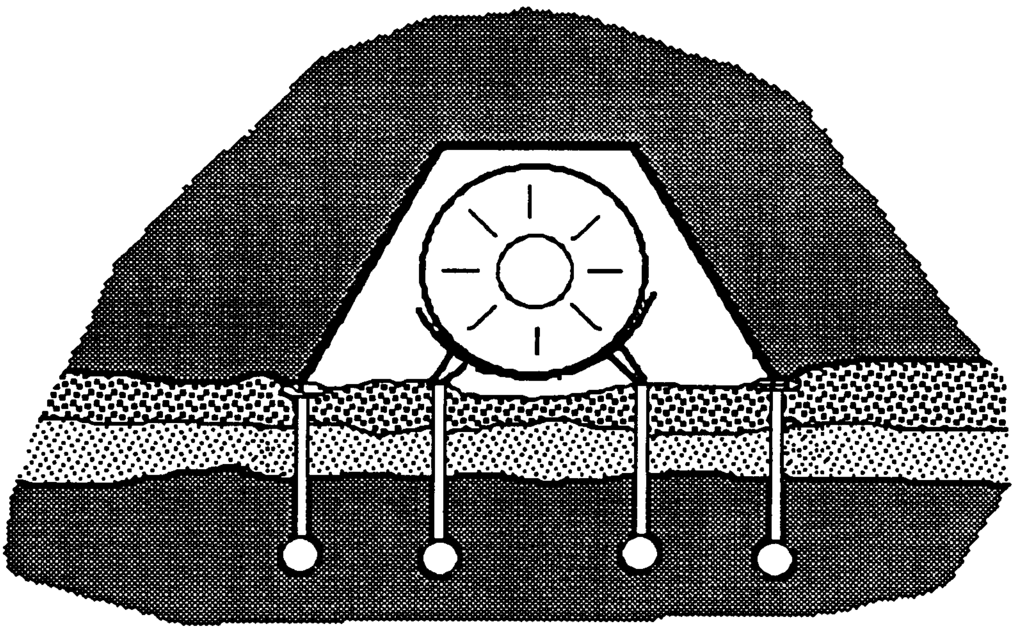

Figure 4.1(a) Above the Surface Configuration

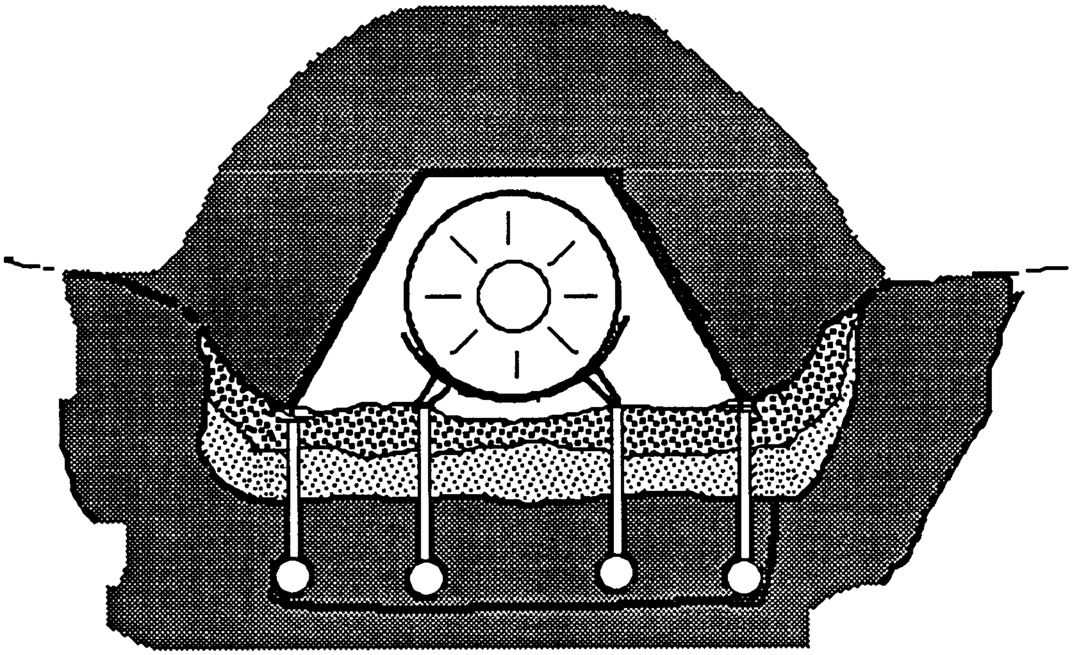

Figure 4.1(b) Partially Buried Configuration

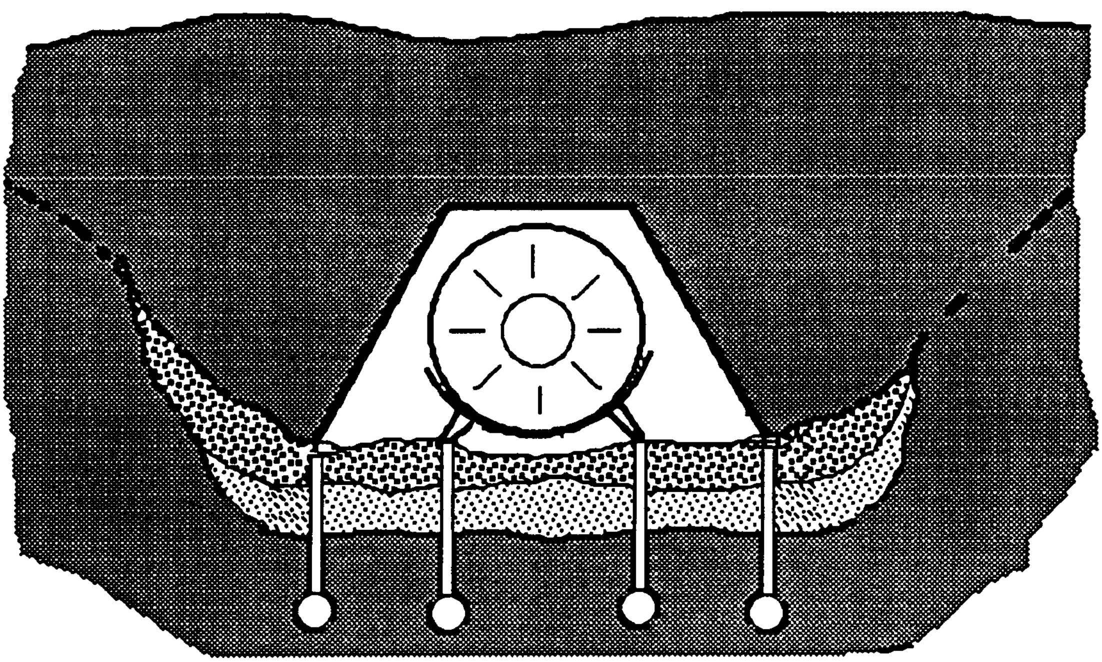

Figure 4.1(c) Below the Surface Configuration

Table 4.2 Construction Decision Matrix

	ATTRIBUTE	ABOVE	PARTIAL	BELOW
(1)	Regolith to be moved	2	1	3
(2)	Equipment Requirements	1	2	3
(3)	Construction Ease	1	2	3
(4)	Foundation Preparation	3	2	1
(5)	Construction Time	3	1	2
(6)	Materials acquisition	3	2	1
(7)	Power Requirements	2	1	3
(8)	Controlled Trajectory Blasting	3	1	2
(9)	Change of Main Power Source	2	1	3
(10)	Safety (weight factor =2)	1	2	3
	TOTALS	22	13	27

C-2

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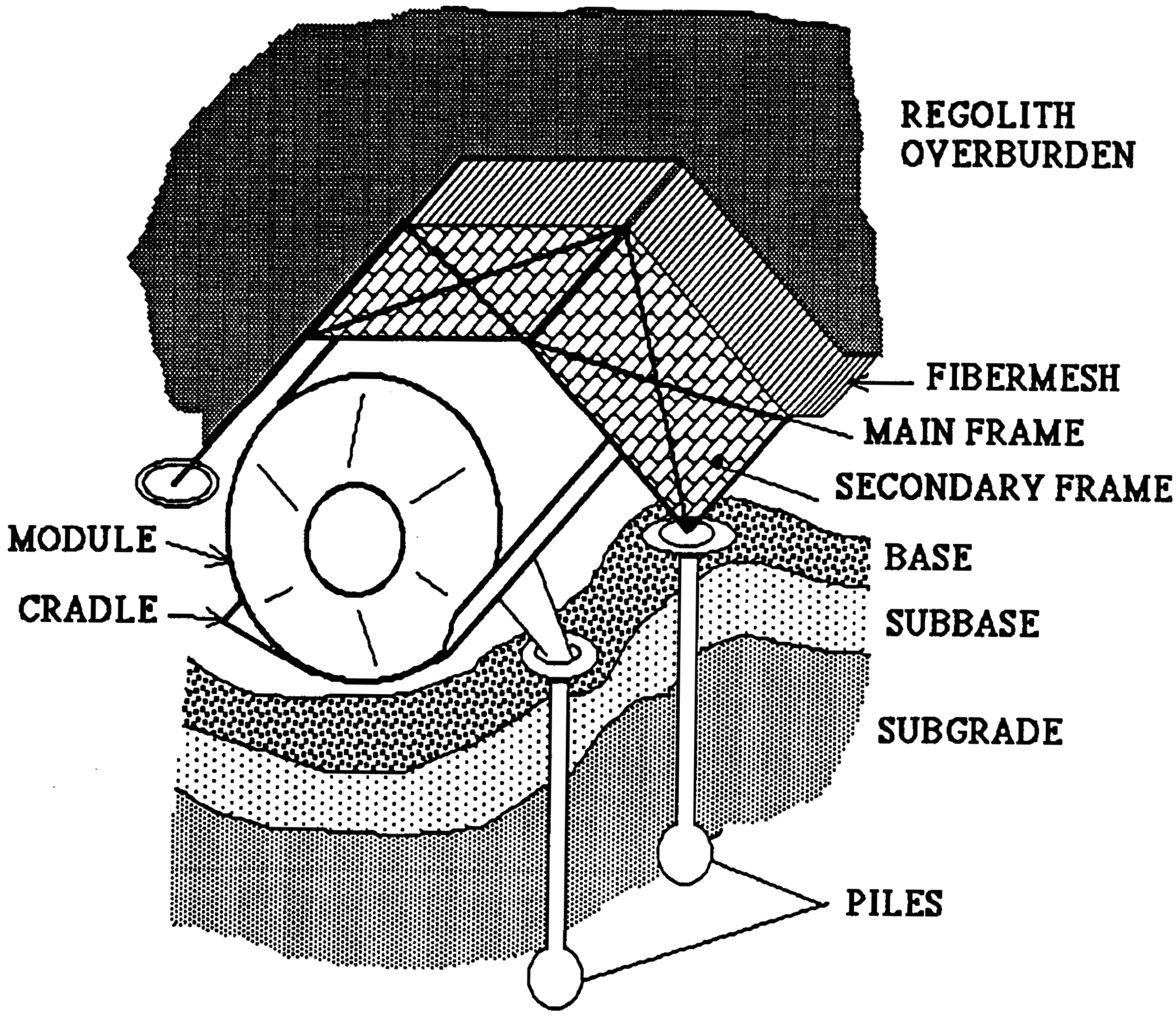
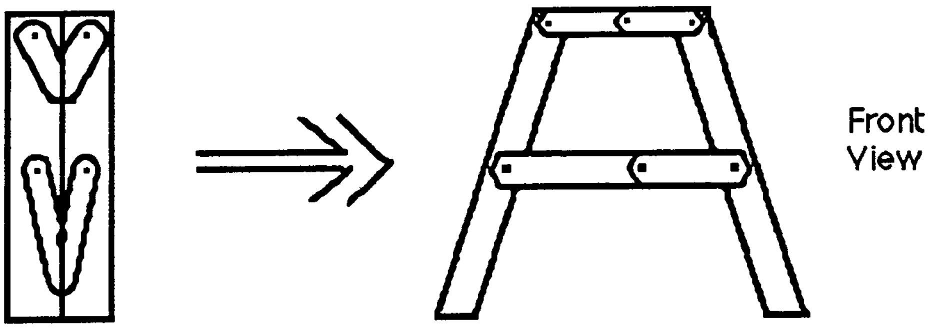


Figure 4.2 RSTS System

Table 4.3 Mass Comparisons

MATERIAL	TRUSS thickness (m)	TRUSS mass (kg)	NO TRUSS thickness (m)	NO TRUSS mass (kg)
ASTM-A36	0.00465	6570	0.01963	27650
ASTM-A242	0.00321	4537	0.01963	27650
Stainless	0.0013	1852	0.01997	28342
1100-H14	0.0123	5982	0.0279	13525
2014-T6	0.0031	1560	0.0276	13382
6061-T6	0.0048	2340	0.0280	13574
Magnesium	0.00245	793	0.0323	10352
Titanium	0.00082	657	0.0237	18927

Approximate mass of a Titanium RSTS = 2500 kg.



Note: End Truss Elements Only

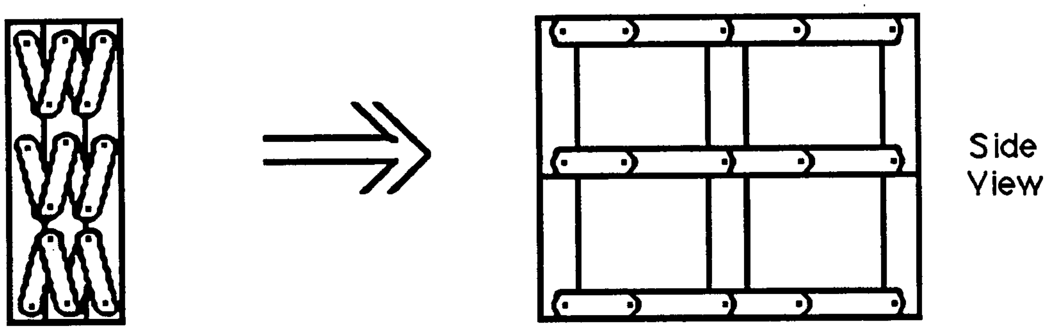


Figure 4.3 Expanding of Conceptual RSTS System

As the cradle assembly is linked into the foundation the entire base moves as a unit, and no loads will applied to the joints between the modules due to localized settling.

A bootstrap construction scenario is as follows:

- Excavate Site for Base
- Construct Foundation
- Secure Cradles to Foundation
- Place Modules on Cradle
- Assemble RSTS
- Secure RSTS to Foundation
- Spread Kevlar fabric across RSTS
- Cover with Regolith
- Power up Base.

Many of these facets of construction would be completed by teleoperations.

4.2.4 Effects of Long Lunar Day/Night

There should not be major restrictions on construction due to the long lunar day or night. Major portions of construction, especially activities that require personnel to conduct EVA on the lunar surface, should be done at night. Night time activities give added radiation protection in the event of increased solar activity. Flood lights can be used to illuminate the construction site as needed. Further studies need to be addressed on the effects of the low night time temperatures on personnel and equipment during lunar construction phases.

Assuming no reactor failure, power restrictions should not be a problem. However, in the event that the main reactor should fail, secondary power sources will be used. A scenario for secondary power usage is to use rechargeable batteries that acquire their energy from solar cells. Construction would still be done during the lunar night, but during the lunar day the batteries that power equipment could be recharged from the solar cells which get their energy from the sun. Keeping in mind that several batteries for each piece of equipment can be available for use. Each battery is recharged during the day and can be quickly installed, or removed, from the machinery.

4.2.5 Base Layout

Figures 4.4 and 4.5 show the top and side views, respectively, of the bootstrap base layout. Space Station Common Modules were used as a starting point for design purposes. Four habitation modules were chosen on the basis of providing enough space for the crew during long durations at the base. The "circular" configuration of the base allows access to the remaining modules in the event one or more modules are damaged and need to be sealed off. The CIMs leading to the surface are emergency exits or safe havens in the event the base needed to be quickly evacuated.

