

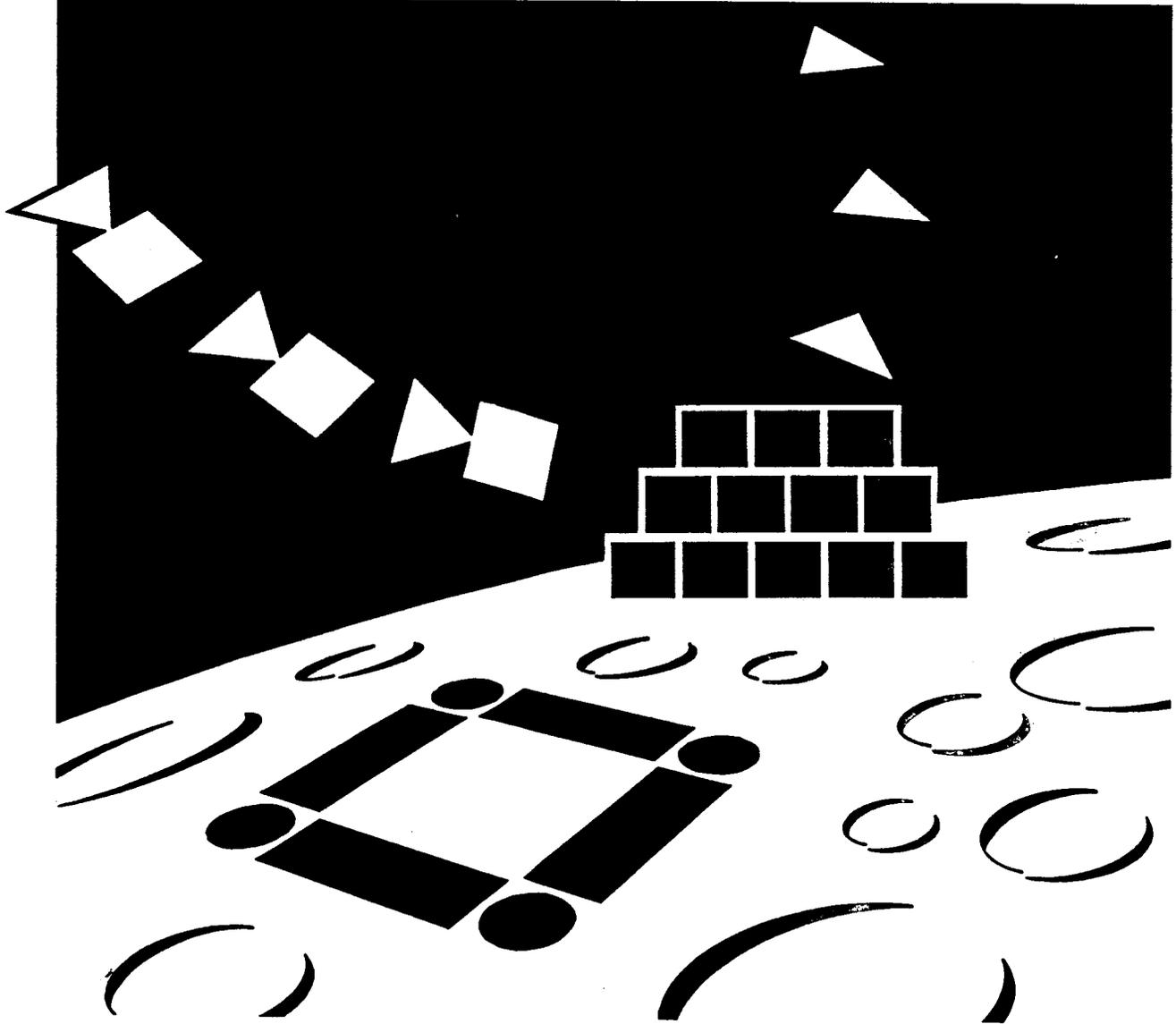


Maintenance and Supply Options

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Foreword

The Maintenance and Supply Options Task was performed as a part of the Advanced Space Transportation Support Contract which is a NASA study to address planning for a Lunar Base near the year 2000. This task investigated crew size, surface stay times, and supply options to support a Lunar Base.

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LIST OF ABBREVIATIONS

CNDB	Civil Needs Data Base
cu.	cubic
ECLSS	Environmental Control and Life Support System
EMU	Extravehicular Mobility Unit
EVA	Extra Vehicular Activity
FE	Flight Engineer
ft.	feet
HM	Habitat Module
IVA	Intra Vehicular Activity
JSC	Johnson Space Center
kg.	kilogram
lb.	pound
lbs.	pounds
LEO	Low Earth Orbit
LRU	Line Replaceable Unit
LS	Lunar Specialist
MMS	Maintenance Management System
m	meter
NASA	National Aeronautics and Space Administration
OMS	Operations Management System
OTV	Orbital Transfer Vehicle
P	Pilot
PTM	Personnel Transfer Module
RD	Reprocessing Depository

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Maintenance and Supply Options

1.0 Executive Summary

The purpose of this task was to define the maintenance and supply requirements for a Lunar Base. Trade studies performed concerned the size of the crew, the impact of lunar stay time intervals, and the options for packaging and shipping of spares and consumables. Design requirements for a logistics supply module were also produced. To accomplish the above, the CNDB Lunar Base Scenario (Ref. 1) was reviewed and a modified version used as a baseline (see appendix A). High level maintenance and supply functions were defined. Some of the design and operational approaches developed for the Space Station were either retained where commonality was desired or modified and applied to the Lunar Base.

The requirement to design for maintainability must play a much larger role in this program than has been the case in the past. A very complex system must be maintained at a great distance by a handful of people. This is without precedent in space work.

A phased approach was taken for both maintenance and logistics operations to support the Lunar Base. Maintenance and logistics operations were minimized during the early phase of the base build up and gradually increased as the equipment and crew complement allowed.

In the first period of 8 day surface stay times, the mode of operation is similar to that of the Apollo missions where the crew operated out of the lander and depended on subsystem redundancy instead of planned maintenance. Logistic activities during this period are primarily limited to delivery of items to the lunar surface and temporary storage of spares and consumables. The next period of 24 day surface stay time missions, allowed operation from a pressurized habitat module which enabled Lunar Base crew interaction with onboard systems which tracked maintenance and logistic activities and hardware. A minimum level of maintenance activities was envisioned for this period with the availability of limited spares and maintenance capabilities. In the final period of 180 day surface stays and permanent occupancy of the Lunar Base, scheduled maintenance and routine logistics are incorporated into the daily activities.

The crew size trade led to a baseline crew size of four which permitted the minimum weight and volume impact to the transportation system but limited the amount of crew time available to perform lunar surface operations. Comparisons between crew skill and specialty mix to surface operational activities led to a preference for a larger crew size to provide the necessary specialty mix and crew hours available to perform the tasks envisioned to support Lunar Base buildup and operation. A crew size of six provided maximum operational flexibility (three shifts) with a minimum of weight penalty.

Investigations into extending the crew surface stay times showed that stay times for both short and medium duration missions could be increased with a small delta weight impact for consumables. These impacts amounted to 52 kg. (113 lbs.) to extend the surface stay time from 8 days to 11 days, and 307 kg. (675 lbs.) to extend the surface stay time from 24 days to 42 days for a crew of 4. In both cases, the impacts are small with respect to performing an additional mission to gain the operational crew time for lunar surface operations. Factors not considered in the stay time extension study were the effects of crew fatigue and limitations due to Earth/Moon orbital mechanics.

Early indications suggest that optimum launch windows occur at intervals of approximately 9 days. The issue of surface stay time should be reevaluated after a detailed study is done on transportation orbital mechanics.

The study on packaging and supply options indicated that for the earlier missions of 8 and 24 day surface stay times, the consumables could be carried with the manned missions. The baseline scenario did not include provisions for spares for equipment delivered to the lunar surface. Spares make up a large fraction of the maintenance and supply mass delivered to the Lunar Base. Mass estimates indicate that dedicated cargo flights carrying only spares may be required. For the later manned missions where permanent Lunar Base occupancy is considered, Logistic Modules should be developed to deliver spares and consumables to the lunar surface. A conceptual design for the logistic supply module evolved to three modules, a pressurized supply module, a tank module, and pallet modules.

Additionally, a need for a facility to temporarily store spares and disposed reusable materials was identified.

2.0 Introduction

The object of the Maintenance and Supply Option task was to develop a high level operational philosophy related to maintenance and supply operations and incorporate those concepts into the Lunar Base Study. Specific products to be generated during this task were three trade studies and a conceptual design of the Logistic Supply Module. The crew size trade study was performed to evaluate crew sizes from the baseline size of four to a crew size of eight and determine the preferred crew size. The second trade study was to determine the impact of extending surface stay times and recommend a preferred duration of stay time as a function of crew, consumables, and equipment support capabilities. The third trade study was an evaluation of packaging and storage methods to determine the preferred logistics approach to support the Lunar Base.

The approach taken was to evaluate the Civil Needs Data Base Lunar Base (CNDB) Scenario and develop a high level approach to maintenance and supply operations. From this, a modified scenario was developed and served as the basis of the individual trade studies. Assumptions and guidelines were also developed from experience with Apollo programs, Space Shuttle operations, and Space Station studies. With this information, the trade studies were performed and a conceptual design for the Logistic Supply Module was developed.

3.0 Baseline Definition

The starting point for a baseline description of the Lunar Base and its missions scenario was the CNDB with its Option III mission elements. This scenario was evaluated and augmented in an inhouse activity under ASTS Task 4.1, Surface Mission Operations, which described a proposed alternative scenario for Lunar Base development. This alternative scenario, (Appendix A), served as a baseline for detailed development of timelines, operational concepts, and definition of surface elements necessary to support a Lunar Base. Detailed equipment variations and timeline changes caused by maintenance and supply considerations are identified in Task 4.1.

4.0 Guidelines and Assumptions

Guidelines and assumptions for this task were derived from three primary sources: (1) Space Station studies, (2) NASA provided guidelines and (3) task developed guidelines and assumptions. Listed below are the guidelines and assumptions grouped according to their category:

O Space Station developed guidelines (Ref. 2)

- ECLSS for the Personnel Transfer Module and Lunar Base Habitat Module will be similar to the Space Station design
- ECLSS water loop closure will be 97%
- ECLSS CO₂ loop will be regenerative
- Atmosphere leakage out of the Personnel Transfer Module is assumed to be .57 kg. (1.25 lb.) of atmosphere per day
- Automatic servicing and checkout of two suits can be accomplished in a 12 hour cycle
- Habitable volume required to support each additional crewperson is 4.25 cu. m. (150 cu. ft.), assuming Space Station size modules (Ref. 3).

O NASA provided guidelines

- EVA will be accomplished with a minimum of two crewpersons
- Each crewperson will have an EMU
- EMU's will be of a high pressure design and will not require prebreathing
- EMU's will incorporate regenerative CO₂ control
- The mass of each EMU will be 136 kg. (300 lb.)
- Crewperson mass will be representative of a 50 percentile male at 82 kg. (181 lb.)
- Personal effects and clothing to support each additional crewperson will be 112 kg. (269 lb.)
- Airlock atmosphere loss is assumed to be .6 kg. (1.32 lb.) per cycle (Ref. 4). The Space Station airlock is predicted to be able to recover all but 6% of the air per cycle.

O Task developed assumptions

- CNDB Alternative Option III is the baseline scenario
- EVA duration is 6 hours nominal/ 8 hours contingency
- Each crewperson shall not exceed 3 EVAs per 7 day period
- Personnel Transfer Module will serve as the lunar surface habitat for the 14 day missions
- No provisions for clothes washing, dish washing, or crew showers will be provided in the Personnel Transfer Module
- The crew will occupy the Habitat Module once it has been delivered to the lunar surface and the subsystems verified operational

5.0 Operational Concepts for Manned Missions

Since the Lunar Base will be developed after the Space Station has been operational for several years, the maintenance and logistics concepts for the Lunar Base will be compatible with the Space Station system. In this section those Space Station concepts are applied

to the Phase II Lunar Base. An operations scenario was developed to outline the tasks that had a direct bearing on the issues of maintenance and logistics. With a basic scenario in place, trade studies were performed to evaluate options desired by NASA.