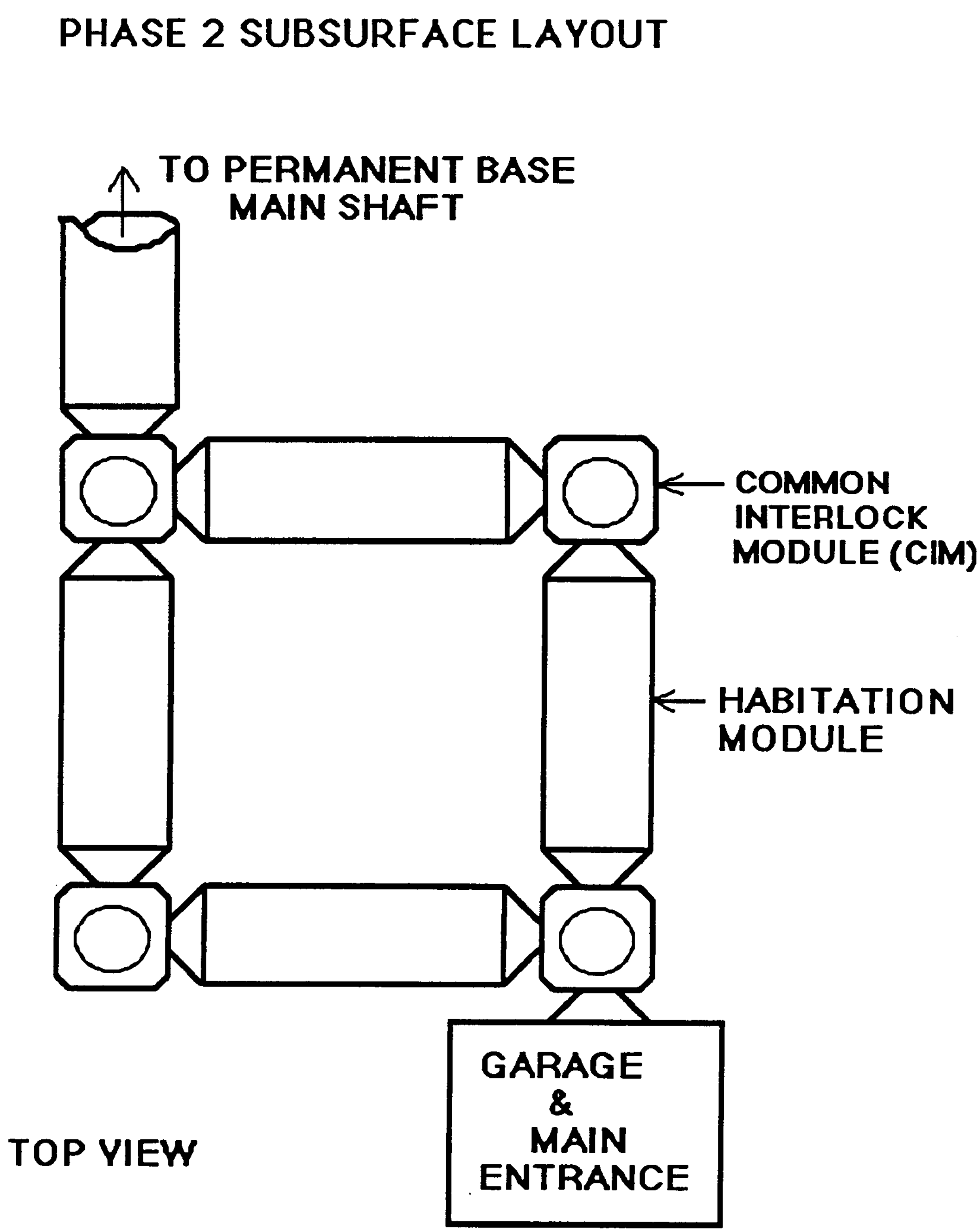


Figure 4.4 Bootstrap Top View Layout

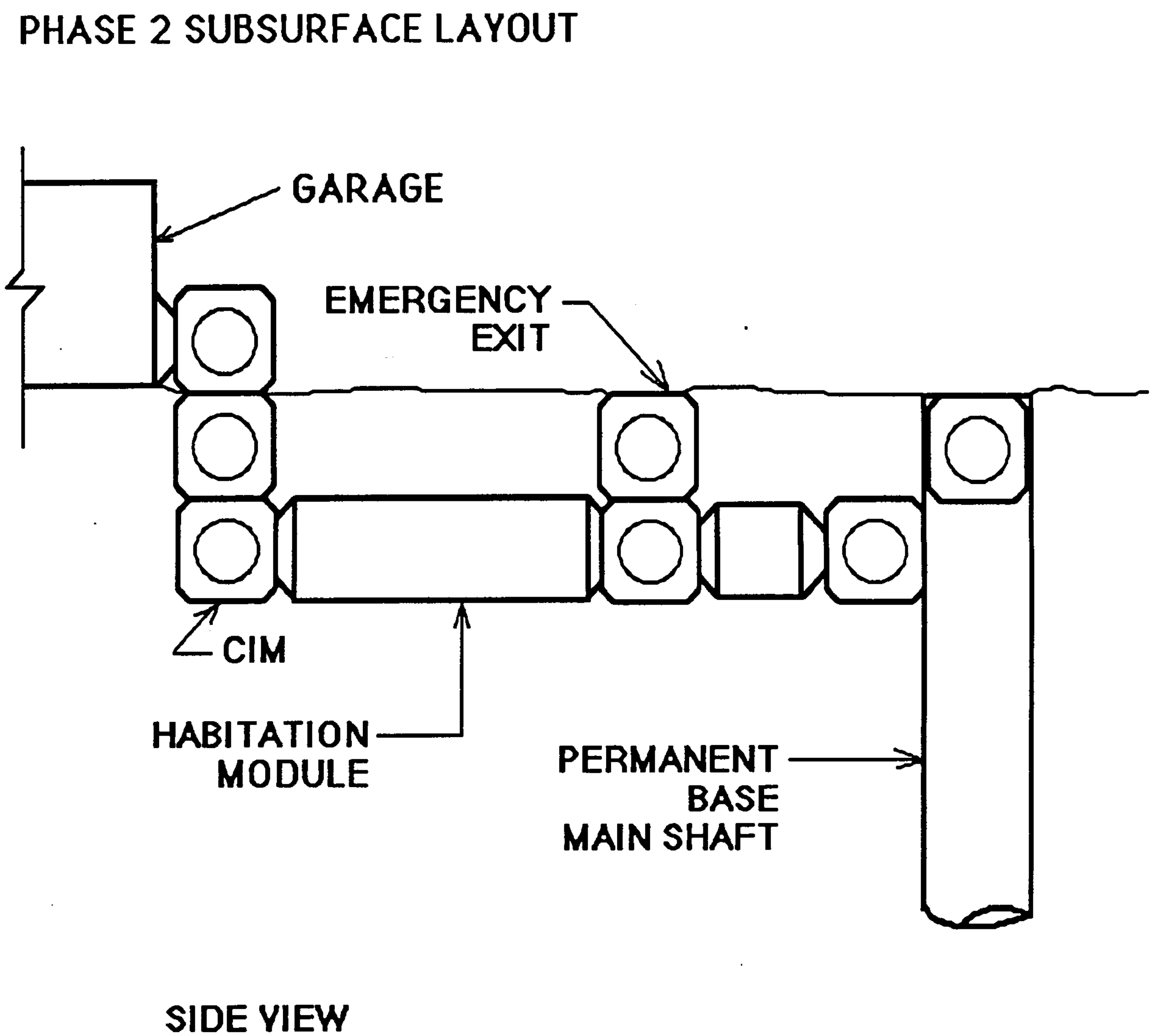


Figure 4.5 Bootstrap Layout

The purpose of the garage, besides being the main entrance to the base, is for maintenance of the construction equipment. The garage is also enclosed in a regolith envelope, similar to the bootstrap base. Any equipment that needs to be serviced can be brought in to the garage, the garage can be sealed, pressurized, and work can be conducted in a shirt-sleeve environment. Due to the problems associated with pressurizing such a large volume, the garage should be pressurized only as a last resort.

Figures 4.6 and 4.7 show conceptual designs for a permanent base layout, regardless of the depth of the base below the lunar surface. As with the bootstrap base, every point within the base can be accessed from alternative directions in the event a section of the base is sealed off. The pressure in the permanent base should be the same as the pressure in the bootstrap base to provide rapid access between the two in the event of an emergency.

The depth of the permanent base has not been fully determined yet, however the permanent base will not be more than twenty meters below the surface. Burying the base twenty meters and pressurizing it to one atmosphere reduces the need for structural supports in the base, because one atmosphere of pressure can balance the weight of twenty meters of regolith overburden. Therefore, a base at twenty meters has unlimited expandability [Ref 4.3]. At four meters, construction techniques are much easier, especially in the harsh lunar environment, however base expansion is limited to the number of CIMs and habitation modules on hand. Therefore, trade studies and further research is deemed necessary before determining the depth of the permanent base.

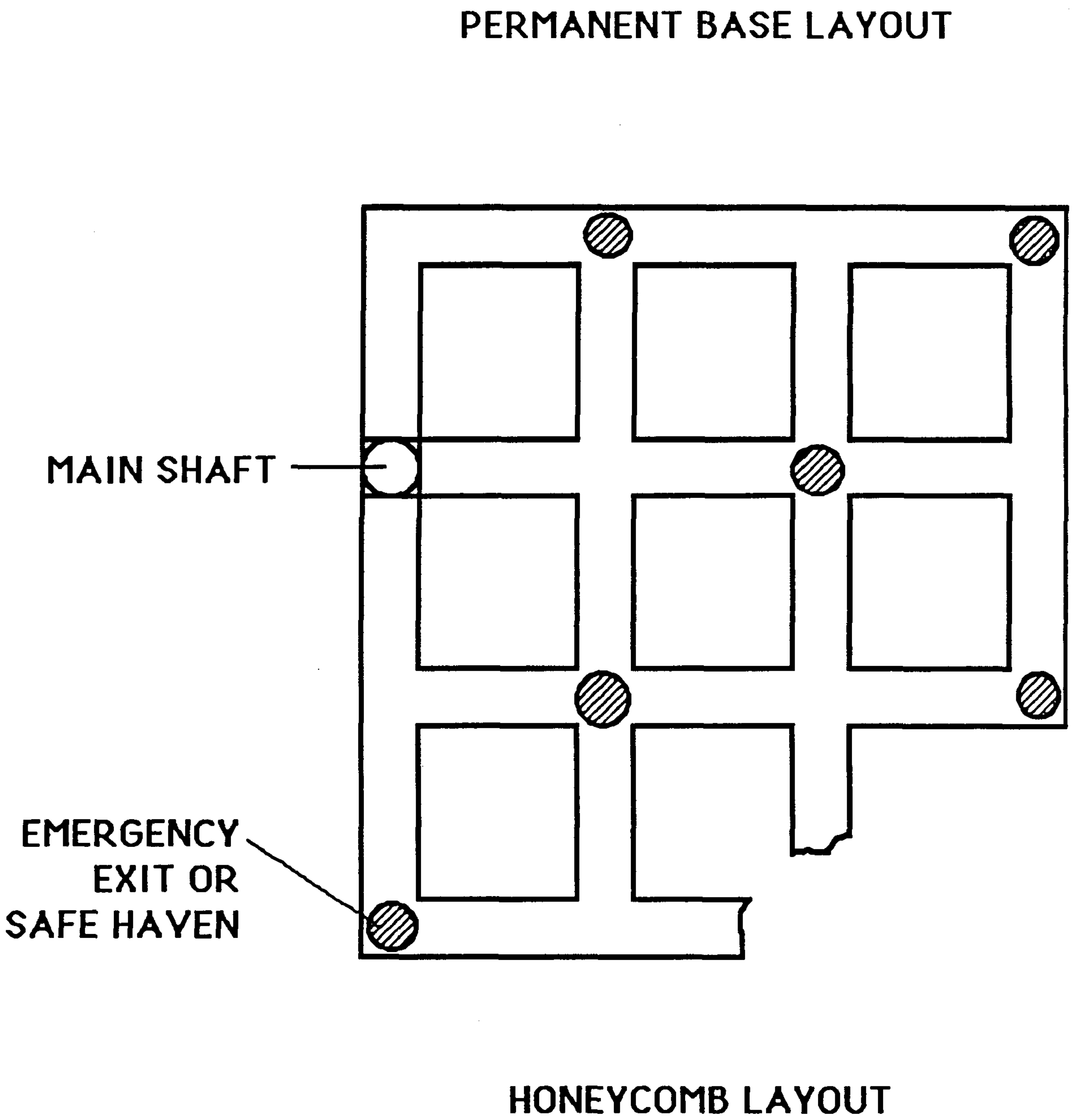


Figure 4.6 Permanent Base Layout Honeycomb

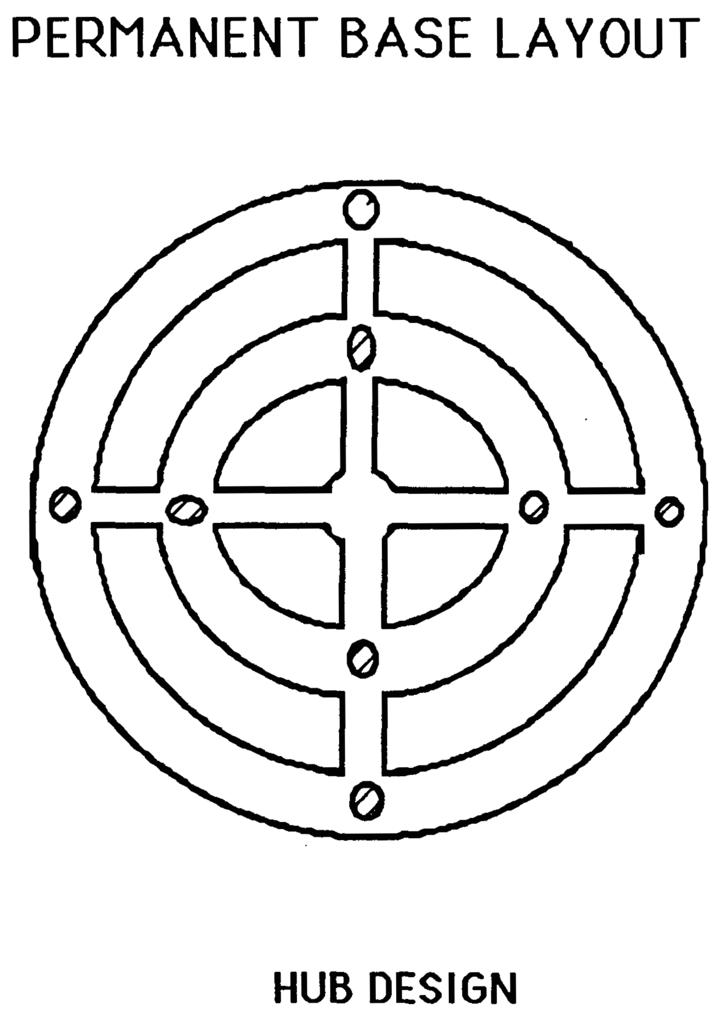


Figure 4.7 Permanent Base Layout Hub

4.2.6 Landing Pad

A centralized location for a vertical ascent / descent landing pad is needed near the base for delivery of personnel and supplies. The characteristics of the initial pad will be simple in order to construct several pads within the vicinity of the base especially in the early development when many landings of machinery and personnel are expected. Figure 4.8 shows a conceptual idea of what the initial landing pad may look like. The protective wall encircling the smooth landing surface is to protect any personnel or equipment in the vicinity from high speed debris while the pad is in use. However, the wall may not be needed if standard procedures are developed for removing personnel and equipment form the area while the pad is in use.

Eventually, the base will develop one or more permanent vertical landing facilities which will be similar to roads on Earth, as far as a foundation and a hard surface [Ref 4.2]. The hard surface could be made from lunar bricks, which can be made locally [Ref 4.3]. A cross section of the permanent landing pad is shown in Figure 4.9.

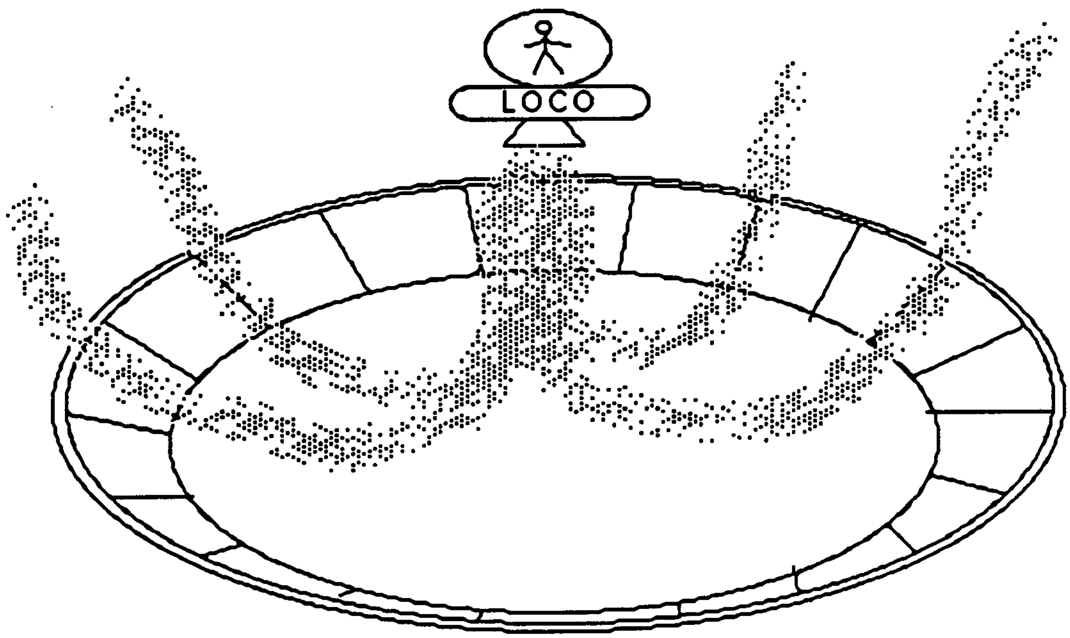


Figure 4.8 Conceptual Initial Landing Pad

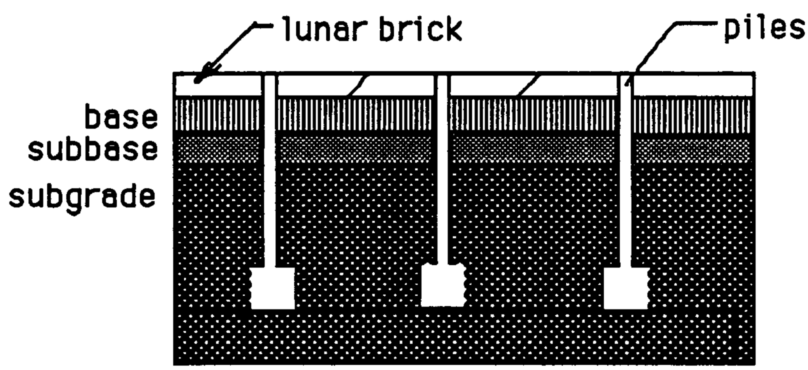


Figure 4.9. Permanent Landing Pad Cross Section

4.3 Habitation Overview

The thorough study of bootstrap habitation is essential to insure a efficient and productive lunar base. Included in these studies are module interior layouts and life support systems. Careful development of these areas will insure proper development of a permanent lunar base. Another area of concern is the psychological effects of living in closed quarters for extended periods.