5.1 Lunar Base Operations

The development of the Lunar Base is divided into three periods of increasing surface stay times. The manned missions are initially 14 days in duration and grow to 30 days and later to 186 day missions. The total mission duration times include the transit times between the Earth and the Moon as well as the surface stay times. Appendix A describes the activities of the crew in detail on a mission by mission basis. The following section provides a descriptive overview of each period and separates the operational philosophy by the available resource capabilities.

5.1.1 Eight Day Stay Surface Missions

The initial series of missions are combined manned and unmanned missions which deliver equipment and crew to the lunar surface to establish the base. During this period, the surface stay time is expected to be on the order of 8 days with the mode of operation very similar to that used for the Apollo Lunar Missions. In this period, essentially everything that is necessary to support the crew and equipment will be carried on-board the vehicles for each mission. The base of operation during these missions will be the Personnel Transfer Module which also serves as the habitable module for travel to and from Earth. No other provisions are available for habitation on the lunar surface during these missions. Planned maintenance during this period is minimal and subsystem fault recovery is primarily dependent upon hardware redundancy.

5.1.2 Twenty-four Day Surface Stay Missions

This series of missions is characterized by the availability of the Habitat Module on the lunar surface which allows the surface stay time to be extended to 24 days. The base of operations will now be centered in the Habitat Module with improved crew accommodations and the availability of the Operations Management System and its attendant Maintenance Management System which are controlled from a workstation in the module. Continual buildup of the Lunar Base occurs with the delivery of major elements to the lunar surface by expendable lunar landers. Scheduled maintenance of equipment is now a part of the crew tasks and unscheduled repairs are performed with spares in stock. Limited diagnosis of Line Replaceable Units (LRU's) is enhanced when the pressurized garage is delivered to the surface on Mission 21.

5.1.3 180 Day Surface Stay Missions

With the completion of the initial Lunar Base with self sufficient electrical power, the third period of Lunar Base operations begins. In this period, the surface stay time will be extended to 180 days which allows permanent occupation of the Lunar Base. Up to 8 people will be at the base for a majority of the time. In this period, the Lunar Base will still be dependent on Earth for consumables such as food, water, nitrogen, crew equipment, and spare parts. Operation of the Lunar Base is now a continual activity with regular scheduled maintenance of equipment on the lunar surface and limited repair capability of LRU's below the modular level. Operations are now focused outwards with emphasis on Lunar Science and Surface Exploration which requires longer duration excursions aboard the rovers. Consumables, spares, and other supplies to support the needs of the

Lunar Base have now outgrown the capability of the manned landers. Dedicated unmanned delivery of Logistics Modules to the lunar surface is now required.

5.2 Maintenance Operations

The approach recommended for maintenance of Lunar Base equipment is similar to that used for the Space Station. The capabilities to perform maintenance related tasks will, however, be phased in a manner consistent with the operational capabilities discussed earlier. These capabilities are driven by the resources available in each period of the Lunar Base development. Table 1 shows the maintenance functions required by each period.

5.2.1 Eight Day Surface Stay Maintenance Operations

During the first period of Lunar Base development, which is marked by the 8 day surface stay time and operations from the Personnel Transfer Module, maintenance will primarily be accomplished by the replacement of LRU's or modular components which are identified as limited life items. Spare replacement components and servicing elements will be identified prior to each manned mission and be carried aboard the manned vehicle for service by the crew. Scheduling and planning of activities related to maintenance will be performed on Earth and support provided to the crew in real time during the maintenance activities. Spares for items to be replaced inside the habitable volume will be stored inside the volume whereas those spares for equipment normally operated in an unpressurized environment will be carried outside the pressurized volume. Subsystem monitoring and trend analysis supporting maintenance activities will be performed on Earth. All unused spares and servicing items not required for the return flight will be left at the Lunar Base in a designated storage area.

5.2.2 Twenty-four Day Surface Stay Maintenance Operations

In the next period with the Habitat Module on the lunar surface and a 24 day stay period, maintenance activities such as subsystem data collection and near-term maintenance scheduling can partially be transferred to the Lunar Base. The presence of the Lunar Base Operations Management System (OMS) and the Maintenance Management System (MMS) allows real-time monitoring of the subsystems, resources, consumables, and spares. The OMS performs the top level function of controlling subsystems and resources and feeds data to the MMS. The data fed from the OMS to the MMS provides information on maintenance status and schedules, and will be available for viewing or interfacing at the crew workstation in the Habitat Module. Maintenance tasks to be performed by the crew will be assisted by MMS generated information on LRU status, spares location, tool usages, and procedures. EVA maintenance and repairs will be assisted by helmet mounted displays and audio cues for presentation of procedures and checklists which are stored in the MMS data memory.

Provisions for shirtsleeve maintenance and repairs of lunar surface equipment will be possible with the availability of a pressurized module which is capable of enclosing a manned rover vehicle. Included in this module will be test and checkout equipment as well as spares and tools. With a pressurized facility, maintenance and repairs of equipment will be greatly enhanced due to the removal of the EVA suit operational limitations. The capability to perform failure diagnosis of LRU's at the subcomponent level will minimize the need to return failed spares to Earth. The diagnostic analysis and system test functions should be accessible from Earth to minimize the impact to crew time. A

TABLE 1

Lunar Base Maintenance Functions

Moon Based Functions	8 Day Mission 1-9	24 Day Mission 10-41	180 Day Mission 42-48
Lunar Base Equipment Checkout	x	x	x
Subsystem Status Monitoring	x	x	x
EVA Equipment Maintenance and Service	x	x	x
EVA Equipment Repair	x	x	x
LRU Spares Storage	x	x	x
Maintenance Management System Operation		x	x
Near-Term Maintenance Scheduling		x	x
IVA Maintenance		x	x
Limited LRU Testing		x	x
Remote Experiment Servicing and Repair			x
Earth Based Functions			
Lunar Base Subsystem Monitoring	x	x	x
Subsystem Data Collection	x	x	x
Subsystem Trend Analysis	x	x	x
Near-Term Maintenance Scheduling	x	x	
Reliability and Failure Analysis	x	x	x
Returned LRU Repair	x	x	x
Long-Term Maintenance Scheduling	x	x	x

trade study should address the level of repair activity that should be performed on the lunar surface with respect to subcomponent repair. Crew time on the lunar surface is extremely expensive and should be utilized for scientific and operational functions as much as possible.

5.2.3 180 Day Stay Maintenance Operations

In the last period of Lunar Base development, the presence of a permanent crew on the lunar surface will change the operational philosophy of maintenance and repair. Maintenance and repair will now be a significant part of the activity of scheduled surface operations. Since the Base will be continually operated, preventative maintenance activities will be emphasized more and scheduled around routine operational activities such as Lunar Base buildup, landing/launch site operations, subsystem management, oxygen mining and production, life science and materials laboratory experiments, and lunar surface and field geology exploration.

Crew support of maintenance activities on the lunar surface is expected to occupy from 5 to 20 percent of the available time. This time estimate is based on Air Force ground electronic equipment earthside experience (Ref. 5). The ground based maintenance is performed by maintenance personnel instead of the flight crew. For the Lunar Base, the flight crew must perform the work, so the systems must be designed to be maintained by the crew without severely impacting operational crew time.

A reference point on the amount of maintenance time required, developed from Space Station studies indicates the need for approximately four crew hours per day for maintenance activities (Ref. 6). For the Lunar Base, factors such as the presence of construction and transportation equipment along with the lunar surface environment of dust will require more maintenance support than expected for the Space Station. The actual time required for maintenance is unknown and could easily be large. The systems must be designed to hold maintenance time to an acceptable fraction of crew time. This will require a higher priority on maintenance in the design phase than has been the practice in previous programs. Service and repair of remote site experiments and their related equipment will be another function of the Lunar Base crew in this period. Spares inventory built up over the previous missions will allow for a large stock of LRU's to support the maintenance activities. Predictive trend monitoring equipment in the OMS coupled with the MMS will schedule the delivery of new spares from Earth to meet the needs of the Lunar Base.

5.3 Logistics Operations

The logistics operations for the Lunar Base are concerned with the packaging, scheduling, distribution, and storage of equipment, spares and consumables to supply the lunar surface operations.

Since the Lunar Base will be developed after the Space Station has been operational for some years, the maintenance and logistics concepts for the Lunar Base should be compatible with the Space Station system. Compatibility issues such as commonality of LRU's and dimensional standards on storage containers to assure that they can be handled and secured properly during each phase of the delivery process from the Earth to the Moon should be considered. Commonality of LRU's is critical for the Lunar Base so that the same LRU will be able to support many different subsystems and subcomponents. By properly

specifying common LRU's, the number of spares should be reduced and the reliability and production costs of the LRU improved.

Logistics for the lunar base involves three locations in a complex tracking and mass handling operation. First, the only source of supplies during the first six years of lunar operations is the Earth. At a later date, oxygen supplies will be supplemented by lunar oxygen production from the pilot and production plants. The data bases which track the equipment availability, maintenance schedule, packaging, shipping and life time use will be based on the Earth and the Moon. The supplies are transported to the Space Station which serves several functions including:

- temporary holding point to prepare for final shipment to the Moon.
- minimal repackaging for shipment
- equipment checkout and minimal refurbishment
- source of supplies needed immediately when unavailable from the Earth

Presently, the Space Station will not be able to support all of these functions. This support capability will be required of the Space Station to make the Lunar Base logistics operations viable.

Logistics support for the lunar base will develop in three periods. The first, the build up phase, supports the shorter 8 day surface stay when the crew is housed in the Personnel Transfer Module (PTM). The second supports the longer 24 day surface stay when the crew is housed in the Habitat Module (HM). The third period begins with permanent occupancy and stay periods of 180 days.

5.3.1 Eight Day Stay Logistic Operations

For 8 day surface stay, the logistics philosophy is similar to the Apollo and Space Shuttle approaches. All critical life support systems are designed and built to be fail operational/fail safe. These will have redundancy so no spares are required. Consumables are on board for the planned duration of the mission plus a contingency period.

Minimal consumables and spares are shipped for the 8 day stay missions which are carried within the habitable volume. During Apollo only a small tool kit and minor spares such as fuses were on board. For Shuttle the equipment for inflight maintenance does not exceed 91 kg (200 lbs). A general purpose computer, 43 kg. (95 lbs.), tool kit, 31 kg, (67 lbs.), fuses, and a vacuum cleaner are in the pressurized volume of the Shuttle. In the lunar Personnel Transfer Module a tool kit and minimum spares will be available. Spares will be determined after an analysis of system redundancy, reliability and repair feasibility.

5.3.2 Twenty-four Day Stay Logistic Operations

For 24 day stay time missions, gradual delivery of supplies and spares will be provided when excess launch mass and volume is available. Because of the remoteness of the lunar base, a minimum supply of spares or pre-positioned LRUs must be available by the 24 day lunar missions. Appendix A lists the excess payload launch capability by mission which may be utilized to deliver the spares. Unused supplies will be left on the lunar surface. A tool kit and minimum spares will be available. The spares inventory will be increased gradually according to a prioritized list of critical LRUs. For failures of lunar equipment for which no spares are available and for which repairs are possible, re-

placement parts will be delivered on the next mission. The approximate intervals between the manned missions is 90 days. The Lunar Base equipment reliability must be sufficiently high to meet this operational time interval. This is similar to procedures followed to respond to failures on Skylab. During Skylab, only a tool kit was available. For major failures, replacement parts were carried up with the crew on the following flight.

5.3.3 180 Day Stay Logistics Operations

For 180 day missions, bulk delivery of consumables and spares will be made in the logistics module and with the crews. Major logistics module deliveries are needed to sustain the longer surface stay times.

6.0 Trade Studies

Three basic trade studies are performed in this task. They are the (1) crew size trade to evaluate the impact of crew size on base operations and transportation systems, (2) surface stay time trade to assess the impact of extending crew stay times above those indicated in the baseline, and (3) packaging and handling options for spares, equipment, and consumables to identify the preferred method of handling supply materials for the Lunar Base.

6.1 Crew Size Trade

A trade study of the size of the Lunar Base crew was performed to determine the impact of crew size on the various elements of the Lunar Base. A baseline crew of four was chosen and crew sizes of 5, 6, 7, and 8 were investigated. The advantages of increasing the crew size was compared to the mass, volume, and consumables impact on the Personnel Transfer Module, Habitat Module and supporting transportation infrastructure.

6.1.1 Approach

First the functions and requirements of the baseline crew are identified. Next the advantage of each additional crew member was determined in terms of skills, increased shift capability, increased crew time available, and increased EVA and IVA support capability. Each of the delta impacts for additional crew members were tabulated in terms of volume and mass increases necessary to support an additional crewmember. When all of the subcomponent volume impacts were determined, then the required volume of the module was determined. From this a delta volume and mass of the pressure vessel and substructure was calculated. With this mass added to the subcomponent mass, the total mass impact for increased crew size was determined. As a final summary, the advantages of the various crew sizes were compared against the disadvantages.

6.1.2 Baseline Crew Functions

The baseline crew has to perform several functions in the total mission cycle of a Lunar Base mission. One of the main functions is to pilot the Lunar OTV and Lander/Launcher from low Earth orbit to the Moon and return. The other main function is to construct the Lunar Base and to perform scientific and geological experiments while on the surface. The specific functions that must be performed are those of a Pilot, Flight Engineer, Medical Officer, Technician, and Lunar Specialist. During the flight to and from the Moon, the functions of the Pilot, and Flight Engineer are critical. Once on the Moon, the functions of the Lunar Specialist becomes more important. The subcategories of the

Lunar Specialist include those of Lunar construction engineer, Lunar Base manager, systems engineer, geologist, biologist, materials scientist, physicist, and astronomer. In both phases, at least one crewmember must be designated as the Medical Officer. To accomplish this with a crew of four, considerable crosstraining is necessary. Maintenance, servicing, and repair functions needed for the equipment located on the lunar surface must also be considered.

A list of crew skills and specialties are tabulated in Table 2 to compare the skill and specialty needs as a function of mission number as the Lunar Base is being developed. The term specialty is being used in the context of career specialty while the term skill is used to define a function a person can be trained to do in a short period of time. From the table, we can see that the requirement for crosstraining builds up rather rapidly as the base is being developed. It may not be reasonable to require any crewperson to have a background in more than two career specialties. Multiple skills, however, can be handled by each crewperson since skills can be acquired after a short training period. In Table 3 the skills and specialties were compared to the operational functions that would be performed to develop the Lunar Base.

6.1.3 Optional Crew Size Functions

Even with a larger crew size, separate flight and surface crews cannot be allowed. The larger crew size permits more crew hours for surface operations and a better mix of specialties becomes available. As the crew size is increased, the primary functions of Pilot and Flight Engineer are retained. For those flights not having a physician crewmember, an individual would be trained to be the Medical Officer. Each of the flight crew would still be trained in specialty fields to support operations on the lunar surface as shown in Table 3.

6.1.4 Number of Crew Shifts

The number of crew shifts for the baseline crew size of four is either one with all crewmembers active during the work period or two with one half of the crew active during each work period. In either case, the total number of crew hours available during a 24 hour period remains the same. The advantage of having all crewmembers active during a work period is for those tasks which may be labor intensive for a short duration of time. The advantage of two shifts is for those tasks which are continuous activities requiring some participation by a crewmember over a long span of time. The possible combinations of the number of shifts compared with crew size is shown in Table 4.

It is anticipated that for the early phase of the Lunar Base construction effort, that the one shift per 24 hour period approach may be preferred to support labor intensive tasks on the lunar surface. After the Lunar Base is well established, the preference will probably change to two shifts to support continuous operations. After the base is permanently occupied and the available crew size grows, the preference would be to support a three shift operation for maximum support of lunar activities. A comparison of the number of 8 hour shifts available within a 24 hour period as a function of crew size is shown in Table 4.

TABLE 2
CREW SKILLS/SPECIALTIES VS MISSIONS

SKILLS	MISSION NO.	2	4	6	9	11	13	16	18	20	22	26	30	31	32	34	36	38	39	42	44	46	47	
Base Manager/Commander		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Electronics Tech				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Aerospace/Mechanical Tech				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emergency Medical Tech		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Suit Technician		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Housekeeping Services		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Heavy Equipment Operator		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Instrument Technician				x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Photo Technician		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chem Lab Technician							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SPECIALTIES																								
Pilot		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Flight Engineer		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Geologist		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Planetologist												x	x	x	x	x	x	x	x	x	x	x	x	x
Physicist																x					x	x	x	x
Geochemist							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Microbiologist											x	x	x	x	x	x	x	x	x	x	x	x	x	x
Plant Biologist											x	x	x	x	x	x	x	x	x	x	x	x	x	x
Physician/Aerospace Medicine											x	x	x	x	x	x	x	x	x	x	x	x	x	x
Astronomer												x	x	x	x						x	x	x	x
Civil Engineer		x	x	x	x	x	x	x	x		x	x					x	x	x	x	x	x	x	x
Electrical Engineer				x	x	x											x	x	x	x	x	x	x	x
Aerospace Engineer		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

TABLE 3
CREW SKILLS/SPECIALTIES VS FUNCTIONS

SKILLS	FUNCTION NO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Base Manager/Commander		x	x	x		x											
Electronics Tech				x	x	x		x			x		x	x		x	x
Aerospace/Mechanical Tech		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Emergency Medical Tech		x	x	x	x	x										x	x
Suit Technician		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Housekeeping Services		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Heavy Equipment Operator			x	x	x						x	x	x	x	x	x	x
Instrument Technician			x	x		x	x	x	x	x	x	x	x	x			x
Photo Technician			x	x			x	x		x		x					
Chem Lab Technician								x	x								x

SPECIALTIES

Pilot		x	x														
Flight Engineer		x															x
Geologist							x	x			x	x		x	x		
Planetologist							x				x	x					
Physicist														x			
Geochemist							x	x	x						x	x	
Microbiologist											x						
Plant Biologist											x						
Physician/Aerospace Medicine											x						
Astronomer											x	x					
Civil Engineer			x	x	x	x					x		x		x	x	
Electrical Engineer				x	x	x								x			x
Aerospace Engineer		x	x	x	x	x			x		x			x			x

FUNCTIONS

- 1 Earth/Moon Transportation
- 2 Landing Site Preparation
- 3 Lunar Base Assembly
- 4 Pilot Power Plant Assembly and Operation
- 5 Lunar Base Operation
- 6 Lunar Science and Field Geology
- 7 Geochemical Materials Laboratory Operation
- 8 Pilot Oxygen Plant Assembly and Operation
- 9 Life Science Research
- 10 Optical Interferometer Telescope Operation
- 11 Crater Dating Experiment Operation
- 12 Deep Drilling Operation
- 13 Advanced Power Plant Operation
- 14 Oxygen Mining Operations
- 15 Oxygen Production Plant Operation
- 16 Lunar Base Maintenance

**TABLE 4
LUNAR BASE CREW FUNCTIONS**

Crew Size	Crew Function(1)	Shifts(2)	Crew Hrs/Day	1 Shift EVA/Shift(3)	2 Shift EVA/Shift(3)	3 Shift EVA/Shift(3)	EVA Hrs/7Days(4)
4	P,FE,2LS	1 or 2	32	2,3,or4	2	NA	72
5	P,FE,3LS	1 or 2	40	2,3,or4	2 or 3	NA	90
6	P,FE,4LS	1,2,or3	48	2,3,or4	2,3,or4	2	108
7	P,FE,5LS	1,2,or3	56	2,3,or4	2,3,or4	2 or 3	126
8	P,FE,6LS	1,2,or3	64	2,3,or4	2,3,or4	2,3,or4	144

Footnotes:

- (1) Crew Functions- P Pilot, FE Flight Engineer, LS Lunar Specialist
- (2) The number of shifts represents the quantity of 8 hour shifts in a 24 hour period
- (3) The number in the column represents the number of crew available for EVA per shift
- (4) EVA groundrules permits three EVA's per crew every 7 days

6.1.5 Mass and Volume Impacts to Crew Size

The delta mass and volume impact due to crew size increase was evaluated on an incremental basis as shown in Table 5. For those items located within the pressurized habitable volume, mass and volume values were assigned and tabulated. Once all of the discrete items associated with an incremental growth in crew size of one crewmember were identified, an estimate for the environmental control and life support subsystem increase per crewmember was assigned the volume of 20 cu. ft. (.566 cubic meters) and 220 lb. (100 kg.) mass. These delta increases in equipment volume and mass were taken from Space Station studies (Ref. 2 and 7) where various crew sizes were evaluated.

The CNDB mass allotment for the crew and crew equipment is insufficient to include the EMU. It is recommended that the estimated EMU mass of 136 kg. (300 lb.) be added to the CNDB weight statement to support later study efforts with a more accurate amount for crew and crew equipment masses.

An increase in the EVA support equipment is required when the crew size exceeds six. This is due to the limitation of the proposed suit servicing equipment to support service of two EVA suits and equipment within a 12 hour period. The total volume increase of the previous items were summed to determine the module volume growth necessary to accommodate an additional crewmember. This volume change then relates to an incremental change in the length of the module for a constant diameter of 166 in. (4.22 meters). Associated with the module length change an estimated value of 315 lb./ft. (469.2 kg. per meter) of module length was assigned for pressure vessel and supporting structure delta weight impact. This information was taken from data on Space Station Common Module weight estimates for various length modules. These delta mass impacts were summed with the consumables located outside the pressurized volume to determine the total mass impact to increase the crew size. These items are summarized in Table 5.

The impacts cited above will be directly reflected in the mass and volume required for the Personnel Transfer Module. If the Habitat Module is sized for a growth crew of eight, no impact will be felt until the period when a permanently manned base takes place. With the 180 day stay mission, if it is assumed that the crew will double to a eight, then additional measures will have to be provided at the Lunar Base to accommodate the larger crew. With the Lunar Base designed for long term growth, it is expected that an additional Habitat Module would be delivered to the lunar surface to accommodate any crew number increase. This inclusion would require the addition of a dedicated mission to deliver the Habitat Module to the lunar surface or resizing the Habitat Module. The CNDB indicates that the Habitat Module is presently sized to support a crew of six.

In summary, mass penalty per unit crew added is linear until the limits of large pieces of hardware, such as the Habitat Module or suit servicing equipment is reached. Then large penalties occur for extra crew.

6.1.6 Crew Size Benefit Comparison

The baseline crew size of four provides the necessary crew to accomplish the mission objectives with a minimum of weight and volume impact. The option to select either one or two shift operation is another advantage of a four crewmember complement. The primary disadvantage of four crew is the limited amount of crew time available to perform useful tasks on the lunar surface. A detailed examination of the tasks to be

TABLE 5
DELTA MASS AND VOLUME

Additional Crew	Cu Ft		Lb		C Equip		EMU		EMU Supp		Lb		Consum		Subsys		Cu Ft		Lb		Subsys		Cu Ft		Lb		Total Vol		Length		Module		Total Mass	
	Hab Vol	Crew	Lb	Cu Ft	Lb	Cu Ft	EMU	EMU	EMU Supp	Lb	EMU	EMU Supp	Lb	Cu Ft	Consum	Cu Ft	Subsys	Lb	Subsys	Cu Ft	Lb	Subsys	Lb	Cu Ft	Lb	Total Vol	Length	Module	Total Mass					
1	150	181	20	269	34	300	34	300	20	75	20	75	20	75	20	220	220	224	224	2	2	473	1518											
2	300	362	40	538	67	600	67	600	40	150	40	150	40	150	40	440	440	447	447	3	3	945	3035											
3	450	543	60	807	101	900	101	900	16	438	16	438	60	225	60	660	660	686	686	5	5	1449	5022											
4	600	724	80	1076	134	1200	134	1200	31	875	31	875	80	300	80	880	880	925	925	6	6	1953	7008											

FOOTNOTES:

- (1) Mass of consumables was based on an 8 day surface stay time
- (2) All data are presented as deltas above baseline crew requirements
- (3) The crew mass of 181 lb. represents the 50 percentile male crew mass

accomplished on each mission may disclose the need for more crew time for each mission to complete the tasks identified.

The increase in crew size always provided more crew hours available per day for a penalty of consumables, equipment, and habitable volume with its attendant weight increase as shown in Table 5. Each additional crew member made 8 hours of crew time per day available to perform EVA and IVA tasks on the lunar surface. A significant penalty came with the addition of the seventh and eighth crew members which required the addition of EVA servicing equipment to allow for EVA operation by the additional crew members. A summary of these advantages and disadvantages are shown in Table 6.

6.1.7 Recommended Crew Size

If total mass delivered to the lunar surface must be minimized, then the baseline crew size of four is the best option. Lunar surface operation would simply have to be tailored to stay within the constraints of available crew time and support capabilities. This would require a certain degree of automation of Lunar Base construction activities, teleoperation capabilities from the IVA crew, and support of operations from Earth. If the maximum degree of operational flexibility is desired with the minimum weight penalty, the crew size of six provides this capability. With a crew size of six, the capability to do three shift operations exists and the maximum EVA support capability can be met without a major impact on the EVA support equipment.