4.3.1 Modules

The Space Station Common Modules (SSCM) were chosen for the Phase 1 and Phase 2 lunar base because of their ability to provide readily available habitation. The SSCM's were adapted to the lunar gravity environment by adding a floor, ceiling and walls, as shown in Figure 4.10. Specifications for the reconfigured modules are given in Table 4.4 [Ref.4.6]. Specific interior layout of the modules has not been determined, however two possible designs are shown in Figures 4.11 and 4.12.

Each habitation module in the bootstrap base should provide private crew quarters, health maintenance facility (HMF), workstations, galley / wardroom, and a hygiene area. Of significant importance are the HMF's and the ECLSS's. Each module should have its own independent ECLSS in the event of catastrophic failure in any one of the modules. In the same respect, HMF's are needed in each module to provide medical and food supplies to personnel in the event of an emergency. Since the base layouts shown earlier in Figures 4.11 and 4.12

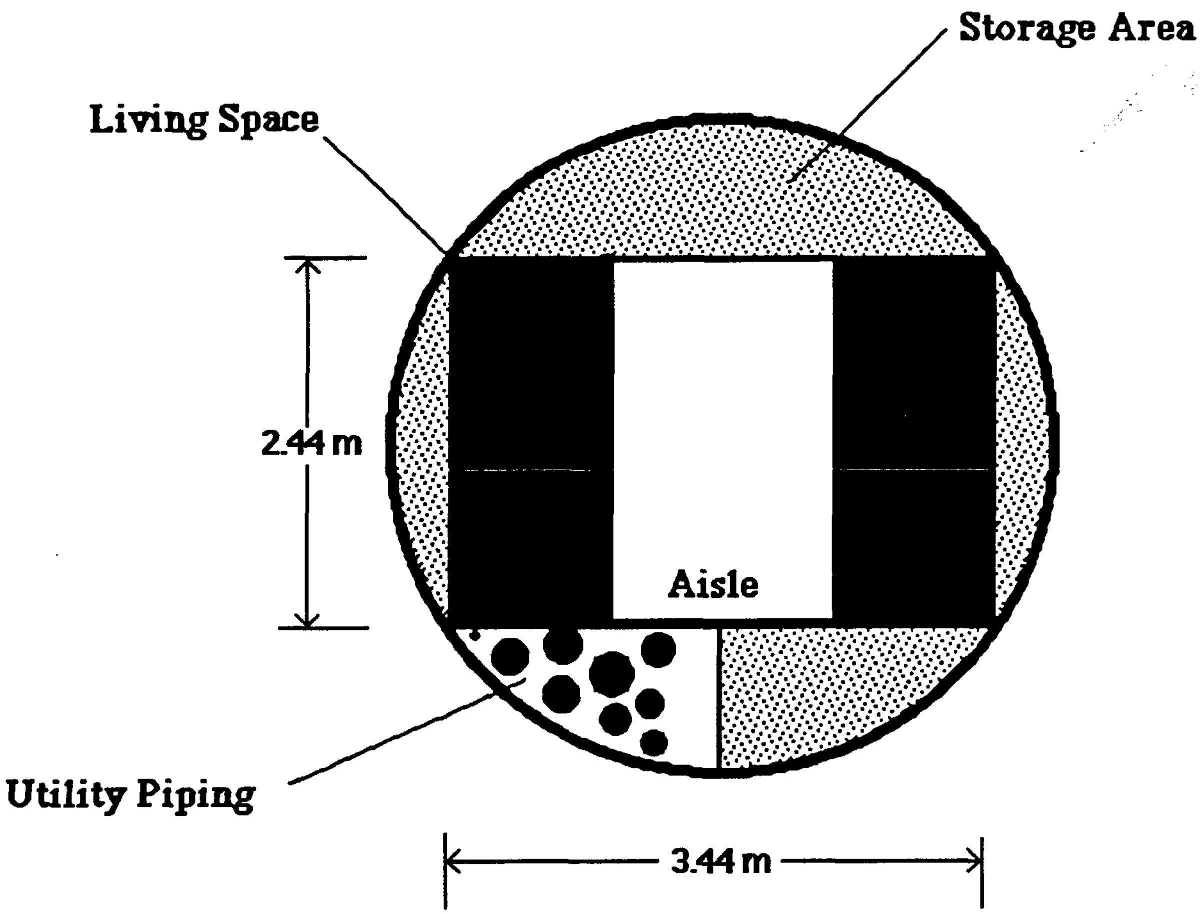


Figure 4.10 Module Cross Section

[Ref. 4.6]

Table 4.4 Module Dimensions: Initial and Reconfigured

[Ref. 4.6]

Space Station Common Module Dimensions

Inner Skin Diameter	4.22 m
Cylinder Length	11.79 m
Cylinder Volume	164.54 m^3

Reconfigured Rectangular Dimensions

Height from floor to ceiling	2.44 m
Width	3.44 m
Length	11.79 m
Interior volume	98.82 m^3
Side Wall Compartment Volume	11.62 m^3
Floor Ceiling Compartment Volume	46.72 m^3
Total Compartment Volume	58.35 m^3

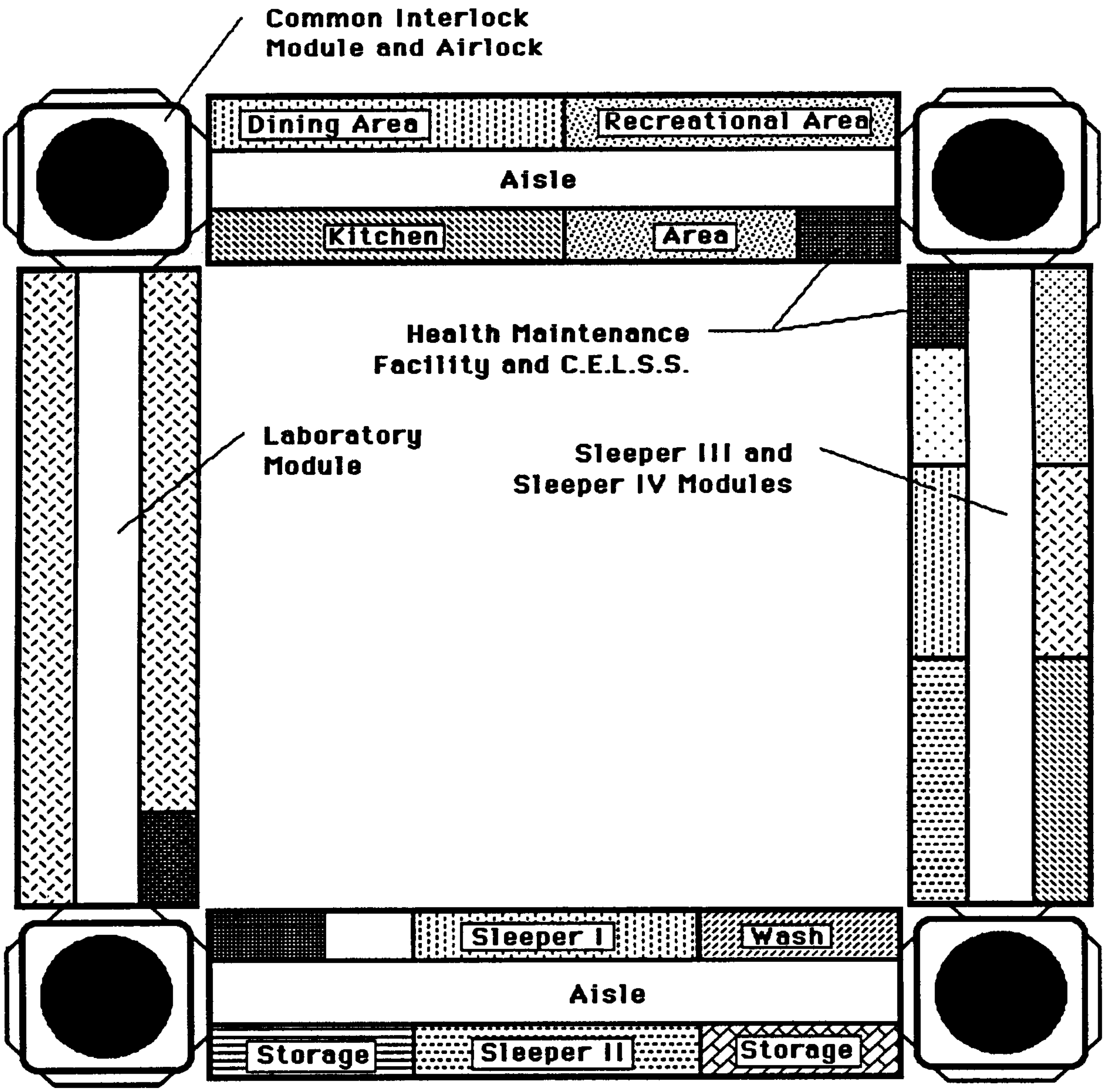


Fig 4.11 Module Layout A

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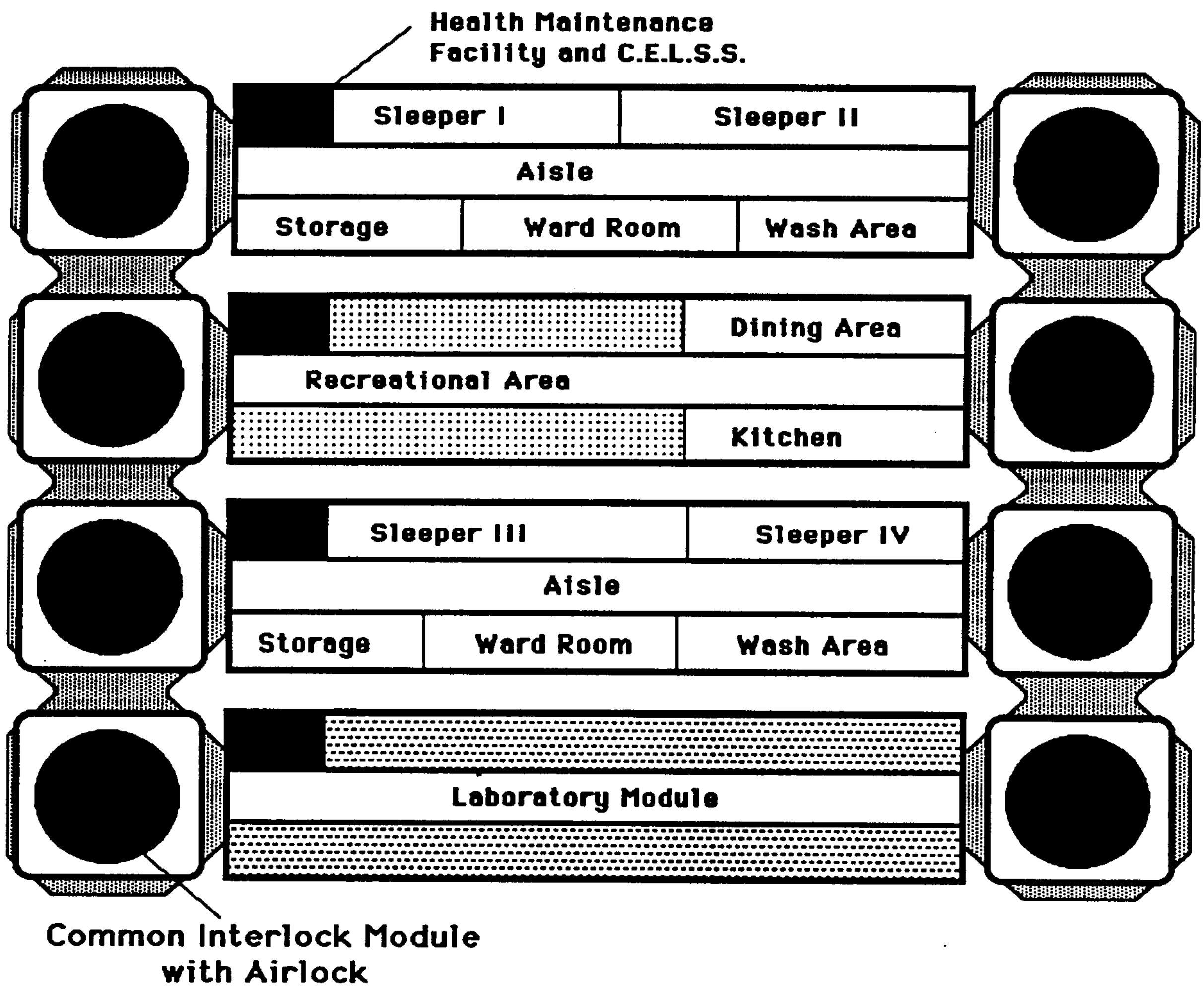

Fig 4.12 Module Layout B

are being used, each of the four modules can have a different primary purpose under normal operating conditions, ie one module for crew quarters, another for galley / wardroom. Under emergency conditions, each module should have the ability of being transformed to provide all needed accommodations.

The CIM's are ideal for module connection and at the same time serve as airlocks and emergency exits to the surface or other modules for the crew. In case of an emergency, the crew could seal off a module and proceed to another module or to a surface safe haven. These CIM's have the ability to connect with habitation modules, or other CIM's, on any of its six sides. This flexibility makes the expansion of the bootstrap base easy.

4.3.2 Environmental Control and Life Support Systems

One topic of major concern to the initial bootstrap lunar base is that of life support. Phase I and Phase II of the lunar base will depend primarily on the resupply of oxygen and all necessary life support essentials from moonport. As the base progresses, the life support system will continue to progress towards a completely closed system, which Phase III will have. Some of the major human life support needs and waste products are shown in Table 4.5 [Ref. 4.1].

Initially, Phase I will be completely resupplied with oxygen and needed life support components from moonport. All other waste products will be collected and stored in various ways. As Phase II begins, the system will reclaim water from urine and hygiene waste and process it to be used again. Fecal water will also be processed for uses other than drinking, such as bathing or any other applications not requiring extremely clean water. In the same respect, carbon dioxide from the crew will be processed to release the oxygen that it contains. Closing the air supply will be done by using the processes of solid amine, sabatier reduction and electrolysis [Ref. 4.7]. These techniques are necessary to decrease the size and frequency of resupply missions. As seen in Table 4.6 [Ref. 4.7], once various components of the life support system are closed, the resupply mass is greatly reduced. In particular, closing the water system reduces the 90 day resupply mass for an 8 person crew by 22,900 kg. Experiments for further closing of the life support system can be conducted during the Bootstrap phase in preparation for the permanent base. Ideally the permanent base would be fully closed to insure independent development of the lunar base.

All phases of the bootstrap base will be pressurized. The pressure at which they will be pressurized to will depend on the lunar suits and vehicles that will be used on the surface. If all systems are pressurized to the same level, then the astronauts can proceed from their suits directly to the modules without any complicated depressurization processes. Transfer from the habitation modules to the lunar rovers would be completed by locking the rover to a access porthole at the module and then transferring the crew. Since they are at the same pressure, this transfer would be completed with ease.

Table 4.5 Basic Requirements and Waste Generation [Ref. 4.1]

Requirements	Per Man Daily	8 Man
Metabolic Oxygen	0.9 kg	7.2 kg
Drinking water	3.6 kg	28.8 kg
Hygiene Water	5.4 kg	43.2 kg
Food	0.6 kg	4.8 kg
Waste Production		
Carbon Dioxide	1.0 kg	8.0 kg
Water Vapor	2.5 kg	20.0 kg
Urine	1.5 kg	12.0 kg
Feces	0.2 kg	1.6 kg
Metabolic Heat	12660.0 kJ	101280.0 kJ

Table 4.6. Closure Scenarios

MASS AND POWER REQUIREMENTS FOR A FOUR PERSON CREW			
CLOSURE SCENARIO	INITIAL TOTAL MASS (KG)	90 DAY RESUPPLY MASS (KG)	POWER REQU WATTS
OPEN TOTALLY	17,895	13,552	1,140
WATER CLOSED	5,814	2,102	1,907
AIR CLOSED	16,216	12,523	5,399
WATER AND AIR CLOSED	4,135	1,069	6,166
3% DIET	5,785	1,064	7,762
50% DIET	15,389	549	17,445
90% DIET	27,002	237	26,740

[Ref. 4.7]

4.4 Resource Production

Analyses of the needs of the bootstrap lunar base indicate that for during the early era, there are no economically viable products. Preliminary trade studies indicate, for bootstrap era, that it will be less expensive to import all materials and consumables than to bring up a processing plant capable of supplying the base [Ref. 4.7]. Once the colony moves into the post-bootstrap era this will be reversed. At that time it will be more logical to produce as much, if not everything, locally. Thus during the bootstrap phase all processing will be strictly for technology verification.

4.4.1 Lunar Resources

Table 4.4.7 shows that the moon contains sufficient quantities of oxygen, aluminum, and silicon to make eventual exploitation a viable option [Ref. 4.8]. In addition there are considerable quantities of Iron, Titanium and Magnesium. Thus the early pilot plant will be proving the technologies needed to recover these elements. The principal technologies will be examined for their ability to liberate O2, Fe, and Al. It is possible that the technologies that work for iron and aluminum may well produce appreciable quantities of Silicon, Calcium, Titanium or any of the other metals. Such a process could make the difference between a self-supporting colony and an Earth-dependent one.

Table 4.7 [Ref. 4.8]

Percentage of Elements Available by Soil Type

Element	Mare	Highlands	Ejecta
O	41	45	43
Si	20	21	22
Fe	13	5	6
Ca	8	11	8
Al	7	13	10
Mg	6	5	6
Ti	3	-	-
S	.1	>.1	>.1
K	.1	>.1	.2
Na	.3	.5	.4
H	ppm	ppm	-

4.4.2 Resource Applications

The potential uses for lunar materials are numerous. Just about every material mined from the moon has multiple applications [Ref. 4.9]. For instance, Oxygen, the most plentiful element on the moon, can be either incorporated into the transportation system or used in the life support system. Alternately aluminum can be used in the propulsion systems of the colony's transportation system or in the construction of habitats or more elements for the transportation system. It is assumed in the following that all production will be for technology verification only. Applications discussion is based on the premise that production will be driven by goals other than scientific.

Oxygen is one of the most useful materials on the lunar surface. Because of its various uses and the large quantities available, this element should be the main element produced. The oxygen could be used in the life support system or in the propulsion systems of the transportation fleet.

For the life support system, the oxygen would be used to bring the system up to full operation. Because the life support system will be closed, once it is in operation, the losses of oxygen will be minimal. Since the processing plant will be of pilot size initially it would not be able to produce the quantities required for even a small lunar colony, although in later phases of the base then it might be profitable to supply the life support system. Thus oxygen will not be mined with the intention of supplying the initial lunar base but rather supplying the transportation system.

In the transportation system the oxygen serves two main purposes. It can be used in a LOX-Hydrogen engine or in solid rocket motors when combined with aluminum from the moon. Although the plant's initial production capabilities will be limited it might be possible to produce enough to supplement the transportation system's needs. Research indicates that a processing plant capabilities are linearly scaleable and can produce its own weight in LOX every week [Ref. 4.10]. As seen in the **Lander Operations Division** section a first cut estimate of 2940 kilograms oxygen per flight are needed. So with a pilot plant of 750 kilograms enough oxygen could be produced for one flight every 28 days. Alternately it is possible that solid rocket motors with Aluminum / Oxygen propellant will we economical. If so the plant could produce enough propellant. In addition to applications of aluminum to propulsion systems, Aluminum and Titanium can be used for structural purposes. These metals could be used for manufacturing the actual craft or in the construction of aerobrakes for the earth moon transportation system. Because of the atmosphere on the earth t aluminum cannot be used as the primary structural element. On craft that will be staying in the lunar vicinity or going farther out into space it would be highly economical to construct them from aluminum. For craft heading back to the earth the use of aerobrakes considerably cuts down the amount of fuel that is needed. Because of the need to dissipate heat aerobrakes are constructed from ceramics in most cases. These ceramics could be made of Alumina, or a Titanium ceramic.

In addition to the uses of metals on spacecraft they could be used for the more mundane purpose of habitat construction. In whichever housing scheme is used for Phase 2 or Phase 3 of the lunar base it will be important that the structures are made from local resources. Whether the entire structure is made from the metals or only structural supports it would be very economical. The metals could be manufactured into sheets for use inside of some other type of structure or they could be made into trusses to support a habitat.

4.4.3 Pilot Processing Plants

There are two distinct options for a pilot processing plant, a mobile plant and a stationary one. A mobile pilot plant has the ability to traverse an extensive region of the moon. This allows for testing of a variety of regolith types. Additionally such a plant can be made modular and small enough that it can be transported into some type of pressurized structure and maintenance performed in a shirt sleeve environment. On the other hand a mobile plant would have more moving parts exposed to the abrasive regolith and thus require repairs more often. In addition the vacuum environment requires the use and/or development of new types of lubricants. It is possible to envision using lubricants similar to those used on the lunar rover of the Apollo era. The Apollo rover was not designed to be used continuously or for an extended period of time.

A stationary pilot plant can be enclosed in some type of external structure and thus have fewer components exposed directly to the lunar environment. This presents problems in transferring the raw material from the vacuum of the surface to a pressurized or otherwise enclosed area. If the interior of the plant were pressurized and large enough, then it could provide a laboratory in which to carry out extensive materials tests as well as allow repairs to be made in a shirt sleeve environment. A disadvantage of a stationary plant is that it requires the raw materials be brought to it. This is a disadvantage only if materials from remote regions of the moon are required.

A second factor to consider is what source of power the plant will use. It is possible that the plant could carry its own power source or it could draw all of its power from the colony itself. If the plant were to draw its power from the base then it could have an unlimited power supply, however the mobility of the plant would be limited. If the plant were to carry its own power supply then complete independence of the base could be achieved. In addition this alternate power supply could act as a backup to the base if the base's prime power supply failed.

Another major consideration of the design of a power plant is whether the plant should be manned or automated. Man rating of the plant requires a great deal of redundancy, life support and radiation protection which would add considerable weight. If the plant were automated, this weight problem would be avoided but at the same time it is possible the plant could get into a situation requiring human intervention. If such a situation does occur there would still be no need for a man rating. The repair person could sit in an external seat to maneuver the machine or else tow it with another vehicle. In any case the man rating can and should be avoided.

4.4.4 Plant Processes

Preliminary analysis has shown the ratio of useful material to bulk soil is on the order of .20, thus for any operation to be feasible the regolith must be beneficiated first [Ref. 4.11, Ref. 4.12]. The principal methods of beneficiation all make use of the inherent electrical charge on lunar particles. The specific technologies include corona electrification, inductive charging and triboelectrification [Ref. 4.13]. Preliminary analyses indicate that triboelectrification will be the most economical way to beneficiate the soil [Ref 4.13]. Even though this has been stated it is not unequivocal and further testing must be done to be sure that the simplest method has indeed been chosen.

The problem seen with the inductive charging is that although it is efficient it requires a good deal of energy to remove the particles from the mechanism that charges the particles [Ref. 4.9]. The corona electrification process is not quite as well defined although it has been proposed that the energy required to charge the particles is greater than that required for the triboelectrification method.

The actual processing of the soil will depend on the material to be refined but analyses indicate that either a carbothermic or silicothermic reaction will be the most efficient. As with the beneficiation processes, more needs to be learned about the various processes, it is possible that hydrofluoric acid leach, or carbochlorination method might be even more efficient in the special environment of the moon.

All of the metal oxides can be separated through any of these processes but the need to be highly efficient means that these methods should be checked for their effect on the other lunar elements. If any one of these methods proves to be highly efficient at producing other elements as byproducts then that would be the method to consider highest [Ref. 4.10]. Early studies indicate that the carbothermic or silicothermic method will yield the best results.

4.5 Surface Operations References

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5.0 Required Technologies

To successfully construct, develop, and inhabit a permanent lunar base, several technological advancements must first be realized. The scientific breakthroughs that enabled the stunning success of the Apollo program will again be needed to establish a permanent presence on the moon, but they will also result in similar spin-off technologies with civilian applications in material science, medicine, power systems, and communications. The following sections outline some of the technological advancements that must be achieved to establish a permanent lunar base.

5.1 Construction in Low Earth Orbit

While most of the subsystems of a lunar base can be assembled on Earth, the size and weight of some of its deployment fleet vehicles might require construction in LEO. Advances in low gravity construction techniques such as welding and truss assembly will certainly come with the development of the Space Station, but they will need further improvement to build vehicles such as the Habitation Lander. Similarly, heavy payloads such as lunar surface construction equipment that can not be placed on the Shuttle will require the development of a heavy lift launch vehicle similar to the Saturn VB used to launch Skylab.

5.2 Construction on the Moon

A permanent lunar base will require technology for construction on the lunar surface. The most important of these developments include heavy machinery such as bulldozers, cranes, and trenching, digging, and drilling equipment. The surface vehicles such as bulldozers or regolith movers will require advances in traction to contend with the sandy lunar soil. Similarly, the digging machinery must be able to function reliably without moving parts rapidly deteriorating due to the gritty, sticky regolith. To aid in the removal of large quantities of regolith for the construction of a Phase 4 base, explosives technology for lunar applications should also be explored. Another important development that will be needed for lunar construction are improved space suits that provide a pressurized environment of nearly one atmosphere and still maintain sufficient flexibility, radiation protection, and material strength.

5.3 Lunar Base Developments

To occupy and maintain the lunar base with a permanent presence, advances in power systems for lunar application must be realized. Nuclear reactors for the base will require an extremely high level of safety and reliability to prevent a terrible accident such as Chernobyl from occurring on the Moon, since a bootstrap base will not have any means of effectively handling such a disaster. Alternate sources of power such as solar batteries or fuel cells will also require significant advances to provide the power necessary to run the base.

Improvements in life support systems will also be needed. While decreasing the resupply mass, advances in closing the oxygen, water, and food systems, as well as waste recycling will eventually lead to an autonomous lunar society. Included in this area is the development of solar flare and micrometeorite detection devices to signal the base personnel on the surface to seek adequate shelter.

Also needed is the technology necessary to derive resources from the lunar soil. Further investigation into electrochemical reactions will make the production of LOX and concrete from regolith and the extraction of metals not only possible, but profitable. These pilot plants will also require the development reliable, durable rotational joints to carry out the processing tasks. Like the surface traction vehicles, the pilot plants will need improved lubrication methods to decrease fatigue in these rotational parts.

5.4 Fleet Vehicle Developments

The generation of new technologies to support the development and performance of the lunar landing fleet and its support vehicles. Innovations in composite materials will result in lighter, stronger vehicles, as well as in lighter, stronger structural supports for a Phase 4 base that is located underground or inside a crater wall. Production of new rocket engine technology would benefit fleet vehicles with engines that are not only throttleable and restartable, but also are detachable and reusable. Advances in guidance, navigation, and control will also need to be achieved so that the fleet vehicles can be landed with an accuracy of a few meters. This will decrease the need for transporting payloads or additional SSCM's and ICM's for base expansion. Improvements in GN&C will also aid the development of return vehicles for payload and personnel that are capable of auto-piloted rendezvous and docking maneuvers with the Moonport OMV.

6.0 Environmental Impact

As with any extra-terrestrial activity, certain aspects of the project have the potential to impact the earth as well as the extra-terrestrial body. The Bootstrap Lunar Base itself has little potential for harming the earth, but during the launch of some of the payloads as well as during Low Earth Orbit construction of base components, several potential problems could occur. The base as well as the moon could be damaged during any phase of base construction.

6.1 Earth Environmental Impact

During the launch phase, several payloads could pose problems on the earth. First, a malfunction of the launch vehicle could cause the reactor core to begin an undesirable activity. Care must be taken, then, in the designing of this lander so that no such event could occur in the reactor core. Second, several payloads will have propellant on board. A problem in the payload bay of the launch vehicle could possibly trigger an explosion, as could several other sources. Propellants should be stored to ensure safety in these cases. Terrestrial impact from debris is always a concern when there is a problem with a launch. Precautions must be taken to limit the probability that the debris could land in an inhabited area.

Low Earth Orbit construction of base components poses impact concerns as well. If a falling piece from the structure being built in orbit survives Earth's atmosphere, it will impact the earth. Therefore, safety measures should be considered when construction activities are taking place. It is conceivable that such an impact could occur; it has happened before when Skylab fell back to Earth, and it could easily happen again.

6.2 Lunar Environmental Impact

A nuclear reactor is inherently dangerous to operate. The surrounding area will be contaminated as soon as the reactor is activated. Meltdown can put lives in jeopardy and prevent future habitation of the moon in certain areas. Safeguards are necessary to minimize contamination potential. In addition, pipes or other medium are needed to transfer coolant to turbines without contamination of the surrounding area.

Impact is a concern on the Bootstrap Base as well as on the Earth. A malfunctioning lander could crash and cause damage to the base. Propellants could initiate a fire in the base. The Crane Lander could errantly cause damage to the base.

Construction of the Bootstrap Lunar Base will inherently damage the surface of the moon. Mining will change the contour of the surface. Dust raised in construction and mining activities will inhibit visibility and cause accelerated fatigue of the machinery.

7.0 Operations Management

Lunar Operations Company (LOCO) is divided into an administrative directorate and an engineering directorate which are subdivided into divisions. The administrative directorate is made up of three divisions; Operations, Documentation and Accounting. The technical area is comprised of four divisions: Surface Operations, Fleet Operations and two Lander Operations design teams. A third lander group — from the Mechanical Engineering department— is working independently under the umbrella of LOCO. Each division has a division chief and staff personnel. LOCO maintains thirty positions —held by 15 members— (Fig. 7.1); two area directors, seven division chiefs, and twenty-one technical and administrative staff positions.

7.1 Operations Management Philosophy

"What is the worst possible reaction when faced with a challenge?"

"Not to respond."

Asked to create an organization capable of effectively responding to the RFP, Lunar Operations Company was born. With the assistance of a program monitor, Dr. George Botbyl, and consultants, Dr. Wallace Fowler and Darrel Monroe, LOCO has been able to respond to all the challenges it has encountered.

LOCO chose to develop an innovative, responsive and flexible company structure (Fig. 7.2). Although everyone holds two positions (Fig. 7.3) each may only hold one leadership role. This reduces the responsibilities of each member and ensures that a reasonable work load is maintained. In addition, LOCO chose this management structure for the following reasons:

—to distribute the technical and administrative tasks

—to maximize distribution of information within the company by providing multiple communication pathways

—to maximize the number of employees with leadership positions and thereby reduce the number of major responsibilities per division chief.

The general duties of each division chief and those of the area directors is given below.

Technical and Administrative Directors

- oversees the technical and administrative aspects of the project
- leads meetings once a week with division chiefs
- acts as one of two points of contact between LOCO and project monitor

Division Chiefs

- oversee technical aspects of division
- lead meetings held three times a week with division staff
- allocate project tasks

Operations

- schedule determination and monitoring
- identify, report and respond to problems

Documentation

- produce reports and presentation material
- resource management
- compile Project Book

Accounting

- cost projection
- payroll and supply management

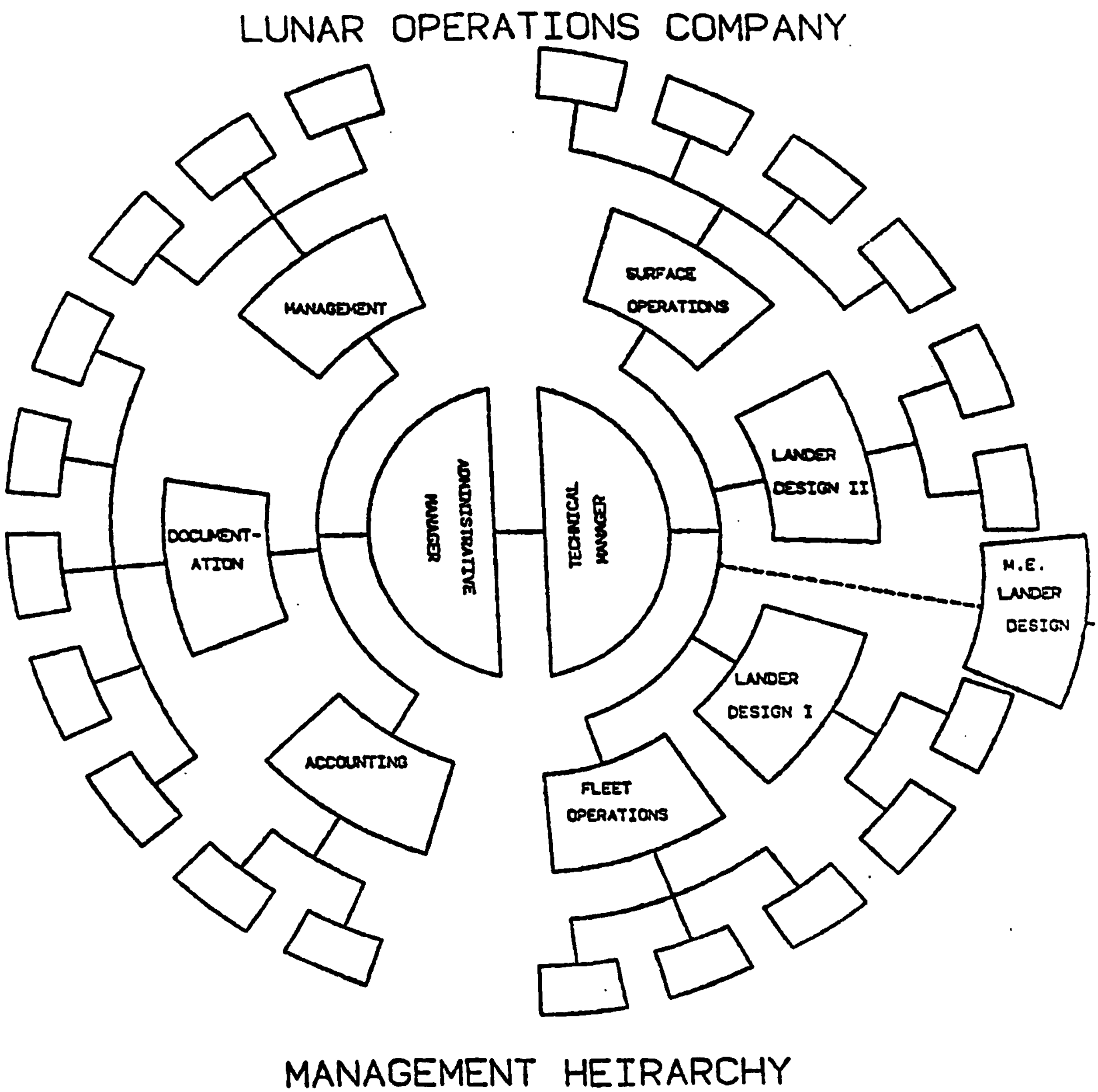


Figure 7.1. Lunar Operations Company Management Structure

Figure 7.2: Lunar Operations Company Management Structure

Engineering Directorate
George W. Davis

Fleet Operations Division	Surface Operations Division	Lander Operations Divisions	
Frank Mendoza	**JamesSturm**	**Lynette Latta**	**Ron Wood**
George W. Davis	Bruce Boulanger	Dario Duran	Leif Schley
Erett Knobloch	Susan Clark	Terry Duval	Janet Wigley
	John Powell		
	Kevin Sagis		
	Miguel Sequeira		