It is also recommended that the CNDB weight statement for crew and equipment mass be increased by 136 kg.(300 lb.) to account for the mass of an EMU for each crewmember.

6.2 Surface Stay Time Trade

A trade study of the lunar surface stay time was performed to determine the impact of duration of lunar surface stay time on operations and support capabilities. A baseline crew of four was chosen for all of the stay times evaluated. The stay times that were evaluated were 8, 24, and 180 days. These times were baselined in the CNDB (Ref. 1). In addition, the optional stay times of 11 and 42 days were evaluated to determine the benefits and disadvantages of the different durations.

6.2.1 Approach

The approach taken in this activity was to start with the baseline crew size of four and identify support requirements necessary to allow the crew to stay on the lunar surface for increasing periods of time. Once these factors were identified, then the impact of each support requirement was tabulated as a function of surface stay time.

One factor that was not addressed was the issue of Earth-Moon orbital mechanics of windows of opportunity for orbital rendezvous. Opportunities to depart from the Space Station orbit to the lunar vicinity and to depart lunar orbit for the Space Station orbit occur at roughly 9 day intervals, the interval between the times the Space Station orbit plane contains the Moon. The posigrade motion of the Moon and the retrograde precession of the Space Station orbit cause this interval. It can be adjusted somewhat by changing the altitude, and therefore the precession rate of the low Earth orbit. Changes to the intervals and windows of opportunity are possible, usually at the expense of propellant. As the stay times and other parameters are varied from optimum values, required propellant

TABLE 6
CREW SIZE BENEFITS

CREW SIZE	ADVANTAGES	DISADVANTAGES
4	<ol style="list-style-type: none"> 1. Minimum Lunar landed mass 2. Minimum amount of consumables 	<ol style="list-style-type: none"> 1. Limited amount of crew time available 2. Limited amount of EVA support capability 3. Skill mix limited 4. Number of shifts limited to two
5	<ol style="list-style-type: none"> 1. Increased skill mix 2. Available crew time increased 8/hrs.day 	<ol style="list-style-type: none"> 1. Increased weight (1517.5 lb) 2. Increased volume (223.5 cu. ft.) 3. Increased consumables required 4. Still limited to two shift operations
6	<ol style="list-style-type: none"> 1. Three shift operational capability 2. Available crew time increased 16 hrs./day 3. Maximum EVA capability with existing equipment 4. Improved skill mix 	<ol style="list-style-type: none"> 1. Increased weight (3035 lb) 2. Increased volume (447 cu.ft.) 3. Increased consumables required
7	<ol style="list-style-type: none"> 1. Three shift operational capability 2. Available crew time increased 24 hrs./day 3. Improved skill mix 	<ol style="list-style-type: none"> 1. Additional EVA support station required 2. Increased weight (5021.5 lb) 3. Increased volume (686 cu.ft) 4. Increased consumables required
8	<ol style="list-style-type: none"> 1. Three shift operational capability 2. Available crew time increased 32 hrs./day 3. Improved skill mix 	<ol style="list-style-type: none"> 1. Two additional EVA support stations required 2. Increased weight (7008 lb) 3. Increased volume (925 cu.ft.) 4. Increased consumables required

quantities slowly then rapidly increase. This investigation was considered out of scope for this task. It is however an important factor concerning lunar surface stay times.

After all of the support requirements have been identified, the stay times were checked for operational constraints such as landing time, frequency of EVA, designated rest periods, lighting considerations, night cycle operations, and launch preparation constraints. With these conditions considered, the total available time for surface operations was calculated and the amount of allowable EVA time was subtracted to determine the amount of IVA time available during the surface stay time. Based on the results of the evaluation, recommendations were made regarding the preferred surface stay times.

6.2.2 Guidelines and Assumptions

The assumptions used in this trade were developed from Space Station studies (Ref. 2) and experience gained from the Apollo Lunar missions. Listed below are the significant assumptions affecting this trade:

- O Space Station developed guidelines
 - An 8 hour work day is assumed for each crewperson
 - EVA will be accomplished with a minimum of two crewpersons
 - EVA duration is 6 hours nominal
 - Each crewperson will not exceed 3 EVAs per a 7 day period
- O NASA provided guidelines
 - Baseline crew size is four
 - Lunar night EVA may occur between 1/4 earthlight and 3/4 earthlight
- O Task developed guidelines
 - Three hours of IVA time is required to support each EVA
 - Allowances were not made for holidays, weekends, eclipses, or solar flares
 - Location of Lunar Base is at Lacus Veris (13° S, 87.5° W)
 - Lunar departure at lunar night is possible
 - Lunar landing will occur during lunar daytime

6.2.3 Support Requirements

The items required to support extended stay on the lunar surface are crew habitation accommodations, crew consumables, spares, and lighting conditions. For the 8 and 11 day surface stay times, the crew lived out of the Personnel Transfer Module. The consumables were originally calculated on a crew day basis and extended to match the various stay times evaluated in this task. Lighting constraints considered in this task were allowances for landing conditions, daylight surface operations and nighttime surface operations. The nighttime operations constraint of operations between 1/4 earthlight and 3/4 earthlight is based on the minimum amount of illumination needed from the crew to allow color discrimination. Nighttime operations will be limited to activities in the immediate area of the Lunar Base for reasons of safety.

6.2.4 Operational Crew Time Availability

The amount of crew time available for useful work on the lunar surface was calculated from the total amount of productive hours available from the crew during their stay on the lunar surface. With any given stay time duration, the available periods for EVA activities were determined using all of the constraints placed on EVA operations. With the number of EVA opportunities identified, the total number of useful EVA hours were calculated. The six hours per EVA is based on the time elapsed between depressurized airlock opening and airlock closure for repressurization. It is estimated that an additional hour might be lost during EVA for equipment and tool gathering in the beginning and equipment storage and dust removal at the end of the EVA. This time is not considered in the tabulated results but is addressed in the Surface Missions Operations Task 4.1. With each EVA, approximately three hours are required in preparations and servicing which must be deducted from the total crew hours available. The total crew hours minus the total EVA hours with its associated preparatory time is the IVA hours available during the lunar surface stay. These results are shown in Table 7.

Factors which may inhibit the actual amount of useful EVA on the lunar surface which were not considered in this trade were crew fatigue levels, lighting conditions, and the effect of temperatures cycles on the equipment.

The schedule of three EVAs per crew per week may be optimistic for long duration missions. Since data of this nature is not available, the amount of time available for EVA is given for a relative comparison purpose.

The lighting and thermal conditions at lunar noon were not considered since the crew rest period for EVA activities happened to coincide with lunar noon for the site and landing time evaluated.

The third factor, the temperature of the surface during lunar night, may be partially resolved by design of the equipment. Since most of the operating equipment generates some heat, the thermal design of the equipment may use this to maintain critical equipment within its thermal operating limits. For passive equipment, thermal embrittlement may be a significant problem.

6.2.5 Surface Stay Time Comparison

There were two comparisons of surface stay time, short and medium. The first is the comparison of the 8 day stay time verses the 11 day stay time while the crew is operating from the Personnel Transfer Module. The second is the comparison between the baseline 24 day stay time and 42 day stay time while the crew is operating from the Habitat Module in the Lunar Base. Consumables, spares, surface lighting constraints, crew fatigue and orbital mechanics are the primary factors. Increasing the surface stay time provides more time to perform useful construction and science activities on the lunar surface.

In the comparison between the 8 day and 11 day surface stay times, only 51.1 kg. (112.5 lbs.) of additional consumables for the crew of four provided three extra days of surface stay time. If landing occurred early in the lunar day, the lighting conditions allow useful activity for the full duration of the extended stay period of 11 days. The location of the landing site combined with the rest period after 3 EVA's per crewmember coincided with lunar noon which minimized problems associated with thermal and shadow visibility considerations. For the cost of consumables, it appears advantageous to extend the stay

TABLE 7

SURFACE STAY TIME TRADE

Stay Time	Accommodations	SUPPORT REQUIREMENTS		Consumables Lbs.
		Lunar Days	Lunar Nights	
8	PTM	1	0	300
11	PTM	1	0	413
24	PTM, HM	1	1	900
42	PTM, HM	2	1	1,575
180	PTM, HM	6	6	6,750

FOOTNOTES:

- (1) Stay time expressed in Earth-days
- (2) Accommodations -PTM-Personnel Transfer Module, HM-Habitat Module

OPERATIONAL CAPABILITIES

Days Stay Time	Total Crew Hours	Total No. EVA	Total EVA Hours	Total IVA Hours
8	256	6	72	148
11	352	8	96	208
24	768	18	216	444
42	1,344	30	360	804
180	5,760	119	1,428	3,618

time to gain crew time to perform surface operations. The short difference in stay times should not cause significant problems in habitability considerations.

For the comparison between the 24 day and 42 day stay times, consumables and lunar night conditions enter as factors restricting the duration of useful EVA. The advantage of considering the 42 day stay time is that two lunar days of surface operations can be accomplished on a single mission for the cost of consumables. With landing occurring early in the lunar day, the limit of EVA operation is reached at approximately 22 days due to surface lighting constraints during lunar night. This surface lighting constraint is site dependent and applies to the site selected for this study. At this point, it is assumed that the additional time during lunar night will be occupied with IVA activities. If it is elected to extend the surface stay time to 42 days, then additional consumables amounting to 306.5 kg. (675 lbs.) must be added to provide the extended stay capability.

In both groups of comparisons, it was assumed that the water loop was 97% closed and the CO₂ loop was regenerative. Crew fatigue and transportation orbital mechanics have not been factored into the considerations.

6.2.6 Surface Stay Time Recommendations

It is recommended that the baseline stay times of 8 days and 24 days be retained at the start of each operational period because of the indeterminate factor of crew fatigue from EVA activities. After experience has been gained from each initial mission, determination of crew capability on the lunar surface can be better evaluated for future missions. If the experience indicates that crew fatigue is not a problem, then on subsequent missions the small amount of consumables required should be added to allow for extension of surface stay time. In addition, this task should be reevaluated after detailed analysis of transportation orbital mechanics has been performed.

6.3 Supply Options Trade

The supply options trade study investigated the packaging and handling options and the required mass for spares, consumables, and equipment to support the supply of the Lunar Base. The items that were evaluated were the nature of the supply item, usage location, storage requirements, environmental requirements, size, and packaging requirements.

6.3.1 Logistics Assumptions

The following assumptions are used in developing the logistics concepts and calculating mass and volume requirements:

1. For life support, food, personal hygiene and clothes, 4.04 kg. (8.9 lb.) /person/day was assumed. This is rounded up to 136 kg. (300 lb.) for an 8 day lunar surface stay time. These numbers are from the NASA Civil Needs Data Base (Ref. 1). This number was checked in our detailed calculations of supply mass requirements.
2. Spares are built up at a rate of 10% of the mass of permanent habitable modules and equipment delivered to the surface of the moon. The 10% rate was derived from an analysis of spares requirements for the Space Station. The masses for the Space Station LRUs in the airlock, habitation module and a node were summed. Assuming one replacement unit was carried to the Space Station for each LRU, the spares mass equaled 10% of the total mass of the airlock, habitation module and a

node. Because of the similar remoteness of the Lunar Base, the 10% mass of the total delivered payload mass was used.

3. A stowage and logistics system compatible with the Space Station will be used. Standard racks will be used in the Habitation and Logistics Modules. Stowage containers will be similar or identical to the Space Station stowage containers.
4. The reusable Personnel Transfer Module will be maintained at the Space Station. The vehicle maintenance facilities, equipment, and personnel will already be available at the Space Station for maintaining other vehicles such as the Orbital Transfer Vehicle. Before taking the Personnel Transfer Module to the lunar surface, a maintenance cycle will be performed to maximize crew safety and mission success. Maintenance at the Space Station saves the weight penalty of transporting maintenance equipment and supplies to the lunar surface.
5. Some failed equipment which can not be repaired on the Moon or at LEO will be returned to the Earth if desired for failure analysis. If the equipment can be dismantled and faulty components identified, only the failed component will be returned. The rest will remain on the Moon in a Reprocessing Depository (RD) for future repair parts or recycling of materials.

Trades studies will have to be done to determine if it is cheaper to fix broken parts or replace them. Since crew time is an expensive commodity, the weight to supply parts or new equipment will be traded against the weight and cost to provide crew repair hours.

6. All supply materials not used as scheduled will be stored on the Moon to build up the supply inventory. Therefore, shielding or storage facilities will be needed at a very early stage. A logging and tracking system will also be needed for inventory control.

6.3.2 Detailed Mass Calculations for Manned Missions

The information in Table 8 represents supply mass tabulation by mission for the mission scenario developed in Appendix A as well as detailed calculations made from the data provided at the beginning of this task. The top rows contain information on the year of the flight, mission number, number of crew, and the days of surface stay time. Directly below are the mass of equipment delivered to the lunar surface and an estimate of the required mass for spares. The next group of information contains the CNDB values for consumables mass.

The mass required for each manned mission was developed in two ways. First, the CNDB lists the mass by crew person and base support requirements. Second, using consumables requirements developed for Space Station (Ref. 2), a mass summary was developed.

Table 8 shows the consumables required for each manned mission. For crew consumables, 4.04 kg (8.9 lb) /person/day was assumed. This is rounded up to 136 kg (300 lb) for an 8 day lunar surface stay time. These numbers are from the NASA Civil Needs Data Base (Ref. 1). These numbers were verified with the "Manned Mars Mission, Working Group Papers" (Ref. 4) guidelines for ECLSS Average Design Loads given in Table 9.

TABLE 8: SUPPLY CALCULATIONS

YEAR	2000			2001			2002			2003			2004			2005						
	1999	2000	2001	2002	2003	2004	2005	1999	2000	2001	2002	2003	2004	2005	1999	2000	2001					
Mission Number	2	4	6	9	11	13	16	18	20	22	26	30	31	32	34	36	38	39	42	44	46	47
Crew on Surface	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Days on Surface	8	8	8	8	24	24	24	24	24	24	24	24	24	24	24	24	24	24	180	180	180	180
Mass Build Up	6000	44500	32900	23080	38500	38500	18400	40000	38300	13200	0	0	0	0	38500	38500	33333	0	10700	38500	40000	0
Lbs For Mission Delivery	6000	50500	83400	106480	144980	183480	221980	280380	318680	331880	331880	331880	331880	331880	370380	408880	442213	442213	452913	491413	531413	531413
Lbs Cumulative Mass																						
Spares (Trade Calculations)	600	4450	3290	2308	3850	3850	1840	4000	3830	1320	0	0	0	0	3850	3850	3333	0	1070	3850	4000	0
Lbs For Mission	600	5050	8340	10648	14498	18348	22198	28038	31868	33188	33188	33188	33188	33188	37038	40888	44221	44221	45291	49141	53141	53141
Lbs Cumulative																						
Lbs For Mission	1.5	900	6675	4935	3462	5775	5775	2760	6000	5745	1980	0	0	0	5775	5775	5000	0	1605	5775	6000	0
+ Container																						
Lbs Cumulative	1.5	900	7575	12810	15972	21747	27522	33297	36057	42057	47802	49782	49782	49782	55557	61332	66332	66332	67937	73712	79712	79712
+ Container																						

Crew	1800		1800		1800		1800		1800		1800		1800		1800		1800		1800		1800	
	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300
Crew Rotation	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
450 Lb/person Msn	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300
Number of Modules	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Crew Logistics	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300
8.9 lb/person/day	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300
300 lb/14 days	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300	285	300
CNDB Consumables Estimates																						
Leakage Air	1.25	1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Lbs Air+Tank	2	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
* (Per Mission Interval)																						
ECLSS																						
Per Man Per Day	1.82	0.05	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Metabolic O2	1.60	1	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51	51
Food Solids	0.99	1	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Food H2O	0.99	1	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Food Packaging	0.13	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Charcoal	1.22	1	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122	122
LBS ECLSS Total	1.5	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183
LBS ECLSS+Container																						
EVA																						
EVA H2O/Man/EVA	7.25	1	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87	87
Lbs H2O+Container	1.2	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104	104
EVA O2/Man/EVA	0.90	0.05	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Airlock Gas Loss	1.32	1	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Garage Gas Loss	44	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lbs EVA Gases Total	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Lbs EVA Consum+Container	2	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Lbs Total Consum	228	228	228	228	228	228	228	228	228	228	228	228	228	228	228	228	228	228	228	228	228	228
Lbs Total Consum+Container	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325

FOLDOUT FRAME

FOLDOUT FRAME

TABLE 9. ECLSS AVERAGE DESIGN LOADS
(from Ref. 4)

Metabolic O ₂	0.83 kg/man day	(1.82 lbs/man day)
Leakage Air	2.27 kg/day total	(1.25 lbs/day/module)
EVA O ₂	0.55 kg/8 hr EVA per man	(.90 lbs/6 hr EVA per man)
EVA CO ₂	0.67 kg/8 hr EVA per man	
Metabolic CO ₂	1.00 kg/man day	
Drink H ₂ O	1.86 kg/man day	
Food preparation H ₂ O	0.72 kg/man day	
Metabolic H ₂ O	0.35 kg/man day	
Clothing wash H ₂ O	12.47 kg/man day	
Handwash H ₂ O	1.81 kg/man day	
Shower H ₂ O	3.63 kg/man day	
EVA H ₂ O	4.39 kg/8 hr EVA per man	(7.25 lbs/6 hr EVA per man)
perspiration and respiration H ₂ O	1.82 kg/man day	
Urinal flush H ₂ O	0.49 kg/man day	
Urine H ₂ O	1.50 kg/man day	
Food solids	0.73 kg/man day	(1.60 lbs/man day)
Food H ₂ O	0.45 kg/man day	(.99 lbs/man day)
Food packaging	0.45 kg/man day	(.99 lbs/man day)
Urine solids	0.06 kg/man day	
Fecal solids	0.03 kg/man day	
Sweat solids	0.02 kg/man day	
EVA Wastewater	0.91 kg/8 hr EVA per man	
Charcoal required	0.06 kg/man day	(.13 lbs/man day)
Metabolic sensible heat	2.05 kW-hr./man day	
Hygiene Latent H ₂ O	0.44 kg/man day	
Food preparation latent H ₂ O	0.03 kg/man day	
Wash H ₂ O solids	0.44 percent	
Shower/hand wash H ₂ O solids	0.12 percent	
Air lock gas loss	0.60 kg/use	(1.32 lbs/use)
Trash	0.82 kg/man day	
Trash volume	0.0028 m ³ /man day	

Spares are gradually increased and remain on the surface for future use. Spares are calculated as a percent of functional surface mass buildup. For example, the functional surface mass buildup by Mission 2 includes an unpressurized rover 1,814 kg.(4,000 lbs) and landing instrumentation/beacons 907 kg. (2,000 lbs.). Ten percent of the total mass of 2,721 kg. (6,000 lbs.) is required for spares which is 272 kg. (600 lbs). The 10% rate of spares buildup was based on Space Station analyses of work package 1 spares requirements. For the lab module, habitation module, pressurized and unpressurized logistics carriers, airlocks and nodes, 693 LRU's were identified. These occupy approximately 27 cu. m. (960 cu. ft.) with packaging and have an average density of 320 kg./cu.m. (20 lbs./cu. ft.). This totals 8,709 kg. (19,200 lbs.). The total mass of the work package modules is 88,961 kg. (196,122 lbs.). To provide spares, 10% of the mass is needed.

Spares will be supplied for the LRUs, equipment, and subsystems. Occasionally, for unplanned and unpredicted failures for which no spares exist on the lunar surface, parts may be shipped on manned or unmanned missions having excess mass and volume payload capability. This will be done in a manner similar to the Skylab repair methods (Ref. 8 & 9).

The group of data entitled Crew Life Support, are the detailed calculations which were developed from the input groundrules and assumptions at the start of this task. Preliminary calculations for ECLSS water usage, which are not included, indicated that with a 97% efficient water recovery system, the makeup water from the food canceled out any losses due to non-recoverable waste water. For safety, however, contingency water should be delivered early to the lunar surface and stored in the safe haven in the event that water closure cannot be achieved either through an accident or by low efficiencies of water recovery.

The data listed under EVA represents those losses due to suit efficiencies and non-recoverable atmosphere losses from the airlock and pressurized garage.

All of the consumables and spares were tabulated and an appropriate factor included for packaging and tankage for results which are listed directly below the bare consumable mass values. One variation that was made to the data in the tables for the data presented in Appendix A was the distribution of supply mass on the last four manned missions. This was done to evaluate the capability of the model to keep the consumables on the same vehicle as the crew.

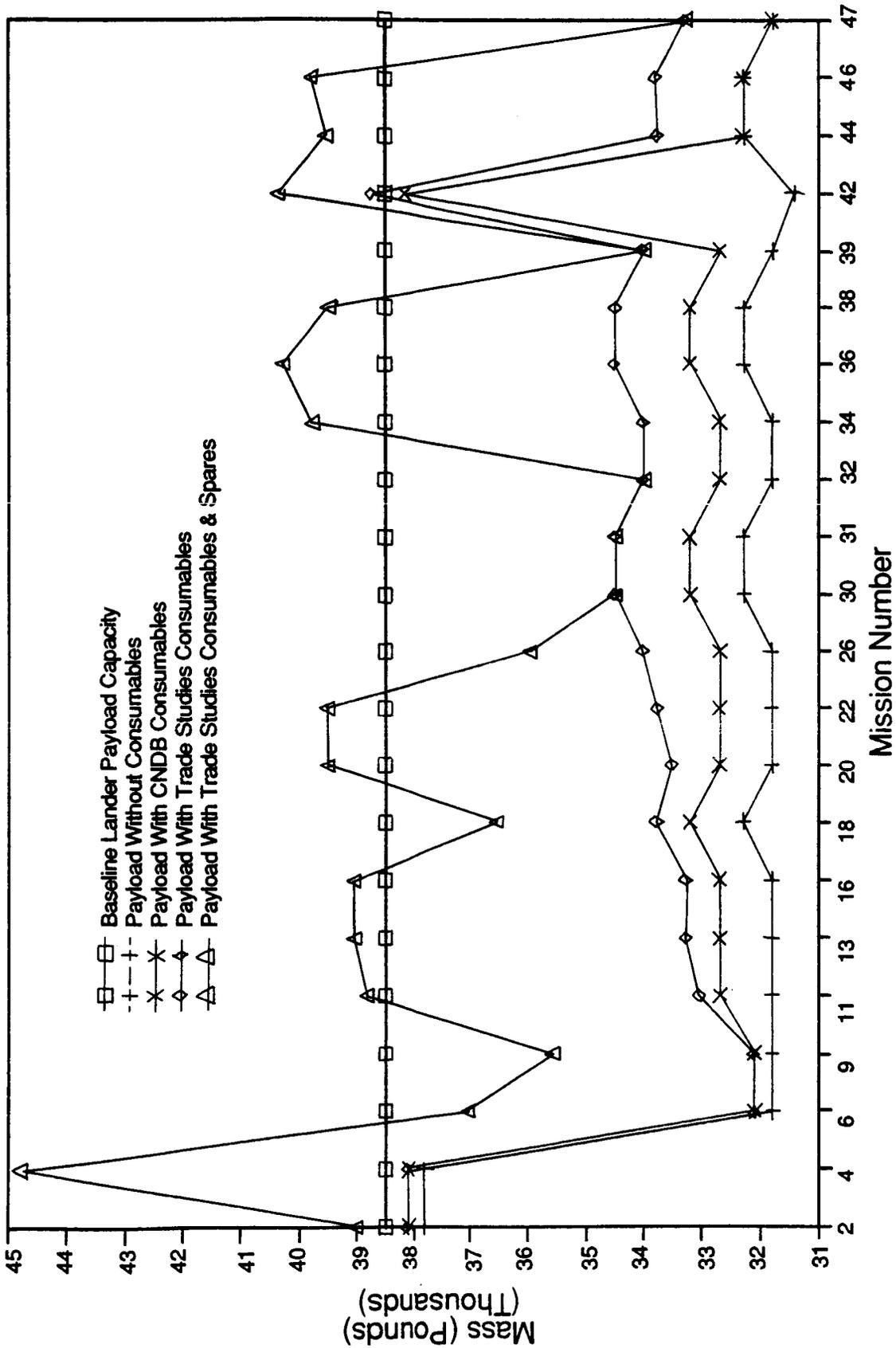
Figure 1 is a graphic plot of the data presented in Table 8. Figure 1 indicates how the consumables and spares mass compare to lander capacity and normal payloads. The landed payload mass on the lunar surface was plotted against the mission number for four cases. The horizontal line at 17,464 kg. (38,500 lb.) represents the maximum delivery capacity of the lander stage. The cases plotted were (1) payload mass with the Appendix A CNDB values for consumables, (2) payload mass without any consumables or spares, (3) payload mass with the trade study calculated consumables and packaging mass, and (4) payload mass with trade study calculated consumables, spares and packaging mass. The last plot may be the most accurate representation of actual landed mass.