Administrative Directorate
Susan Clark

Operations	Documentation	Accounting
Dario Duran	**John Powell**	**Erett Knobloch**
Lynette Latta	Terry Duval	Frank Mendoza
Leif Schley	Miguel Sequeira	Kevin Sagis
James Sturm	Janet Wigley	
	Ron Wood	

Figure 7.3: Lunar Operations Company Employee Roster

Name	Positions Held	Phone
Bruce Boulanger	Engineer, Surface Operations Div. Clerk, Documentation	441-4479
Susan Clark	Director, Administration Engineer, Surface Operations Div.	452-8515
George W. Davis	Director, Engineering Engineer, Fleet Operations Div.	473-2457
Dario Duran	Manager, Operations Engineer, Lander Operations Div.	472-8681
Terry Duval	Engineer, Lander Operations Div. Clerk, Documentation	1-321-5376
Erett Knobloch	Manager, Accounting Engineer, Fleet Operations Div.	472-5282
Lynette Latta	Chief, Lander Operations Div. Clerk, Operations	445-4785
Frank Adam Mendoza	Chief, Fleet Operations Div. Clerk, Accounting	467-7210
John Powell	Manager, Documentation Engineer, Surface Operations Div.	385-5629
Kevin Sagis	Engineer, Surface Operations Div. Clerk, Accounting	385-5629
Leif Schley	Engineer, Lander Operations Div. Clerk, Operations	476-2761
Miguel Sequeira	Engineer, Surface Operations Div. Clerk, Documentation	251-7342
James Sturm	Chief, Surface Operations Div. Clerk, Operations	451-5917
Janet Wigley	Engineer, Lander Operations Div. Clerk, Documentation	442-9309
Ron Wood	Chief, Lander Operations Div. Clerk, Documentation	442-9309

7.2 Operations Management Update

LOCO has been able to maintain its ambitious schedule throughout the contract period. Determined to complete their tasks by the Thanksgiving holiday, LOCO increased its work load during the weeks of November 6 - 23. A schedule of major milestones and their presentation dates is shown.

Task	Presented
PDR I	October 26, 1987
Inter-University Conference	October 29, 1987
Report I	November 4, 1987
PDR II	November 20, 1987
Report II	November 25, 1987
NASA Presentation	December 4, 1987

As a result of practice gained with the various presentations, most, if not all of the documentation is now done by each member or within the division.

With the completion of the Preliminary Design Review II briefing, the major setback encountered has been a gradual decrease of initiative and motivation in this last week of the contract period. With the end in sight, this has not had an adverse affect on LOCO's schedule. Any personnel problems which may have existed through November 4th, such as low productivity on the part of several members, have been corrected by the Operations Management division.

7.3 Operations Management Recommendations

In spite of the fact that LOCO has been able to effectively respond to every obstacle it has faced, it is by no means perfect. Several strengths and limitations which are inherent to the heirarchical structure shall be pointed out, as well as recommendations to future companies under NASA/USRA contract.

— Factioning arose in Surface Operations and Lander Operations. This was do in part to the size of the groups, lack of well defined heirarchy and ill defined goals.

  — A possible solution would be to employ small groups (3-4 members) throughout the company. These will provide several advantages:

    — allow for ease of task allocation and progress evaluation

    — yield a high level of communication

    — grant each group the freedom necessary to develop and mature within the company framework.

— The effectiveness of the director's position was compromised by its dual nature. Friction caused by its "I lead you while you lead me ..." nature was evident several times during the work period.

  — Require the director to work in all groups in a capacity of a third-hand, only assisting and answering only to the needs of the company. This will provide several advantages:

    — it allows the director to monitor first-hand the development of the project

    — it eliminates the contradictions inherent to having a leader follow

— The most crucial task, that of documentation, fell pray to a common Christian demon. The desires of the slothful many being served by the efforts of the industrious few. "No man is an island unto himself". It is unreasonable to assume that a few can carry an entire project.

  — Maintain a manager for documentation, but require that the other positions in the division be filled by an equal number of members from each division.

    — This will provide each division with the resources to produce documentation on demand.

— Also, it eliminates the tensions which arise several days before any major presentation.

8.0 Cost Analysis

Lunar Operations Company's projected budget for the Bootstrap Lunar Base design work was $37,609.00. This amount was determined using figures given in RFP #274L, Fall 1987 as well as amounts quoted from other sources. Lunar Operations Company has stayed close to that dollar figure, as the actual cost of the base design effort is $38,286.50, only $677.50 over budget. This amounts to less than 2% over the projected cost. The major reason that LOCO went above the projected figure is that the budget was figured over a ten week schedule, while the project actually lasted eleven weeks. A listing of costs is included in Table 8.1.

Table 8.1 Lunar Operations Company Cost Summary

Item	Actual Cost	Projected Cost	Difference
Directors	$7400.00	$7500.00	-$100.00
Technical Heads	9120.00	8000.00	1120.00
Management Heads	5370.00	6000.00	-630.00
Engineers	12465.00	8250.00	4215.00
Administrative Staff	708.00	600.00	108.00
Consulting	3037.50	3750.00	-712.50
Transparencies	81.00	60.00	21.00
Copies	105.00	30.00	65.00
Subtotal	38286.50	34190.00	4096.50
Plus 10%		3419.00	
TOTAL	**$38286.50**	**$37609.00**	**$ 677.50**

9.0 Project Evaluation

To review the design effort of LOCO over the contract period, the following sections discuss the strengths and weaknesses of the project as identified by the individual teams. Recommendations for future work based on this self-examination are presented in the Section 10.

9.1 Fleet Operations

This division's overall performance met expectations. With every design project, however, details will get accidently overlooked and simplifying assumptions may be used to excess. Therefore, the following will include information on some of the areas which require more work and possibly modification.

The strength of the preliminary mission planning work was the agreement of Δ V calculations with those incurred in the Apollo landings, using Hohmann transfers and Lambert targeting. This allowed good estimates of the fuel needed to deorbit to the lunar surface and thus helped to size the lunar landers. More work, however, could have been done for minimum time of flight calculations for both descent and ascent to and from the lunar surface since these become very important in emergency scenarios.

The communication and navigation subdivision requires additional research in the satellite area. More information is needed on what the effects would be when reducing the TDRSS subsystems as well as information on upgrading existing less expensive communication and navigation satellites. The proximity equipment that was analyzed, (ILS, TACAN, and Laser Ranging), is for atmospheric applications, therefore research needs to be conducted on applying these systems to the vacuum of space.

Finally, since the fleet vehicle support subdivision used existing hardware for deploying satellites and for docking/undocking payloads from Moonport, technology advancements at the time of bootstrap deployment need to be incorporated into the analysis. It would have also been desirable to investigate the use of restartable liquid fuel motors for satellite deployment.

9.2 Lander Design

Self-evaluation is an oft dreaded task, but it is as critical a part of the design process as the design itself. The Lander design teams accomplished its goals as set at the start of the contract period. Many concepts were introduced and reviewed. Trade studies were undertaken resulting in the five lander designs presented in the body of this report. In general, several shortcomings were evident with the study: its depth and its compatibility with other base systems. Specifically, the study did not explore, the feasibility of alternate power plants and RCS's; the applicability of extensive modularity and major subsystems. In addition, communication difficulties prevented a more thorough integration of specific lander designs with corresponding surface systems. Integration with Moonport systems (i.e., fleet operations) was non-existent. It was also determined that designing transformable landers is a difficult process without a fully developed lunar base with which to work. It is hard for designer to develop landers that are transformable and reusable unless they know exactly what types of landers are needed and into what possible base elements they can be realistically transformed. This became readily apparent with the design of the Box Lander and the Slide Lander developed for PDR 1. Valuable time spent working on these impractical vehicles could have been spent on designing landers that could actually be used in a *bootstrap* lunar base.

9.3 Surface Operations

Evaluation of the progress and accomplishments of the Surface Operations Division is most difficult. The Division's work was based on the concept of developing functional requirements for all systems deemed necessary. It was felt that there was not enough knowledge to enable an actual design of most of the surface components. The group did not work with the idea of developing functional requirements first and foremost Specifically, components were designed and emplaced without any real feeling for what the components had to do. Requirements were imposed on the systems only after they were in place, and as such, reflected the biased opinions of a system already designed. Systems should be fit to previously defined requirements rather than having the requirements fit a previously designed system. As is often found in design groups it was difficult for all members of the group to 'throw out' ideas that had outlived their practicality. A 'communal intelligence' realized that there would be many blind alleys before a practical design was reached, but when the time came and it was an individual's design that was at question, tempers flared. As the time drew near to present final results the group began to realize that certain 'sacred cows' had to be thrown out and whole systems reworked to fit requirements that other groups or sections within Surface Operations had imposed. Final designs accomplished goals set out in the proposal but often at the cost of creating innovative solutions. Many solutions are methods that are tried and true, which is not negative since such methods have little or no R&D outlays. A lunar base does not necessarily require entirely new concepts but innovation lies at the heart of any successful program. Nevertheless, had there been additional time, it would have been desirable to further develop some aspects of the bootstrap base such as of the surface construction equipment needed to construct the base and possible scientific experiments to be carried out by the base personnel while they are not engaged in construction activities. In-depth investigations into partially closing the ECLSS of the bootstrap base would have also been desired.

10.0 Recommendations

The bootstrap lunar base developed by LOCO leaves many options for future work. The first option is to fully develop the bootstrap base. Discussion should begin with construction processes using teleoperated robotic equipment, crew activity that is not related to construction such as scientific experiments as well as recreation, and immediate benefits to the bootsrap base from resources extracted by the processor. This work could be augmented by point designs for surface construction equipment such as diggers, trenchers, etc. by the ME design groups.

Another option would be to expand the bootstrap base into a permanent Phase 3 or Phase 4 base. This would require a study of closing the ECLSS for such a settlement, deep mining operations, and how to effectively export raw and manufactured products to LEO. Closing the ECLSS would involve investigations into closed ecosystems, agriculture, full water recycling, full waste recycling, etc. Deep mining operations would require work on tunneling procedures and the use of explosives technology in a lunar environment. A permanent base will also require research into new forms of transportation on the lunar surface where traction vehicles will not be as effective. This might include an investigation of legged robots that can walk on uneven surfaces as well as negotiate obstacles.

A final option would be to take the bootstrapping concepts discussed in this report and apply them to a manned mission to Mars. This would be a challenging project because of the difficulties imposed by the travel and resupply time due to the incredible distance between Earth and Mars and because of the harsh Martian environment. Nevertheless, such a mission is inevitable as the U.S. space program begins to reach out beyond the confines of the Earth-Moon system and into the rest of the solar system.

APPENDIX A : ADDITIONAL CONCEPTUAL VEHICLE DESIGNS

Slide Lander

The purpose of the slide lander is to transport general cargo and payloads to the lunar surface as efficiently as possible. To do this, it would avoid the "brute force" method of conventional vertical landings by transferring to the lunar surface via a pseudo-Hohmann transfer, touching down on skids, and deploying a "dirt-brake" to slow to the lander to a stop. The Slide Lander is shown in Fig. A.1.

The landing sequence would begin with an orbital maneuvering vehicle (OMV) removing the assembled slide-lander from Moonport and placing it in a "safe" area to begin the burn for the necessary deltaV to transfer to low lunar altitude. The lander would then activate its engines and perform a pseudo-Hohmann transfer with the perigee of the transfer orbit slightly above the lunar surface.

Upon arrival at perigee, the engines would be rotated in such a way as to push the lander toward the lunar surface. If one or more of the engines misfire or the landing site is overshot, the burn is quickly terminated and the lander is allowed to continue along its original transfer orbit trajectory until it can be recovered and repaired. If, however, all goes as planned, the lander would be pushed toward the surface and the touchdown sequence initiated.

When surface contact is near, the engines would be rotated so that they thrust upward to support most of the lander weight as it touches down in order to provide a "soft" landing.

Once the craft has stabilized its touchdown, the engines would be rotated so that the thrust was used to slow the lander. Then, the dual "dirt parachutes" would be lowered onto the lunar surface. The parachutes would deflect regolith in a desired direction, thereby providing friction and mass-flow braking as well as the thrust braking being applied.

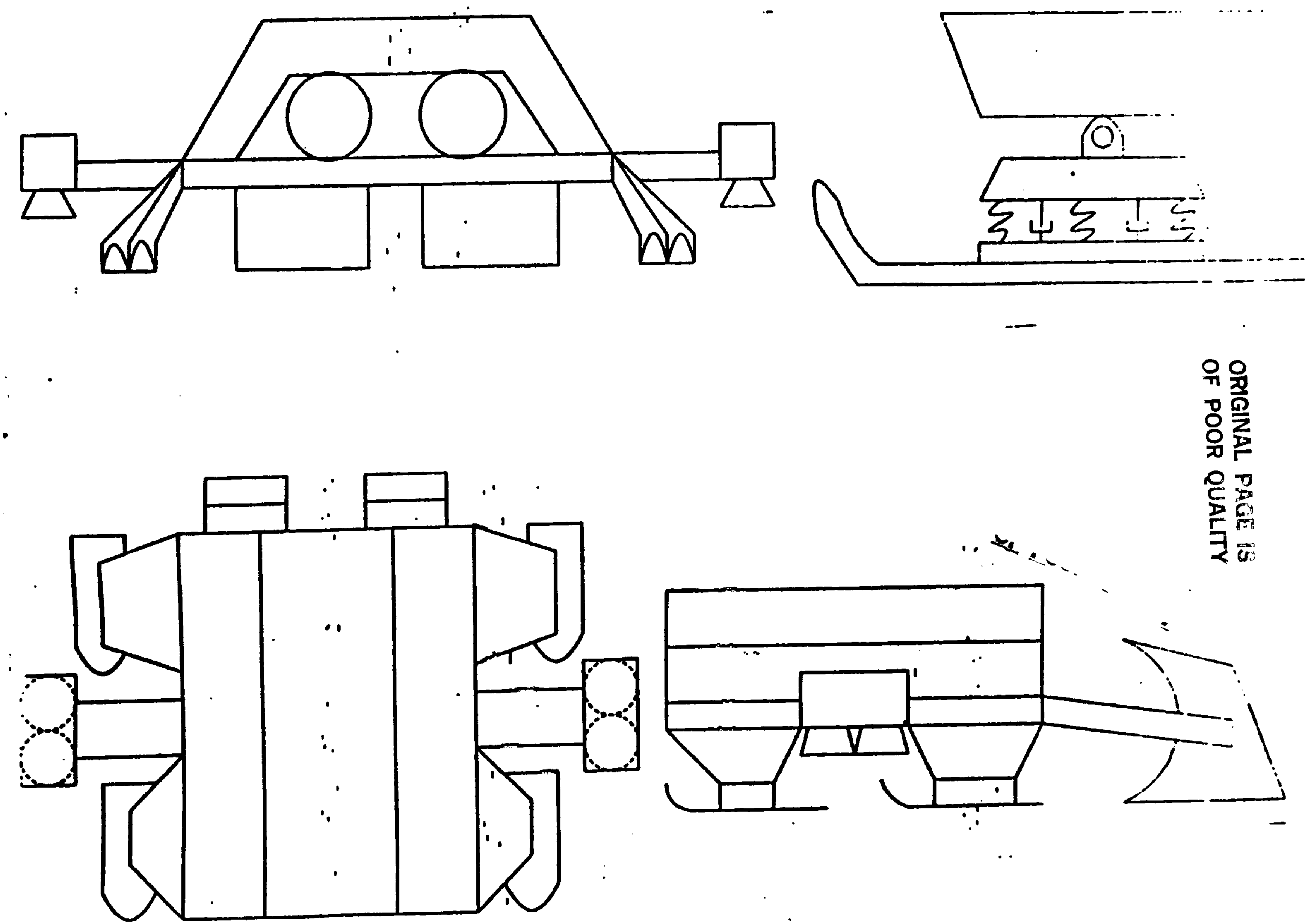
To minimize the landing area preparation and increase the number of possible landing sites, the dirt parachutes are positioned so that increased downward pressure on one of the parachutes would increase the force on that parachute and be unbalanced by the force on the other parachute. The result would be a steering ability, allowing the lander to maneuver around obstacles in its path. Therefore, it could literally "drive" to the desired destination.

There are many advantages to landing cargo in this manner. First, a complete abort ability exists throughout much of the landing procedure in case of overshooting the landing site or in case of a single or multiple engine failure. Also, the amount of fuel needed to perform this type of landing is much less than for a conventional landing. Fuel is needed only for the initial delta V for the Hohmann transfer and the optional braking thrust during and after touchdown.

Another advantage to slide landing is that the large amount of kinetic energy the lander has while in lunar orbit is counteracted by the friction from the lunar regolith instead of by using fuel to diminish it. The kinetic energy can also be converted into usable work by deflecting the regolith with the dirt brake to a desired direction, possibly to cover the payload on the lander itself. This could be useful for providing radiation protection to a habitation module being transported to the surface.

Slide landing with the developed design also offers the appealing option of "driving" the lander to a desired location. This eliminates the need for the pinpoint accuracy need in vertical landings used previously.

A disadvantage of the slide lander is that it would require an extremely reliable and quick-responding guidance and control system to steer it during and after touchdown. Also, even with a quick guidance system, a relatively large, smooth initial touchdown area is required. Another disadvantage is that the diversity of uses for the engine thrust calls for the engines to have a high degree of rotational ability. This is an area that would require significant research and development.



Slide Lander (3-View) and
Close-Up of Skid System

Jump Jet

During the first and second phases of construction, it has become evident that both Moonport and lunar base will be highly dependent on each other. For this reason, it became necessary to design a vehicle that would provide transportation and serve as an emergency escape craft for both bases. After a preliminary design study, it was also determined that the vehicle could be used for long range surface exploration.

The vehicle must be designed to a particular set of criteria in order to be used as a man rated ascent descent craft. Primary among these is reliability. Because the vehicle will be making frequent trips between bases, it will be necessary for the engines to be started and stopped many times between servicing while maintaining a high degree of reliability. The vehicle must also be designed to carry enough fuel to make a round trip with a maximum payload of 1,100 kg. This would provide transport or emergency escape for six crew members with suits or twelve personnel without. In the transport mode, the vehicle, or jump jet, would carry only a minimum amount of supplies for crew accommodation.

When used as a surface exploration vehicle, the jump jet would be refitted with extra fuel pods, oxygen, and food to support a crew of three for two weeks. In addition, the craft would provide U.V. protection, a shirt sleeves environment, and suitable work space for the crew.

The major consideration in the design of the vehicle must be adaptability. Since the craft is to be used for a variety of purposes, the cabin must be able to be rearranged to suit each particular mission. Fig. 3.11 is an initial design and indicates how the following requirements may be met.

- an overall design that would enable the craft to be used with or without pressure suits
- an onboard computer to determine the ballistic trajectory for surface hops or rendezvous trajectory for orbital transport
- airlock and docking mechanism located on the front or side
- extra fuel pods, oxygen and food located in either the front or

back to maintain center of gravity

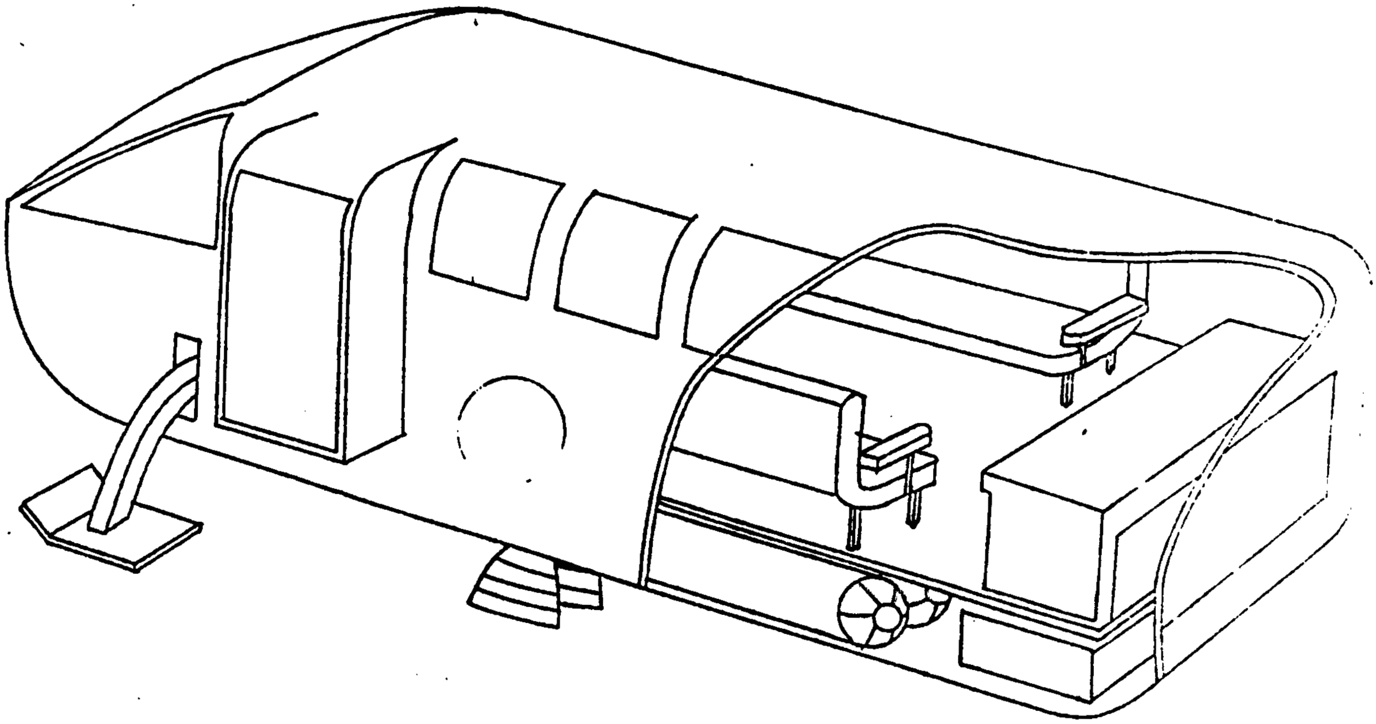
- collapsable rover stored in back
- bench type seats that can be removed or inclined to form a bed
- work area in back that can also be used for cargo storage
- compressible suspension for rough terrain landing

Primary propulsion for the vehicle would be two throttlable, gimbaled rocket motors located on the center of gravity. Each motor should be operable at more than 100% power in the event that the other motor fails. The motors would use the common LH2-LO2 fuel. Fuel tanks would be located in the floor of the vehicle with attachments for extra fuel pods for extended trips. Electrical power would be provided by LH2-LO2 fuel cells with solar cell backup for surface exploration.

Control would be provided by RCS clusters located at the front and rear of the craft in conjunction with the gimbaled rocket motors. An onboard computer would provide complete trajectory control with pilot override available just before landing.

To meet the design requirements, the vehicle must be large enough to carry twelve personnel while remaining light enough to be handled by the OMV. An initial cabin size of 3m X 3m X 8m with a dry weight of 2,750 kgs. was chosen.

While this is probably unrealistic at this time, it should be attainable by the year 2000. Using this initial geometry and a payload of 1,100 kgs., it was estimated that 5000 kgs. of fuel would be necessary for a round trip. This gives a departure weight of 8,850 kgs. which is the upper limit of the OMV's handling abilities.

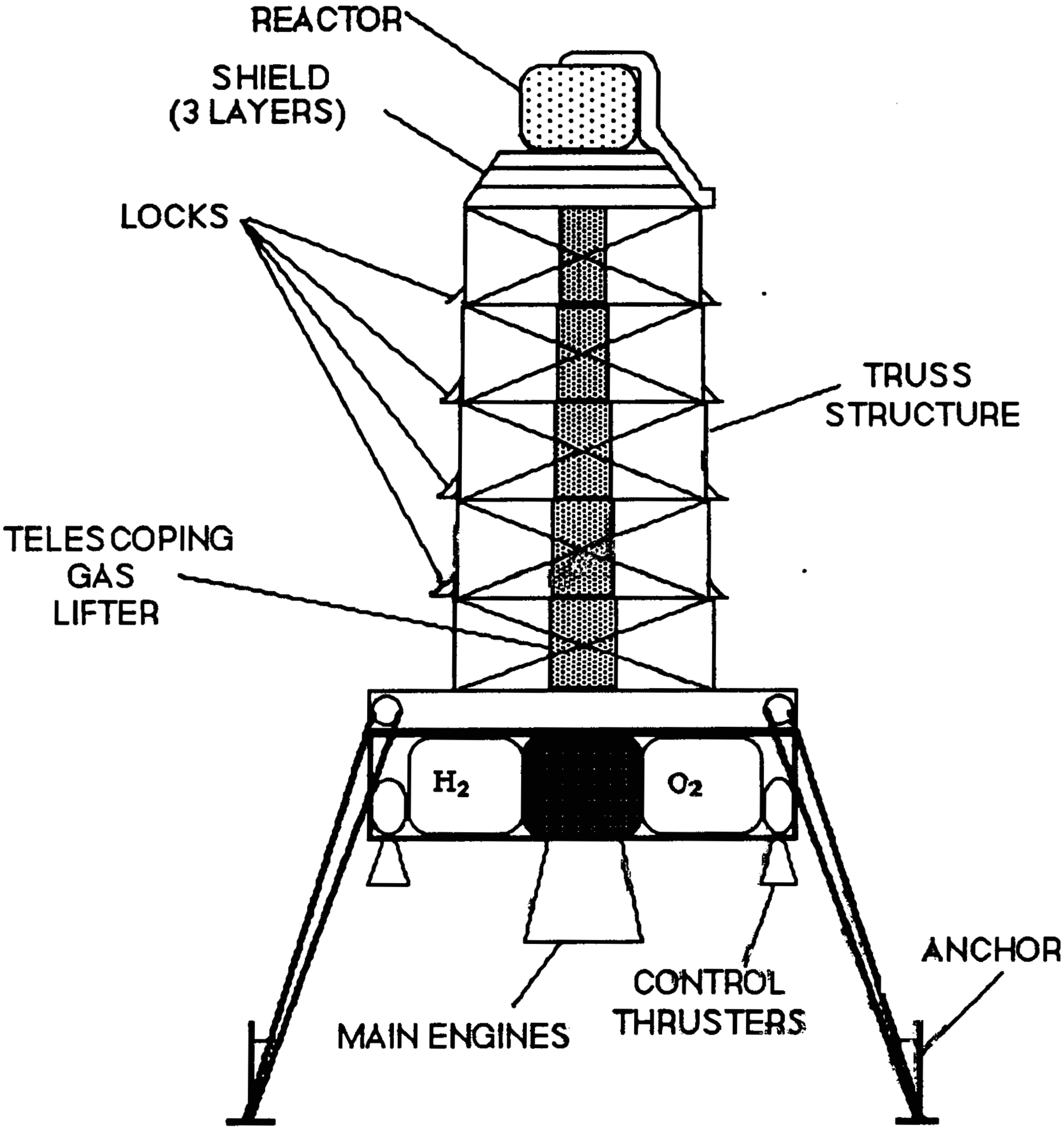


Telescoping Lifting Device

A telescoping lifting device can be used in many situations in a bootsrtap base. For example, it can be used to raise communication antennas to a certain height above the lunar surface. It can also be used to raise payloads to be loaded on a return vehicle. The lifter shown below was first developed to raise the nuclear reactor 15.5 m above the lunar surface. It was later decided to use a reactor that was located on the surface, but the telescoping lifter can still be employed in different capacities, as described above.

LIFTING FORCE CALCULATIONS

X (m)	V (m^3)	P (Pa)	F (N)	a (m/s)
1.7	.2689	463,034.75	73,252.09	2.2584
3.4	.5534	224,991.04	35,593.58	.2238
5.1	.8527	146,018.58	23,100.14	- .4505
6.8	1.1696	106,455.24	16,841.22	-.7879
8.5	1.5033	82,824.48	13,102.83	-.9890



POWER PLANT RAISED BY TELESCOPING LIFTING DEVICE

APPENDIX B : CALCULATIONS

Hohmann Transfer Calculations

The following parameters describe the Moonport orbit from where deployment will occur :

$$i = 0$$
$$e = 0$$
$$alt = 100 \text{ km}$$

The following lunar physical constants were used :

$$R_{moon} = 1738 \text{ km}$$
$$\mu_{moon} = 4.90287 \times 10^3 \text{ km}^2/\text{sec}^3$$

Results obtained for a single Hohmann burn to a vacuum perigee are

$$R_1 = R_{Moonport} = 1838 \text{ km}$$
$$R_2 = R_{surface} = 1738 \text{ km}$$
$$A_{TO} = (R_1+R_2)/2 = 1788 \text{ km}$$
$$TOF_{TO} = 1080 \text{ sec} = 18 \text{ minutes}$$

$$V_{1c} = 1.6334 \text{ km/sec}$$
$$Va_{TO} = [\mu(2/A_{TO}-1/1R_a)]^{1/2} = 1.6102 \text{ km/sec}$$
$$Vp_{TO} = [\mu(2/A_{TO}-1/1R_p)]^{1/2} = V_{landing} = 1.7029 \text{ km/sec}$$

$$DV_{tot} = |\ 1.6102 - 1.6334\ | + |\ 0 - 1.7029\ | = 1.7259 \text{ km/sec}$$

It should be noted that these velocities are absolute and that the velocity of the vehicle relative to the lunar surface depends upon whether the transfer orbit is posigrade or retrograde. A point on the lunar equator moves with a velocity of V = 0.0046 km/sec so a vehicle landing with the direction of the Moon's rotation has a *relative* velocity of V_{rel} = 1.7029 - 0.0046 = 1.6983 km/sec and a vehicle landing opposite to the Moon's rotation has a *relative* velocity of V_{rel} = 1.7029 + 0.0046 = 1.7075 km/sec.

Lander Division Calculations

*** Given the Δv's from George (a Hohmann from 100 km circular to surface)**

$\Delta v_1 = -23$ m/s $\qquad \Delta v_2 = -1702$ m/s $\qquad \|\Delta v_{total}\| = 1725$ m/s + 15% = 1983.75 m/s

***** $\Delta v = I_{sp}\, g \ln (M_o / M_b)$ **where** $M_o = M_b + M_{prop}$

***** $M_{prop} = \{\exp [\, \Delta v / I_{sp}\, g] - 1\}\, M_b$

*** Use I_{sp} for Oxygen / Hydrogen $I_{sp} = 420$**

NTO / 50% UDMH $I_{sp} = 293$

$M_{prop} = 19{,}296.73$(kg) $\qquad M_{prop} = 31{,}015.72$ (kg)

38% more prop for NTO / 50% UDMH than LO_2 / LH_2

*** Mass of the habitation lander**

***** $M_{\text{Habitation Lander}} = M_{\text{Modules}} + M_{\text{Structure}} + M_{\text{Propellant}}$

$M_{\text{Habitation Lander}} = 6783 \text{ kg} \times 4 + 15\% \, (M_{\text{Modules}} + M_{\text{Propellant}}) + M_{\text{Propellant}}$

$M_{\text{Habitation Lander}}$ = 66,870 (kg) = 147,278.5 (lb) ——— {NTO...}

$M_{\text{Habitation Lander}}$ = 53,393 (kg) = 117,596 (lb) ——— {LOX/LH2...}

Weight (Habitation Lander on moon) = 24,570 (lb) ——— {NTO...}

Weight (Habitation Lander on moon) = 19,618 (lb) ——— {LOX/LH2...}

*** Given the mass of propellant and density, a volume can be calculated**

$V_{prop} = 26.2\ (m^3) = 940.6\ (ft^3)$

density of NTO / 50% UDMH = 1180 (kg / m^3)

$V_{prop} = 71.47\ (m^3) = 2{,}519\ (ft^3)$

density of LOX/LH2 = 270 (kg / m^3)

*** Given a volume for propellant, volume of modules and interlocking modules**

$V = 26.8 + 656 + 128$

$V_{lander} = 812.8\ (m^3)$

*** Dimensions in a general way**

5 m x 13 m x 13 m

*** Using Apollo LEM as a base-line to determine a thrust to weight ratio**

Thrust (LEM) = 1,050 - 10,500 lb (w/ an average value of 5,775 lb)

Weight (LEM on moon) = 5,000 lb

T / W = 2.1 (or using the average value of thrust T / W = 1.155)

Thrust (Habitation Lander) = 51,598 (lb) ——— {NTO...}

Thrust (Habitation Lander) = 41,199 (lb) ——— {LOX/LH2...}

* **Use thrust and specific impulse to determine the mass flow rate**

***Thrust = I_{sp} g m**

m = 176.1 (lb / sec) ——— {NTO...}

m = 98.09 (lb / sec) ——— {LOX/LH2...}

POWER PLANT

The following is the calculations for the gas lifter.