6.3.3 Packaging and Handling Trade Options

The supply packaging and handling trades concern the transfer of supplies to the lunar surface and the surface stowage method.

Payload Delivery By Mission

Figure 1



- Notes:
- (1) Payload consists of Ascent Stage, Personnel Transfer Module, Crew, and any added surface cargo
 - (2) Spares are items for hardware delivery on the previous unmanned delivery flights that will be used by the crew to maintain and repair the equipment

Four alternatives exist for transferring the supplies to the lunar surface. First the Personnel Transfer Module can be sized to accommodate consumables and spares for internal stowage. Second, external provisions could be attached to the Personnel Transfer Module for storage of spares and consumables. Third, the Expendable Lunar Lander can be fitted to transport Space Station compatible stowage racks. Fourth, a dedicated logistics module can be transported.

For surface stowage, several alternatives are possible. First the existing Lunar Base modules can be used. Second, a small module can be developed with pieces which lock together on the lunar surface. Third, shielded unpressurized stowage under the Expendable Lunar Lander can be used.

The storage container design must accommodate pressurized and unpressurized stowage, liquids, gases, and cryogenics. It must support the return of scientific samples and products and failed equipment. It must also provide stowage for waste products which may become future recyclable resources.

The logistics container and module design should be Space Station compatible (Ref. 10). Since the Space Station will be the transfer point for supplies and a source for additional rush supplies when time does not permit delivery from the Earth, the use of the standard rack will simplify loading and transfer of supplies.

The Space Station Program has generated several container designs (Ref. 11). These include Shuttle-type drawers with net covering, frames with pockets and inflatable air bladders between frames, honeycomb matrix containers, carousel drawers with sliding tambour doors and triangular bins. A rack has approximately 1.93 cu. m. (68 cu. ft.) of stowage volume. The stowage container efficiency ranges from 54% to 81% of the pressurized container volume.

The supplies can be stored in pressurized and unpressurized facilities. For all missions, a two week supply of food will always be in the pressurized module as a minimum. Food, crew equipment and spares can be stored in short and long term stowage in pressurized and unpressurized containers.

The Expendable Lunar Lander can be designed with beta cloth shades to be attached and deployed on the lunar surface. Unpressurized, sheltered stowage will be appropriate for tanks of liquids, gases and cryogenics. Dry goods and equipment can be stored in vacuum sealed packages and also left in a sheltered storage area.

All materials carried to the Moon will be expensive to lift from the Earth's surface. Therefore, a Reprocessing Depot (RD) will be needed for dry trash, brine, human waste and other solids. The RD must be located in an environmentally acceptable place. It must be within convenient access, not visually unsightly, and not blocking access to lunar resources. Materials stored must not pollute the lunar environment.

Items stored at the RD should be separated and stored depending on possible future use. Based on solid waste estimates from Space Station, .044 cu. m. (1.548 cu. ft.) of waste will be generated per day for a four person crew. The density is 116.6 kg./cu. m. (7.28 lbs./cu. ft.). After compaction, the density is estimated to be 416.5 kg./cu. m. (26 lbs./cu. ft.) (Ref. 2). Dry trash will be stored within the habitable areas of the lunar station for up to seven days then transferred to a temporary unpressurized external holding area and finally transported to a RD.

6.3.4 Supply Module Design Considerations

From the results of the investigation, it became apparent that several distinct categories of packaging and handling requirements exist to support the transportation and distribution of consumables, spares, and equipment to the lunar surface. Supply of the Lunar Base during the first two periods with stay durations of eight to twenty-four days should be accomplished by utilizing space in the Personnel Transfer Module and the Lander bays.

This is possible with the excess payload capacity available on the manned missions. The required total landed for 180 day missions mass exceeds the capability of the lander however. Based on this, the spares can be spread over all of the missions as shown in Figure 1 or a dedicated supply flight to provide the necessary consumables and spares for a planned period of time can be flown.

Percentage estimates for tankage and packaging on each class of item, and item masses result in an estimated supply mass for 180 day missions. The tankage and packaging factors utilized are 20% for liquids, 50% for solids, and 100% for gasses (Ref. 12). Summing the total supply requirements (spares and consumables) for the last four manned missions, produces a total mass of 19,531 kg. (43,058 lbs.).

The total liquid and gas masses for the last four missions for module leakage and EVA activities (without tankage) are 3,814 kg. (8,408 lb.). Delivery of all the consumables and spares to support the Lunar Base for two years is not practical on one mission. It is assumed that some of the consumables and a limited amount of critical spares identified between missions will be delivered with the manned missions. An estimate of 20% of the total mass calculated for two years of consumables and spares is assigned for delivery with the manned missions. Since 20% of this mass is to be delivered with the manned missions, the remaining liquid and gas mass that must be delivered with the Logistics Module is 3,052 kg. (6,726 lb.).

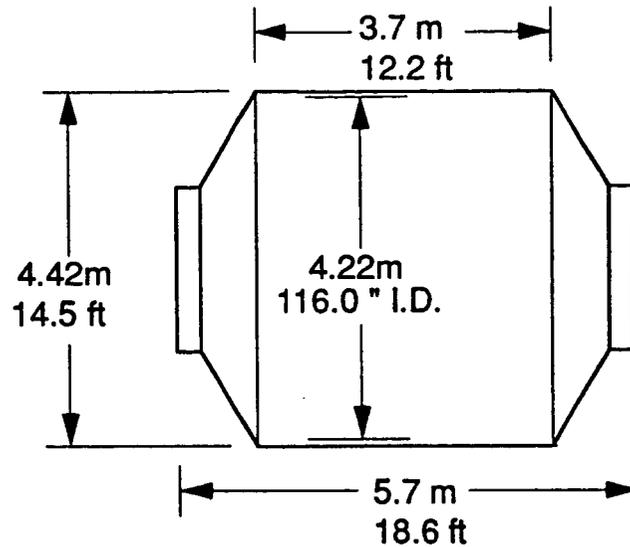
The sum of the ECLSS consumables and general spares with their packaging weight, is 13,548 kg. (29,868 lbs.). With the delivery of 20% of this mass on the manned missions, the amount remaining to be delivered on the Logistics Module is 10,838 kg. (23,894 lbs.).

Given the above values for mass of consumables and spares, a logistics module having an overall length of 5.66 meters (18.6 ft.) and an empty mass of 4,053 kg. (8,936 lb.) could accommodate the items and still provide space for crew access and support equipment. Similar calculations resulted in a liquid tankage module having a length of 2.2 meters (7.2 ft.) and a empty mass of 1,525 kg. (3,363 lbs.). To accommodate items not requiring pressurized storage which will not fit inside the module, pallets similar to those used by the Space Lab may be adequate. These modules are shown in Figure 2 and Figure 3.

The masses of the modules were derived from designs developed for the Space Station and the Spacelab (Ref.3, 13, & 14). The referenced modules were designed to be flown on the Shuttle and have to meet the launch and landing loads experienced during operations. As a consequence, the design is conservative when applied to the Lunar Base. The incorporation of lighter materials for the Modules and repackaging at the Space Station for the lunar transportation environment will probably reduce the mass of the modules and improve the payload mass fraction delivered to the lunar surface.

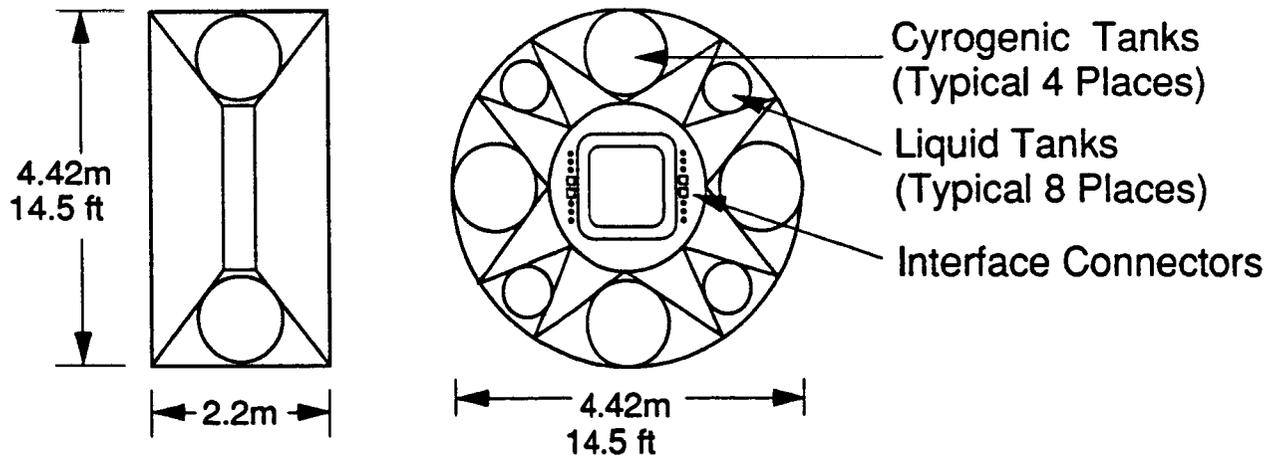
Most of the consumables with the exception of the liquids and gasses, should be stored inside a pressurized volume to allow the base crew shirtsleeve access to the consumables and spares. Standard docking hatches should be provided on both ends of the module to

Logistics Supply Module



Module Length	Structure and Hardware Mass	Subsystems	Payload	Total Mass
5.7 m 18.6 ft	3,525 Kg 7,771 lbs	528 Kg 1,165 lbs	10,838 Kg 23,894 lbs	14,891 Kg 32,830 lbs

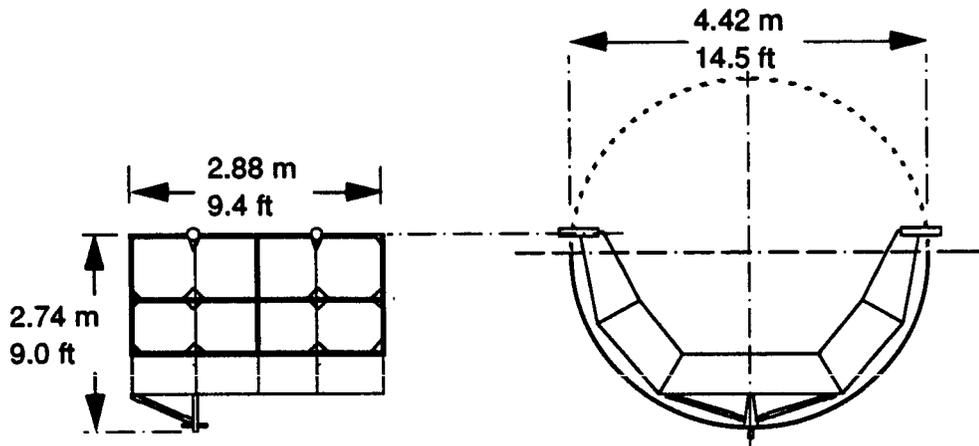
Fluid Shipping Module



Module Length	Struct. Mass	Subsystems	Cryo & Liquids	Total Mass
2.2 m 7.2 ft	305 Kg 673 lbs	1,220 Kg 2,690 lbs	3,051 Kg 6,726 lbs	4,576 Kg 10,089 lbs

Figure 2

Logistics Module Pallets



Module Length	Struct Mass	Payload	Total
2.88 m 9.4 ft	816 Kg 1,800 lbs	3110 Kg 6,856 lbs	3,926 Kg 8,656 lbs
5.76 m 18.8 ft	1632 Kg 3,600 lbs	6,220 Kg 13,712 lbs	7,852 Kg 17,312 lbs
8.64 m 28.2 ft	2448 Kg 5,400 lbs	9,330 Kg 20,568 lbs	11,778 Kg 25,968 lbs

Figure 3

allow a series interconnect capability for subsequent Logistics Modules. The liquids and gasses could remain attached to the module in a ring arrangement occupying the annular volume between two interfacing conical end bulkheads and docking mechanisms, and interconnected to the Lunar Base through lines passing through the docking interfaces. The design of the Logistics Module stowage container attachments should be of a standard length with standardized rack fittings which are compatible with the Space Station racks.