A. Calculations for telescoping gas lifter mass:

Assumtions : 1. Wall thickness is .25 in or .0064 m.
2. Density of steel alloy is 7900 kg/m^3.
3. There are 5 segments of the gas telescoping lift of 1.7 m length.

Equations:

V_t=total volume	r_o=outside radius	M=mass
$V_j=(r_o^2-r_i^2)*\pi*$	$M=V_t*p$	p=density
V_j=volume of segment	r_i=inside radius	
$V_t=\Sigma V_j$	L=length	

Sample:

$V_1=\{(.2564)^2-(.2500)^2\}*\pi*1.7 = .0173\ m^3$

$V_t = .0822\ m^3$

$M=(.0822)*(7900)=649.38$ kg

B. Calculations for work required to raise reactor and shield.

Assumptions :
1. Height needed to be raised is 6.8 m.
2. Frictional force of 150 lbs or 667.23 N is acting over this distance
3. Mass of each truss structure segment is 20 kg.

Equations:

$W=(m^*g_L{}^*h) + \Sigma(m_i{}^*g_L{}^*\Delta h_i) + \Sigma(m_j{}^*g_L{}^*\Delta h_j) + f^*h$

W=work

m=mass of reactor and shield

m_i=mass of cylinder segment

m_j=mass of truss structure segment

g_L=lunar gravity

h= height

Δh_i=height of cylinder stucture i raised

Δh_j=height of truss structure j raised

f=frictional force

Sample:

W= (18500*(9.81/6)*6.8) + (9.81/6)*{(133.51)*(1.7) +(129.56)*(3.4) + (126.40)*(5.1) + (123.24)*(6.8)} +(9.81/6)*{(20)*(1.7) + (20)*(3.4) + (20)*(5.1) + (20)*(6.8)} + (667.32)*(6.8 = 214,291.55 J

C. Calculations to determine pressure required to raise reactor and shied.

Assumption: Temperature is constant.

Equations:

$(P^*V)_1 = (P^*V)_2$

P=pressure

$V_i = \Sigma (r_i)^{2} {}^* \pi^* L$

V=volume

$W = \int P(V)\, dV$

W=work

r_i=radius of cylinder i

L=length of cylinder

Sample:

$P(V) = (P^*V)_1/V$

$V = \pi^* 1.7^* \{(.2500)^2 + (.2436)^2 + (.2372)^2 + (.2308)^2 + (.2244)^2\} = 1.5033\ m^3$

$W = \int (P^*V)_1/V\, dV = (P^*V)_1{}^* \ln(V_2 + V_1)$

with V1=.2689 and V2=1.5033=.4628*P_1 = 214,291.55

P1=463,034.75

Pa = 67.16 psia

D. Calculations for force and acceleration.

Assumption: Compressed gas is released instantaniously.

Equations:

$F_{gas} = P^*A$

P=pressure

$\Sigma F=(m+m_c+m_t)*a=F_{gas}-w-f-(w_c+w_t)$

A=surface area

F=force

m=mass of reactor and shields

f=frictional force

w=lunar weight of reactor and shields

w_c=cylinder weight

w_t=truss weight

m_c=cylinder mass

m_t=truss mass

Sample:

F=(463,034.75)*(.1582) = 73,252.097 N = 16,467.804 lbs

ΣF=(18500+20+123.24)*a=73,252.0974 - 667. 23 -
(9.81/6)*(18500+20+123.24)

a=2.2584 m/s = 7.4094 ft/s

APPENDIX C : PROGRAM LISTINGS

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```
      PROGRAM LAMBRT(INPUT,OUTPUT,TTY,TAPE5=INPUT,
     +         TAPE6=OUTPUT,TAPE11=TTY,TAPE12=TTY)
C-----------------------------------------------------------------------
C
C     THE PURPOSE OF THIS PROGRAM IS TO CALCULTE THE DV'S REQUIRED TO
C     TRANSFER PAYLOAD TO THE LUNAR SURFACE USING LAMBERT TARGETING
C     AT SOME TIME T AFTER INITIATING A HOHMANN TRANSFER
C
C-----------------------------------------------------------------------

      DIMENSION P(7), RI(3), VI(3), RF(3), VF(3), ESET(8)
      DIMENSION RTARGT(3), VTARGT(3), VTLAM(3)
      DIMENSION DV1(3), DV2(3), DATA(209,3)

C---- INITIALIZE CONSTANTS

      PI = ACOS(-1.0)
      DTR = PI/180.0
      RTD = 180.0/PI

      RMOON = 1738
      RMU = 4.9028E3
      ALT = 100
      RMP = RMOON + ALT
      VMP = SQRT(RMU/RMP)

      RI(1) = RMP
      RI(2) = 0.
      RI(3) = 0.

      VI(1) = 0.
      VI(2) = VMP
      VI(3) = 0.

C---- TRANSFER TO LUNAR SURFACE USING LAMBERT TARGETING

      I = 0

      DO 100 ANGLE=30.,330.,30.

      DO 50 TOF=1000.,10000.,500.

        I = I + 1

        P(1) = TOF
        P(2) = PI/2.0
        P(7) = RMU

        RLAT =
        RLON = ANGLE*DTR
        IF ( ANGLE.EQ. 180. ) RLON = 179*DTR
        IF ( ANGLE.GT. 180. ) P(2) = 1.5*PI

         RTARGT(1) = RMOON*COS(RLAT)*COS(RLON)
         RTARGT(2) = RMOON*COS(RLAT)*SIN(RLON)
         RTARGT(3) = RMOON*SIN(RLAT)

        CALL SLMBRT (P,RI,RTARGT,VTLAM,VTARGT,IERR)

C---- DETERMINE DELTA V
```

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```
      DV1(1) = VTLAM(1) - VI(1)
      DV1(2) = VTLAM(2) - VI(2)
      DV1(3) = VTLAM(3) - VI(3)

      DV2(1) = -VTARGT(1)
      DV2(2) = -VTARGT(2)
      DV2(3) = -VTARGT(3)

      DVTOT = ABV(DV1) + ABV(DV2)

      DATA(I,1) = ANGLE
      DATA(I,2) = TOF
      DATA(I,3) = DVTOT

      WRITE(4,3000) TOF,ANGLE,DVTOT
3000  FORMAT(/,5X,' TIME OF FLIGHT = ',F8.2,/,
     +       5X,' TRANSFER ANGLE = ',E12.5,/,
     +       5X,' TOTAL DELTA V = ',E12.5,/)

 5    CONTINUE

100   CONTINUE

      DO 200 J=1,209
        IF ( J.LT.20 ) WRITE(15,*) DATA(J,2), DATA(J,3)
        IF ( J.GE.20.AND.J.LT.39 ) WRITE(16,*) DATA(J,2),DATA(J,3)
        IF ( J.GE.39.AND.J.LT.58 ) WRITE(17,*) DATA(J,2),DATA(J,3)
        IF ( J.GE.58.AND.J.LT.77 ) WRITE(18,*) DATA(J,2), DATA(J,3)
        IF ( J.GE.77.AND.J.LT.96 ) WRITE(19,*) DATA(J,2), DATA(J,3)
        IF ( J.GE.96.AND.J.LT.115 ) WRITE(20,*) DATA(J,2), DATA(J,3)
        IF ( J.GE.115.AND.J.LT.134 ) WRITE(21,*) DATA(J,2), DATA(J,3)
        IF ( J.GE.134.AND.J.LT.153 ) WRITE(22,*) DATA(J,2), DATA(J,3)
        IF ( J.GE.153.AND.J.LT.172 ) WRITE(23,*) DATA(J,2), DATA(J,3)
        IF ( J.GE.172.AND.J.LT.191 ) WRITE(24,*) DATA(J,2), DATA(J,3)
        IF ( J.GE.191 ) WRITE(25,*) DATA(J,2), DATA(J,3)

200   CONTINUE

      DO 300 I=1,19

        WRITE(8,4500) DATA(I,2), DATA(I,3), DATA(I+19,3), DATA(I+38,3),
     +  DATA(I+57,3), DATA(I+76,3), DATA(I+95,3), DATA(I+114,3),
     +  DATA(I+133,3), DATA(I+152,3), DATA(I+171,3), DATA(I+190,3)

4500    FORMAT(F8.1,1X,11(F5.3,1X))

300   CONTINUE
      STOP
      END
```

```
      PROGRAM LAUNCH
C
C     ******************************************************************
C     *                                                                *
C     *    THIS PROGRAM DETERMINES THE ASCENT FLIGHT HISTORY OF A      *
C     *    LAUNCH VEHICLE BY RUNGE-KUTTA ITEGRATION OF THE EQUATIONS   *
C     *    OF MOTION.  THE EQUATIONS ARE INTEGRATED FROM FINAL         *
C     *    CONDITIONS TO DETERMINE OPTIMUM INITIAL CONDITIONS.         *
C     *                                                                *
C     ******************************************************************
C
      IMPLICIT REAL*8 (A-H,O-Z)
      PARAMETER (N=6,M=3,MEQ=3,LCN=7,LW=600)
      DIMENSION X(N),FX(N),C(M),CX(LCN,M),W(LW),THETAT(5)
      COMMON /THETAT/ THETAT
      COMMON /SPECS/ TF, NSTEPS, IP
      COMMON /NFEST/ NFEST
      COMMON /IGX/ IGX
      NSTEPS = 20
      PI = 4.0D+00 * DATAN(1.0D+00)
      DE2RA = PI / 180.0D+00
C
      OPEN(6,FILE ='OUT2', STATUS ='NEW',CARRIAGE CONTROL = 'FORTRAN')
C
      OPEN(1,FILE ='OUT1', STATUS ='NEW',CARRIAGE CONTROL = 'FORTRAN')
C
C     *****  MAKE INITIAL GUESS AT VECTOR X  *****
C
      X(1) = 272.0D+00
      X(2) =  90.0D+00 * DE2RA
      X(3) =  80.0D+00 * DE2RA
      X(4) =  45.0D+00 * DE2RA
      X(5) =  10.0D+00 * DE2RA
      X(6) =   0.0D+00 * DE2RA
      THETAT(1) = X(2)
      THETAT(2) = X(3)
      THETAT(3) = X(4)
      THETAT(4) = X(5)
      THETAT(5) = X(6)
C
C     *****  SET ACCURACY OF CALCULATIONS AND MAXIMUM FUNCTION
C     *****  EVALUATIONS
C
      ACC    = 1.0D-07
      MAXFUN = 100
C
C     *****  Echo print inputs  *****
C
      WRITE(6,200)MAXFUN,ACC
      WRITE(*,200)MAXFUN,ACC
      DO 10 I=1, N
            WRITE(6,210)I
            WRITE(*,210)I
   10 CONTINUE
      WRITE(6,*)' '
      WRITE(*,*)' '
      DO 15 I=1, N
            WRITE(6,220)X(I)
            WRITE(*,220)X(I)
   15 CONTINUE
C
      IPRINT = +1
      INF    = -1
C
      CONTINUE
```

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```
C        *****  Calculate performance index and constraints  *****
C
         WRITE(*,*) ' CALLING SG IN MAIN PROGRAM'
         IP = 1
         CALL SG(X,N,M,F,C)
C
C        *****  Calculate first partials of F and C  *****
C
         WRITE(*,*) ' CALLING SGX IN MAIN PROGRAM'
         IP = 0
         CALL SGX(X,N,M,F,C,FX,CX,LCN)
*
*        *****  Call VF02AD  *****
*
         WRITE(*,*) ' CALLING VF02AD'
         CALL VF02AD(N,M,MEQ,X,F,FX,C,CX,LCN,MAXFUN,ACC,IPRINT,
     C                       INF,W,LW)
C
      IF(INF.EQ.0)GO TO 20
C
  200 FORMAT(' INPUTS',/,' -------',/
     C       ' Maximum # of iterations = ',I3,/
     C       ' Search accuracy         = ',G12.5//)
  210 FORMAT('&       X0(',I2,')     ')
  220 FORMAT('&  ',G14.7)
  300 FORMAT('&       FX(',I2,')     ')
      STOP
      END

***********************************************************************
      SUBROUTINE SG(X,N,M,F,C)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X(N), C(M), Y(4), THETAT(5)
      COMMON /SPECS/ TF, NSTEPS, IP
      COMMON /THETAT/THETAT
      PI = 4.0D+00 * DATAN(1.0D+00)
      DE2RA = PI / 180.0D+00
      TAU  = 0.0D+00
      Y(1)  = 0.0D+00
      Y(2)  = 0.0D+00
      Y(3)  = 0.0D+00
      Y(4)  = 0.0D+00
      TF    = X(1)
      THETAT(1)  = X(2)
      THETAT(2)  = X(3)
      THETAT(3)  = X(4)
      THETAT(4)  = X(5)
      THETAT(5)  = X(6)
      DO 10 I = 1, NSTEPS
           IF(IP.EQ.1) THEN
                T = TAU * TF / 20.0D+00
                WRITE(1,100)T,Y
           ENDIF
           CALL RUNGE (TAU,Y,1.0D+00,4)
   10 CONTINUE
      F = TF
      PHI   = 20.0D+00 * DE2RA
      C(1)  =  (Y(2)/3280800.0D+00) - 1.0D+00
      C(2)  =  (Y(3)/ 5358.4D+00) - 1.0D+00
      C(3)  =   Y(4)/ 5358.4D+00
      IF(IP.EQ.1) THEN
           WRITE(1,100)TF,Y
           WRITE(1,200)C
      ENDIF
  100 FORMAT(' T    = ',G14.7,'   Y(1) = ',G14.7,'   Y(2) = ',G14.7
```

```
C         '   Y(3)  = ',G14.7,'   Y(4)  = ',G14.7/
200 FORMAT(' C(1)  = ',G14.7,'   C(2)  = ',G14.7,
C         '   C(3)  = ',G14.7,'   C(4)  = ',G14.7/
C         '   C(5)  = ',G14.7,'   C(6)  = ',G14.7,
C         '   C(7)  = ',G14.7,'   C(8)  = ',G14.7)
      RETURN
      END
***************************************************************************************
      SUBROUTINE DERIV(TAU,Y,DY)
C
C     **************************************************************************
C     *                                                                        *
C     *    THIS SUBROUTINE CONTAINS THE EQUATIONS OF MOTION FOR A              *
C     *    LUNAR ASCENT TRAJECTORY.  ASSUMPTIONS IMPLICIT                      *
C     *          i.   FLAT PLANET MODEL IS USED, NON-ROTATING                  *
C     *          ii.  NO ATMOSPHERE                                            *
C     *          iii. POINT MASS REPRESENTATION, ALL FORCES ACT                *
C     *               THROUGH THE CENTER OF GRAVITY.                           *
C     *                                                                        *
C     *    INPUTS TO THE SUBROUTINE (IN CALL PARAMETERS)                       *
C     *          TAU      ≡ SCALED TIME                                        *
C     *                   ≡ NUMBER OF INTEGRATION STEPS * TIME / TF            *
C     *          Y(1)     ≡ RANGE                  (X)                         *
C     *          Y(2)     ≡ ALTITUDE               (Y)                         *
C     *          Y(3)     ≡ X VELOCITY COMP.       (U)                         *
C     *          Y(4)     ≡ Y VELOCITY COMP.       (V)                         *
C     *                                                                        *
C     *    INPUTS TO THE SUBROUTINE THROUGH COMMON BLOCKS                      *
C     *          VARIABLE                           BLOCK NAME                 *
C     *          ========                           ==========                 *
C     *          TF       ≡ FINAL TIME               /SPECS/                   *
C     *          NSTEPS   ≡ NUMBER OF                                          *
C     *                     INTEGRATION STEPS        /SPECS/                   *
C     *                                                                        *
C     *    OUTPUT FROM SUBROUTINE                                              *
C     *          DY(1)    ≡ X COMPONENT OF VELOCITY                            *
C     *          DY(2)    ≡ Y COMPONENT OF VELOCITY                            *
C     *          DY(3)    ≡ X COMPONENT OF ACCELERATION                        *
C     *          DY(4)    ≡ Y COMPONENT OF ACCELERATION                        *
C     *                                                                        *
C     **************************************************************************
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION Y(4), DY(4)
      COMMON /SPECS/ TF, NSTEPS, IF
      G  = 5.32D+00
      A  = 16.1D+00
      U  = Y(3)
      V  = Y(4)
      RN = NSTEPS
      RN = TF / RN
      C = THETA(TAU)
C
C     ***** DERIVATIVES *****
C
      DY(1) = RN * U
      DY(2) = RN * V
      DY(3) = RN *  (A * COS(C))
      DY(4) = RN * ((A * SIN(C)) - G)
      RETURN
      END
***************************************************************************************
      FUNCTION THETA(TAU)
      COMMON /THETAT/ THETAT
      IMPLICIT REAL*8 (A-H,O-Z)
```

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```
      I  = INT(TAU / 5.0D+00) + 1
      DT = TAU - (5.0D+00 * REAL(I-1))
      IF(I.NE.20) THEN
           THETA = THETAT(I) + ((THETAT(I+1) - THETAT(I)) * DT/5.0D+00)
      ELSE
           THETA = THETAT(I)
      ENDIF
      RETURN
      END
```

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```
*************************************************************************
      SUBROUTINE RUNGE(T,X,DELT,N)
C
C     ******************************************************************
C     *                                                                *
C     *    THIS SUBROUTINE INTEGRATES N FIRST ORDER ORDINARY DIF-      *
C     *    FERENTIAL EQUATIONS BY THE RUNGE-KUTTA METHOD.              *
C     *                                                                *
C     ******************************************************************
C
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X(6), DX(6), DELX(6,3), XV(6)
      T2 = T + DELT/2.0D+00
      CALL DERIV(T,X,DX)
      DO 10 I=1, N
           DELX(I,1) = DX(I) * DELT
           XV(I) = X(I) + DELX(I,1) / 2.0D+00
   10 CONTINUE
      CALL DERIV(T2,XV,DX)
      DO 20 I=1,N
           DELX(I,2) = DX(I) * DELT
           XV(I) = X(I) + DELX(I,2) / 2.0D+00
   20 CONTINUE
      CALL DERIV(T2,XV,DX)
      DO 30 I=1,N
           DELX(I,3) = DX(I) * DELT
           XV(I) = X(I) + DELX(I,3)
   30 CONTINUE
      T = T + DELT
      CALL DERIV(T,XV,DX)
      DO 40 I=1,N
           X(I) = X(I) + (DELX(I,1) + DX(I) * DELT +
     C             2.0D+00 * (DELX(I,2) + DELX(I,3))) / 6.0D+00
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SGX(X,N,M,F,C,FX,CX,LCN)
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION X(N),C(M),FX(N),CX(LCN,M)
      DIMENSION XF(25),XB(25),CF(50),CB(50)
      COMMON/NFEST/NFEST
      COMMON/IGX/IGX
      DATA EPSP/1.0D-04/
      IGX=1
      DO 15 I=1,N
           XF(I)=X(I)
           XB(I)=X(I)
   15 CONTINUE
      DO 30 I=1,N
           DX=ABS(EPSP*X(I))
           IF(DABS(X(I)).LE.EPSP) DX=EPSP**2
           XF(I)=X(I)+DX
           CALL SG(XF,N,M,FF,CF)
           XF(I)=X(I)
           XB(I)=X(I)-DX
           CALL SG(XB,N,M,FB,CB)
           NFEST=NFEST+2
           XB(I)=X(I)
           FX(I)=0.5D+00*(FF-FB)/DX
           DO 20 J=1,M
                CX(I,J)=0.5D+00*(CF(J)-CB(J))/DX
   20      CONTINUE
   30 CONTINUE
      IGX=0
      RETURN
      END
```

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APPENDIX D : TASK TIMELINE and SCHEDULE CHART

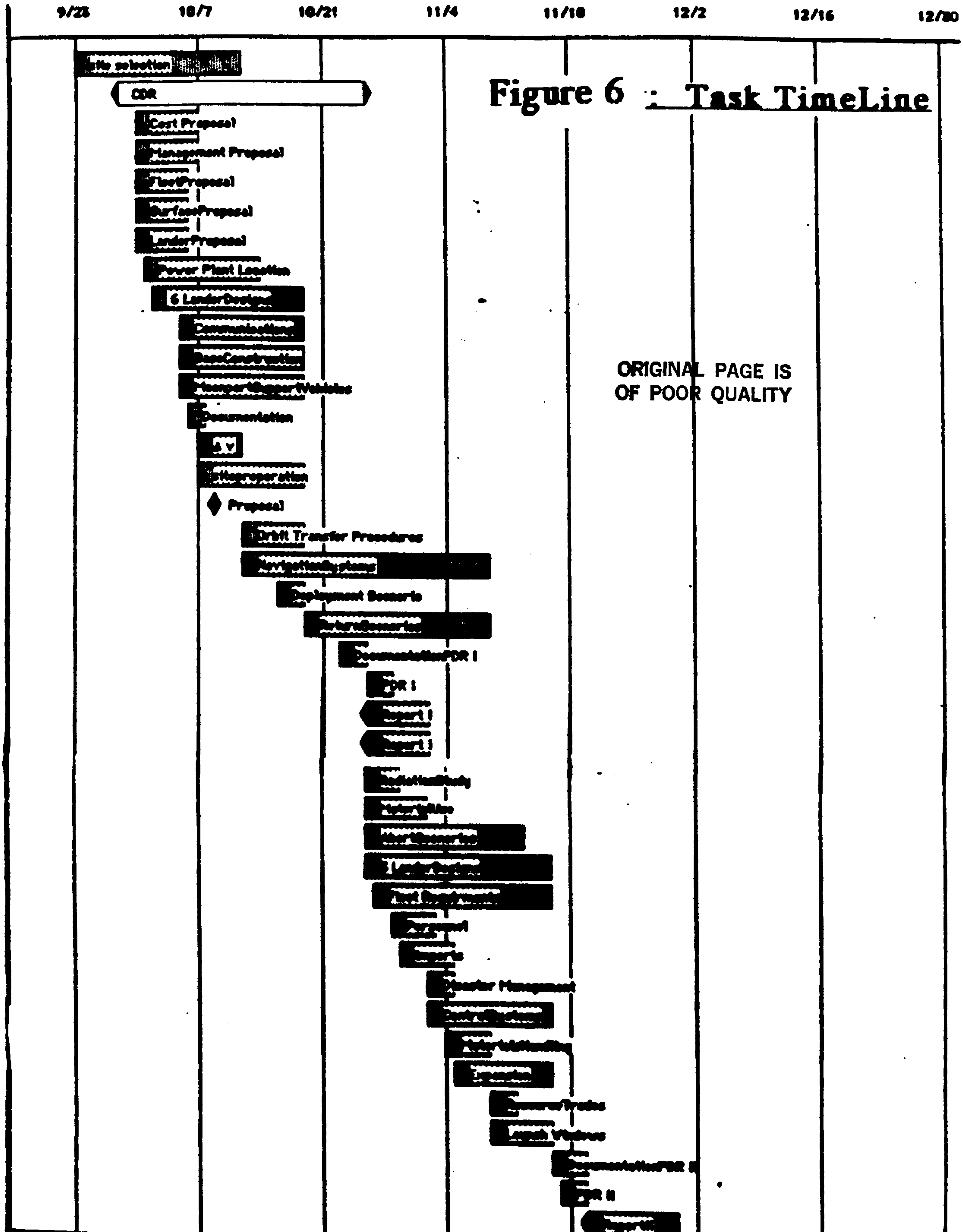

Figure 6 : Task TimeLine

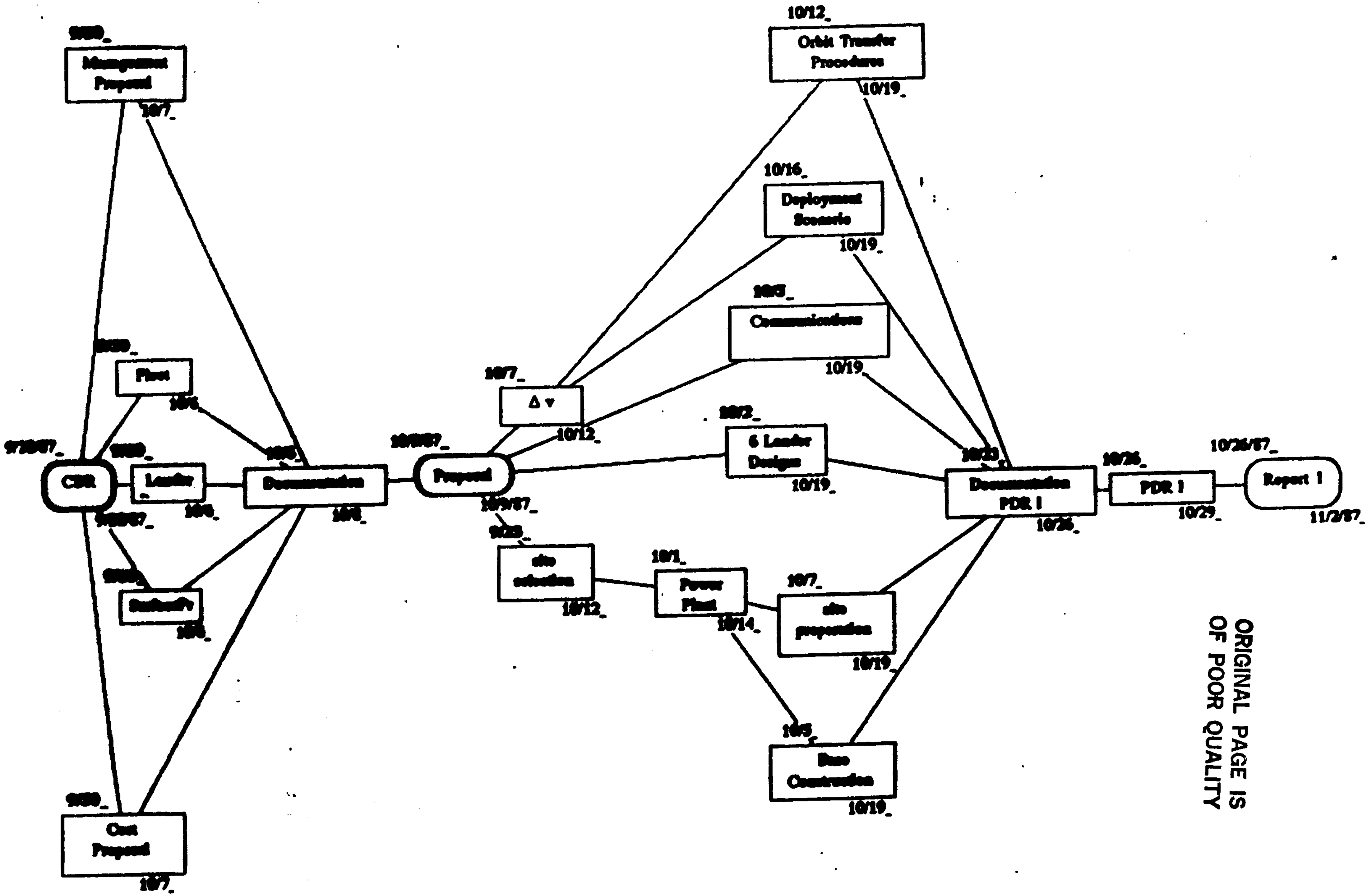

Figure 7 (a.): Schedule Chart

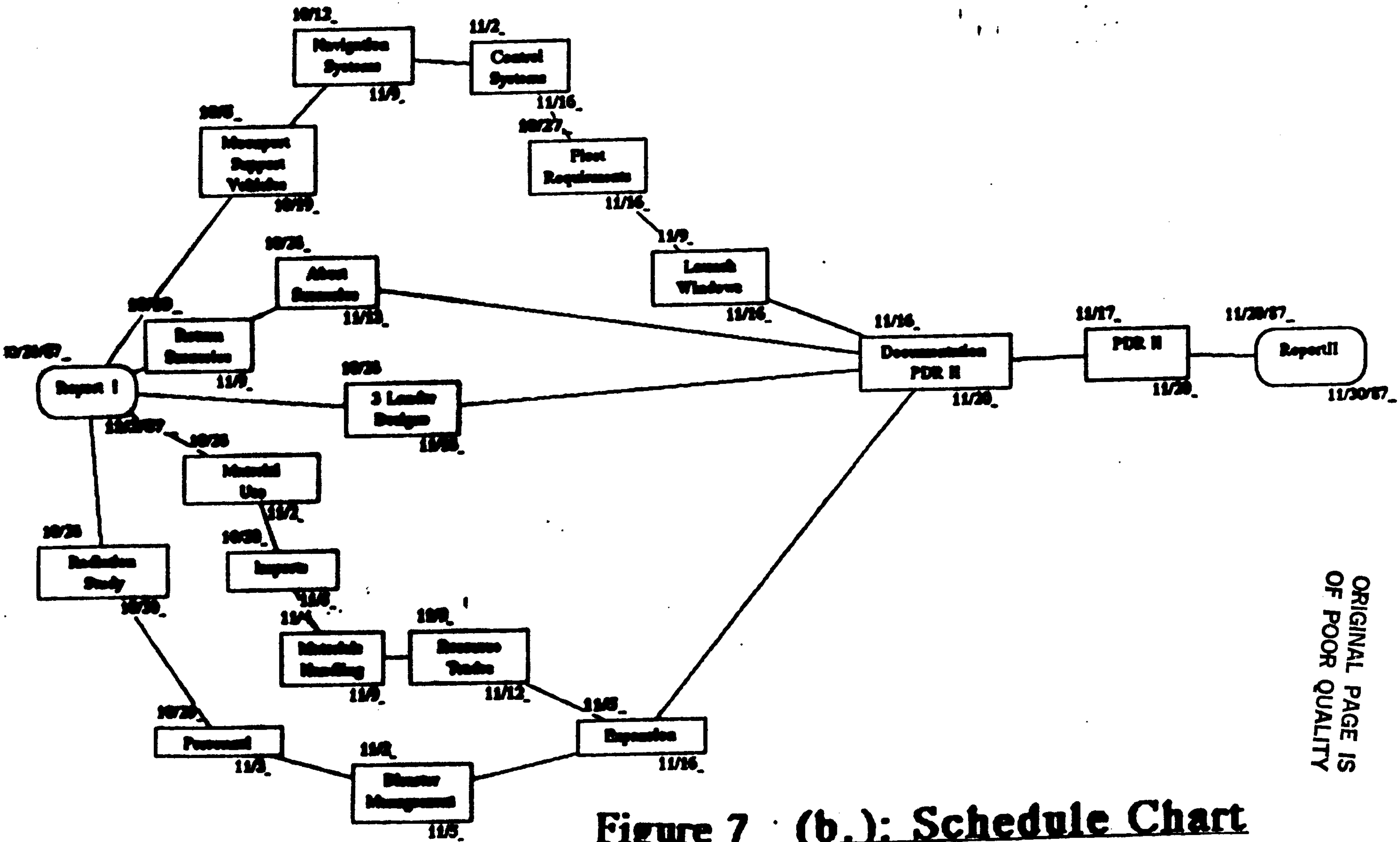

Figure 7 (b.): Schedule Chart

APPENDIX E : PERSONNEL PROFILES

Name: Bruce Boulanger

Specialization: Flight and Orbital Mechanics; Reliability and Test Engineering

Future Plans: Get a job and possibly return to school in a few years; would like a job that focuses on the space program in area of interest.

Name: Susan Clark

Specialization: Orbital Mechanics

Future Plans: Work with the nation's space program/NASA after finishing master's degree; interests include space shuttle payloads, space station, lunar base colonization

Name: George W. Davis

Specialization: Advanced Mission Design and Analysis

Future Plans: Work for civilian space program at NASA, get Ph.D., teach and research at a major university (UT), eventually become Chief Administrator for NASA.

Name: Dario Duran

Specialization: Strucutres, Computer Systems

Future Plans: Obtain a position where I can feel the financial pulse Aerospace industry. M.B.A. in Finance. Aerospace industry advisor to Big Eight firm.

Name: Erett Knobloch

Specialization: Celestial Mechanics

Future Plans: Become active in the space program; get an advanced degree in science and help build a lunar base and settle Mars

Name:	Lynette Latta
Specialization:	Orbital Mechanics, Long Term Project Planning
Future Plans:	Primarily interested in design and implementation of long range space exploration efforts such as manned space stations, lunar bases and colonization

Name:	Frank Adam Mendoza III
Specialization:	Orbital Mechanics, Satellite Attitude Control, Satellite Pointing, On-Orbit Proximity Operations
Future Plans:	Work in Houston and apply above specialization with a small company; become a design team supervisor and design interplantetary missions; will go into astronaut training and hope to go on a shuttle mission

Name:	John Powell
Specialization:	Fluid Mechanics and Aircraft Structures
Future Plans:	Become a pilot for a major commercial airline or work for a space contractor

Name:	Kevin Sagis
Specialization:	Structures: Design and Testing
Future Plans:	Become a successful engineer working to improve himself and the company

Name:	Leif Erik Schley
Specialization:	Orbital Mechanics, Propulsion, Nuclear Physics
Future Plans:	Work on a nuclear and/or propulsion system; become a mission specialist

Name: Miguel A. Sequiera

Specialization: Aerospace Structures

Future Plans: Pursue a career as a design or development engineer, ideally with a company whose work is directed toward the space program

Name: James Sturm

Specialization: Systems Engineering, Mission Design

Future Plans: Work on advanced missions at NASA with eventual goal of opening own advanced planning consulting firm

Name: Ron Wood

Specialization: Aerospace Computational Methods, Structures

Future Plans: Beginning career as an Aerospace Engineer in the Flight Design and Dynamics Group of McDonnell Douglas Astronautics Co.- Houston.

Name: Janet Wigley

Specialization: Flight Control Systems

Future Plans: Pursue career of designing and improving control systems for the Space Shuttle and the Space Station.

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