The location of the tanks for the liquids and gasses may be outside the pressurized volume and attached in a modular fashion to either the Personnel Transfer Module or the Logistics Module to allow growth capability for future missions. Those items which are not required to be pressurized may be delivered on a pallet or truss structure attached to the Logistics Module. This structure would be for the delivery of spares for surface equipment which may be larger than the volume that can be transferred through the standard hatch opening. Open structures will also be lighter in weight and allow access for equipment operating in the exposed lunar environment.

A major advantage of having a pressurized module with modular detachable tanks and incrementally sized pallets, is that the pressurized module could be centrally located for both mass and volume by adding the modular tanks and pallet or pairs of pallets at either end of the pressurized module. This would allow the center of gravity and volume to be better located to keep them within the limits for the OTV and Lunar Lander during delivery to the Moon.

Attachment fittings which would allow standard size racks to be attached to the pallet structure should be considered for this structure.

To allow attachment of subsequent Logistics Modules to the pressurized volume, the open structure would have to be removed from the pressurized module to access the docking interface at the end of the pressurized Logistics Module.

6.3.5 Supply Options Recommendations

It is recommended that the supply consumables and spares be delivered with the manned missions for the 8 day and 24 day surface stay missions. Considerations for packaging mass should be factored into the data for the next series of tasks. In addition, provisions for spare parts delivery and lunar surface storage should be included in the scenario for the development of the Lunar Base.

With the increased support requirements of the 180 day missions, modules should be developed to carry the supply items to the Lunar Base. To accomplish this, three categories of shipping modules should be developed and the selection of the type of container for packaging the supply item should be made on the basis of its nature, size, and intended usage location. These are a pressurized Logistics Module, fluid and cryogenic tankage module, and incrementally sized unpressurized pallets. Standardized attachment points should be utilized on the Logistics Module and Lander bays to allow transfer and storage of supply items between both elements. The Logistics Module should be designed to provide pressurized storage which can be interconnected to the Lunar Base for shirt sleeve access to supplies, tankage module for liquids and gasses, and unpressurized structure for carrying large items and those items designed to be used on the exposed lunar surface.

Additional trade studies should be performed to investigate the option of repackaging equipment, consumables, and spares at the Space Station to allow for significant reduction in mass for the Logistic Module, fluid module, and pallets if they are designed for space

transportation and Lunar landing loads instead of Shuttle operational loads. These mass reductions may be offset by the requirement to launch additional empty, low mass logistic modules, pallets, etc. from Earth. This study should also evaluate the operational role of the Space Station for the support of the Lunar Base and identify the impact of those requirements on the present Space Station baseline.

The support of the permanently manned Lunar Base should include a logistics supply flight every two years of an unmanned lander to deliver the necessary spares and consumables. The lunar base models currently in existence do not adequately account for this supply mass and it must be considered when manifesting flights for a more mature base, and in lander sizing for an early base.

7.0 Conclusions and Recommendations

This task developed a phased approach to maintenance and supply of the Lunar Base. As the crew stay time and crew complement grew, maintenance tasks were gradually transferred to the Lunar Base. This was also matched with the availability of spares and repair equipment as the Base developed.

The results of the crew size trade indicated that the baseline crew size of four had the minimum mass impact but also had limited resources in terms of crew time available. If operational flexibility is desired however, a crew complement of six provided the most flexibility with the least amount of impact. It is also recommended that the sizing of the Habitat Module be increased to accommodate the crew for the permanently manned base.

Evaluation of crew surface stay times disclosed that increased operational crew time can be easily obtained through the extension of surface stay times with a small increase in consumables. For short surface stay time extensions, the extra consumable mass was small compared to all other factors. For medium length stay times, the advantage of increasing the stay time from 24 days to 42 days was that two lunar day cycles could be gained on a single mission for the cost of the consumables to support the crew. The advantage of gaining the additional crew time on the lunar surface on a single mission is obvious. To assure that the crew operational limits will not be exceeded, it is recommended that the stay times begin with the baseline values and be increased as experience indicates the ability to perform surface operations will not be severely constrained by stay times or level of activity on the surface. These conclusions assume a partially closed ECLSS for all stay times. A major concern was the impact of transportation orbital mechanics which may limit the windows of opportunity for travel between the Earth and the Moon. It is recommended that the issue of surface stay time be readdressed after a detailed study of transportation orbital mechanics has been performed.

The supply option trade indicated a phased approach of supply delivery to the lunar surface. During the periods while the crew spends either 8 or 24 days on the surface, supply items should be carried with the Personnel Transfer Module or in available space in the Lander bays.

Subsequent studies and data bases should increase the total supply mass estimates to include containerization mass and spares to the items delivered in the supply packages. The estimates of consumables mass indicated in the CNDB data should be increased since this task evaluation almost equalled the supply masses by only considering crew metabolic needs and losses due to leakage and EVA activities. In reality, housekeeping consumables, and maintenance and servicing consumables for the equipment on the lunar surface will equal or exceed those amounts calculated for crew needs alone. Future lander sizing work must also take these additional masses into account.

With the extended duration missions of 180 days, a Logistics Module should be utilized. The Logistics Module is estimated to weigh 4,053 kg. (8,936 lb.) and be 5.7 meters (18.6 ft.) in length. To support the majority of the supply needs of the Lunar Base, a dedicated unmanned lander is required to deliver the Logistics Module to the lunar surface every two years. Additionally, provisions for carrying large spares and items to be operated in the unpressurized environment should be provided with the incorporation of a pallet or truss structure which can be connected to the Logistics Module. Fluids and gasses are best handled by modular ring tanks which can either be attached to the Personnel Transfer Module or the Logistics Module.

Other issues raised by this study are as follows:

- The reliability of the Lunar Base equipment must be significantly higher than that of the Space Station due to the longer interval for resupply and repair of failed equipment.
- The equipment must be designed to be easily maintained and repaired by the crew without occupying over 20% of their available time.
- The role and support capability of the Space Station needs to be assessed and provisions made to provide that capability to support the Lunar Base.

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**Appendix A
Alternative CNDB Scenario**

Year 1999

Surface:

Mission 1 (Unmanned, dedicated expendable lander to Lunar base site)

1. Surface Unmanned Surveying Rover (2,200 lbs) - CNDB No. 5034

Mission 2 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Unpressurized Rover (4,000 lbs) - CNDB No. 5031
3. Landing Instrumentation/Beacons (2,000 lbs, est.)
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
5. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
6. Crew Rotation - 4 crew/14 day mission/8 day surface stay (1,800 lbs) - CNDB 5002
7. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB 5052
8. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 38,075 lbs Total = 79,735 lbs Payload available = 425 lbs

Year 2000

Surface:

Mission 3 (Unmanned)

1. Crane and cargo carrying trailer, Prime Mover (PM), PM trailer for carrying soil (dumpable), PM attachments (bulldozer blade, front loader shovel, etc.), PM attachment changeout fixture (38,500 lbs) - Similar to CNDB No. 5032
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 4 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Unpressurized Rover (4,000 lbs) - CNDB No. 5031
3. Landing Instrumentation/Beacons (2,000 lbs, est.)
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
5. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
6. Crew Rotation - 4 crew/14 day mission/8 day surface stay (1,800 lbs) - CNDB 5002
7. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB 5052
8. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 38,075 lbs Total = 79,735 lbs Payload available = 425 lbs

Mission 5 (Unmanned)

1. Surface Communications Relay Station - Phase 2 (2,500 lbs) - CNDB No. 5036
2. Initial Power Plant (7,000 lbs) - CNDB No. 5013
3. Radiation Storm Shelter/Safe Haven Module (20,000 lbs est.)
4. Radiator/Thermal Control System (for 2 modules/2 nodes) (3,400 lbs est.)
5. Bulkheads and Hopper/Conveyor System (for covering module) (3,000 lbs est.)
6. Unpressurized Storage Shed (for vehicles & PM attachments) (2,000 lbs est.)
5. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5053

Payload = 37,900 lbs Total = 79,560 lbs Payload available = 600 lbs

Mission 6 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/14 day mission/8 day surface stay (1,800 lbs) - CNDB 5002
5. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB 5052
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,075 lbs Total = 73,735 lbs Payload available = 6,425 lbs

Mission 7 (Unmanned - spare ascent vehicle for contingency/emergency return)

1. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
2. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
2. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB No. 5052
3. Expendable Lunar Ascent Vehicle - CNDB No. 5053 (16,275+? lbs)

Payload = 29,775+? lbs Total = 71,435+? lbs Payload available = 8,725-? lbs

Year 2001

Surface:

Mission 8 (Unmanned)

1. Module Interface Node (8,200 lbs) - CNDB No. 5082
2. Airlock (6,800 lbs est.)
3. (2) Initial Power Plants (7,000 lbs/each) - CNDB No. 5013
4. (Lunar Base) Geophysical Network Station (1,080 lbs, est.)
5. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 30,080 lbs Total = 71,740 lbs Payload available = 8,420 lbs

Mission 9 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018

Mission 9 (Continued)

4. Crew Rotation - 4 crew/14 day mission/8 day surface stay (1,800 lbs) - CNDB 5002
5. Crew Logistics - 4 crew/14 day mission/8 day surface stay (300 lbs) - CNDB 5052
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,075 lbs Total = 73,735 lbs Payload available = 6,425 lbs

Mission 10 (Unmanned)

1. Habitat Module - Phase 2 (38,500 lbs) - CNDB No. 5011
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 11 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5002
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5052
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 12 (Unmanned)

1. Geochemical Materials Laboratory (38,500 lbs) - CNDB No. 5073
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 13 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5002
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5052
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 14 (Unmanned - dedicated expendable lander to polar site)

1. (Polar) Geophysical Network Station (8,000 lbs est.)

Year 2002

Surface:

Mission 15 (Unmanned)

1. Liquid Oxygen Pilot Plant (38,500 lbs) - CNDB No. 5028
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 16 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 17 (Unmanned)

1. Module Interface Node (8,200 lbs) - CNDB No. 5082
2. Airlock (6,800 lbs est.)
3. Radiator/Thermal Control System (for 2 modules/2 nodes) (3,400 lbs est.)
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 18,400 lbs Total = 60,060 lbs Payload available = 20,100 lbs

Mission 18 (Manned)

1. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 19 (Unmanned)

1. (1) Life Science Research Facility (40,000 lbs/each) - CNDB No. 5015
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 40,000 lbs Total = 81,660 lbs Payload available = -1,500 lbs

Mission 20 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068

Mission 20 (Continued)

5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 21 (Unmanned)

1. (2) Pressurized Rovers (4,180 lbs/each - 8,360 lbs total)
2. Pressurized Garage (15,000 lbs est)
3. Optical Interferometer Telescope (15,000 lbs) - CNDB No. 5037
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,360 lbs Total = 80,020 lbs Payload available = 140 lbs

Mission 22 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 23 (Unmanned - dedicated expendable lander to near-side site)

1. (Near Side) Geophysical Network Station (8,000 lbs est.)

Year 2003

Mission 24 (Unmanned to Earth-Moon L2 Libration Point)

1. Communications Relay Satellite - Phase 2 (2,500 lbs) - CNDB No. 5078

Surface:

Mission 25 (Unmanned)

1. Life Science Research Node (8,200 lbs) - CNDB No. 5079
2. Crater Dating Experiment Equipment (1,000 lbs est.)
3. Deep Drilling (4,000 lbs) - CNDB No. 5065
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 13,200 lbs Total = 54,860 lbs Payload available = 25,300 lbs

Mission 26 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Mission 26 (Continued)

3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 27 (Unmanned, farside payload, deployable from lander, may be able to combine with Mission 28)

1. Lunar Farside UV Telescope (10,000 lbs) - CNDB No. 5009
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050 - or use dedicated lander

Payload = 10,000 lbs Total = 51,660 lbs Payload available = 28,500 lbs

Mission 28 (Unmanned, farside payload, deployable from lander, may be able to combine with Mission 27)

1. Lunar Based SETI (20,000 lbs) - CNDB No. 5008
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050 - or use dedicated lander

Payload = 20,000 lbs Total = 61,660 lbs Payload available = 18,500 lbs

Mission 29 (Unmanned, farside payload, dedicated expendable lander)

1. (Farside) Geophysical Network Station (8,000 lbs est.)

Mission 30 (Manned)

1. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 31 (Manned)

1. Service Life Science Facility (500 lbs) - CNDB No. 5070
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 32 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Year 2004

Surface:

Mission 33 (Unmanned)

1. Advanced Power Plant (38,500 lbs) - CNDB No. 5006
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 34 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Mission 35 (Unmanned)

1. Oxygen Mining Equipment (38,500 lbs) - CNDB No. 5071
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 38,500 lbs Total = 80,160 lbs Payload available = 0

Mission 36 (Manned)

1. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5018
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5068
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 37 (Unmanned)

1. Liquid Oxygen Production Plant Mission (33,333 lbs) - CNDB No. 5029
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5053

Payload = 33,333 lbs Total = 74,993 lbs Payload available = 5,167 lbs

Mission 38 (Manned)

1. Service Life Science Facility (500 lbs) - CNDB No. 5070
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
6. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
7. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 33,175 lbs Total = 74,835 lbs Payload available = 5,325 lbs

Mission 39 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/30 day mission/24 day surface stay (1,800 lbs) - CNDB 5068
5. Crew Logistics - 4 crew/30 day mission/24 day surface stay (900 lbs) - CNDB 5075
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,675 lbs Total = 74,335 lbs Payload available = 5,825 lbs

Year 2005

Mission 40 (Unmanned to Earth-Moon L1 Libration Point)

1. Communications Relay Satellite - Phase 3 (2,500 lbs) - CNDB No. 5026

Surface:

Mission 41 (Unmanned)

1. Communications Relay Station - Phase 2 (2,500 lbs) - CNDB No. 5036
2. Module Interface Node (8,200 lbs) - CNDB No. 5082
3. Logistics Module (19,220 lbs est.)
4. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 29,920 lbs Total = 71,580 lbs Payload available = 8,580 lbs

Mission 42 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018

Mission 42 (Continued)

4. Crew Rotation - 4 crew/180 day mission & surface stay (1,800 lbs) - CNDB No. 5067
5. Crew Logistics - 4 crew/180 day mission & surface stay (6,400 lbs) - CNDB No. 5076
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 38,175 lbs Total = 79,835 lbs Payload available = 325 lbs

Mission 43 (Unmanned)

1. Propellant Depot/Refueling Station on Surface (38,500 lbs est.)
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 40,000 lbs Total = 81,660 lbs Payload available = 0

Mission 44 (Manned)

1. Service Geochemical Materials Lab (500 lbs) - CNDB No. 5074
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/180 day mission & surface stay (1,800 lbs) - CNDB No. 5067
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,275 lbs Total = 73,935 lbs Payload available = 6,225 lbs

Mission 45 (Unmanned)

1. (1) Life Science Research Facility (40,000 lbs) - CNDB No. 5015
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050

Payload = 40,000 lbs Total = 81,660 lbs Payload available = -1,500 lbs

Mission 46 (Manned)

1. Service Life Science Facility (500 lbs) - CNDB No. 5070
2. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
3. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
4. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
5. Crew Rotation - 4 crew/180 day mission & surface stay (1,800 lbs) - CNDB No. 5067
6. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 32,275 lbs Total = 73,935 lbs Payload available = 6,225 lbs

Mission 47 (Manned)

1. Lunar Science and Field Geology (500 lbs - return 100 lbs) - CNDB No. 5027
2. Expendable Lunar Lander (41,660 lbs) - CNDB No. 5050
3. Four-crew Personnel Transfer Module (13,200 lbs) - CNDB No. 5018
4. Crew Rotation - 4 crew/180 day mission/180 day surface stay (1,800 lbs) CNDB 5067
5. Expendable Lunar Ascent Vehicle (16,275 lbs) - CNDB No. 5053

Payload = 31,775 lbs Total = 73,435 lbs Payload available = 6,725 lbs

Year 1999

Mission 2 (4 crew, 8 day surface stay)

1. Flight certification of manned Earth-Moon transportation systems in first manned landing since Apollo.

Navigation aids emplaced or carried by the unmanned rover of the previous mission could assist landing by the manned lander on the selected base site.

2. Make an manned on-site evaluation of the optimum base location.
3. Survey and mark locations for major surface elements (modules, power, communications).
4. Collect surface samples with the Lunar science/field geology equipment/tool package carried on the lander.
5. Select and prepare two landing sites for the following missions. The landing instrumentation/beacon package would include electronic navigational aids.

The crew would use an unpressurized rover for surface exploration and sampling, and perhaps to assist in landing site preparation if it was outfitted with a light weight bulldozer blade. The rover would remain on the surface near the prepared landing sites.

Year 2000

Mission 4 (4 crew, 8 day surface stay)

1. Lands on site selected/prepared in the previous manned mission (other occupied by unmanned mission 3 lander).
2. Unload the crane from the mission 3 lander.
3. Use the crane to unload other equipment: crane cargo carrier (trailer), prime mover (PM), PM attachments, PM cart (soil carrier - dumpable), fixture to store and exchange PM attachments.
4. Check out equipment.
5. Begin preparation of the site selected for the pressurized modules: Earth teleoperation of PM, EVA during final site grading/leveling, Lunar teleoperation of utility trenching operations.
6. Monitor start of excavation of shallow trenches for emplacing modules.
7. Prepare landing sites for next two missions. Landing site preparations could involve preparing permanent sites (4 needed at least) or selecting new landing sites suitably spaced from each other. The launch/landing pads would require navigational aids and lighting. The lights would assist manned vehicles visually locate the landing sites in the event of failure of electronic navigational aids, allow manned night landings/-launches, and allow night unloading of cargo. Preparation of permanent pads could involve construction of a blast shield/wall of local materials using the prime mover through teleoperation from Earth.
8. Collect additional surface & subsurface samples for analysis back at Earth that will lead to selection of the optimum site for collecting feedstock material for an oxygen extraction pilot plant and full scale processing plant.
9. Recharge all vehicle fuel cells before departure (or leave on charging cycle). May need to provide protective shelter for thermal control during lunar night. Leave rovers near landing site (but protected from descent engine exhaust) for next crew.

Mission 6 (4 crew, 8 day surface stay)

1. Land on landing site prepared by the previous manned crew. Recover unpressurized rovers and checkout systems.
2. Unload the unmanned lander from Mission 5.
3. Finish installing utility-ways to complete module site preparation.
4. Begin preparations to bury/cover module for radiation protection from solar flares: setup bulkheads around shallow trench dug on previous mission (and by teleoperation), emplace the solar flare shelter and tunnels, complete bulkhead construction, and position hopper/conveyor system, monitor teleoperation of Prime Mover loading hopper with soil and conveyed over/into bulkhead. Connect all utility interfaces with the shelter (through berthing ring of tunnels).
5. Setup/checkout the power plant and distribution system.
6. Emplace the thermal control system (radiator, sun screens, and control systems) and connect interfaces with module site and solar flare shelter.
7. Setup/checkout the communications relay station.
8. Provide power to the landing navigation and lighting systems
9. Prepare landing sites for next three missions by either removing spent descent stages from permanent landing sites or selecting and preparing new sites. Three sites are needed for manned, cargo, and delivery of contingency ascent vehicle missions.
10. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Year 2001

Mission 9 (4 crew, 8 day surface stay)

1. Checkout the powered-up safe haven systems (completely covered by teleoperated PM & hopper/conveyor system prior to arrival). Access shelter through pre-emplaced tunnels through the overburden.
2. Unload the Mission 8 lander.
3. Berth the module interface node to the tunnel connecting the solar flare shelter and the airlock to the node.
4. Connect utility interfaces to the modules (through an unused node berthing port and a redundant path through the alternative tunnel into the buried solar flare shelter).
5. Setup and checkout of two more power modules.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to Earth.
7. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
8. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 11 (4 crew, 24 day surface stay)

1. Unload the Mission 10 lander.
2. Berth the habitation module to the interface node emplaced in Mission 9. The habitat forms the core of the man-tended and permanently manned base. It contains the primary ECLSS system while other modules will contain safe haven consumables

Mission 11 (Continued)

stored in the event of an emergency. After the module is emplaced, utilities connected, and systems checked out, the Lunar base can be declared a functioning man-tended base and crew stay times extended to a full Lunar day.

3. Also conduct geological research studies and will transport the geophysical station delivered in Mission 8 by unpressurized rover to a local site. The geophysical experiment package is designed to map density variations and the seismic, magnetic, and electrical properties of the subsurface. Portable seismometers and a number of explosive packages will be required, as well as portable magnetometers and gravimeters. A remotely controlled rover will be necessary to help emplace the explosive charges in the 10-100 km range from the seismic arrays to provide the active seismic sources for each deep profiling experiment.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to Earth.
5. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
6. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 13 (4 crew, 24 day surface stay)

1. Unload the Mission 12 lander.
2. Berth the geochemistry materials laboratory to the other end of the module interface-node emplaced in Mission 9.
3. Connect services/utilities interfaces and thoroughly checkout all on-board systems and scientific equipment.
4. Preventive maintenance, resupply, and logistics tasks.
5. Additional Lunar exploration and sample collection trips can be accomplished with the unpressurized rovers. The specific purpose of these geology trips will be to determine the optimum mining locations for excavating feedstock material for the lunar oxygen pilot plant.
6. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Year 2002

Mission 16 (4 crew, 24 day surface stay)

1. Unload the mission 15 lander.
2. Setup the pilot oxygen plant, checkout the system.
3. Monitor initial teleoperated operation: excavation of feedstock material with the Prime Mover, plant startup, correct system problems as required, allow pilot to remain up and teleoperated from Earth.
4. While the crew is on the surface, the geochemical laboratory can be used to support pilot plant startup and operation by analyzing samples retrieved from process flow streams to verify automatic analytical techniques and trouble shoot startup problems.

Mission 16 (Continued)

The pilot plant should be located near the base, or attached to it, to allow easy access by the crew for correcting process difficulties.

5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
8. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 18 (4 crew, 24 day surface stay)

1. Offload Mission 17 lander.
2. Berth an interface node to the habitation module.
3. Berth an airlock to the module interface node.
4. Emplace an additional radiator and interface into the thermal control system
5. Service the geochemical materials laboratory with fluids, experiment changeout, and return of any lunar manufactured materials.
6. Preventive maintenance, resupply, and logistics tasks.
7. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
8. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 20 (4 crew, 24 day surface stay)

1. Offload the Mission 19 lander.
2. Emplace the first life science facility (berthed to the interface node emplaced on Mission 18). The plant and animal experiments begun during this mission will be remotely monitored from Earth after departure of this crew.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 22 (4 crew, 24 day surface stay)

1. Offload the Mission 21 lander.
2. Berth the pressurized garage to the airlock landed in Mission 17, connect services/-utility interfaces to the pressurized garage.
3. Checkout pressurized rovers.
4. Checkout optical telescope components. Manned traverses are required to survey, select, and prepare locations for the 28 optical interferometry elements (27 scopes and central station). The optical interferometer telescope should be placed some distance (several km's) from the base to avoid contamination from base and landing pad operations. Contamination includes both physical (rocket exhaust, dust, etc.) and optical (lights, etc.) products. The optical interferometer is a Y-shaped array of 27 telescopes with each arm 6 km long and the maximum baseline being 10 km. Due to its size and distance from the base, the pressurized rovers are needed to facilitate emplacing the optical interferometer.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research in geochemical and materials processing laboratory.
8. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Year 2003

Mission 26 (4 crew, 24 day surface stay)

1. Offload the Mission 25 lander.
2. Berth the life science research node to the end of first life science module delivered on Mission 19.
3. Emphasis on this mission is Lunar planetary science. Using pressurized rovers, the crew will collect samples to allow accurate dating of a number of local craters. Longer traverses (up to 400 km round-trip will be required on this or later missions).
4. Activate the deep drilling experiment for drilling to approximately a kilometer in depth to acquire Lunar core samples and to collect volatile release data during the drilling.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research in geochemical and materials processing laboratory.
8. Prepare landing site for next mission by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new site.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 30 (4 crew, 24 day surface stay)

1. Continue science applications experiments in Lunar planetology, life sciences, material sciences, and Lunar resource development.
2. Additional effort required for crater dating and deep drilling.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing site for next mission by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new site.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 31 (4 crew, 24 day surface stay)

1. Continue science applications experiments in Lunar planetology, life sciences, material sciences, and Lunar resource development.
2. Additional effort required for crater dating and deep drilling.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing site for next mission by either removing spent descent stage from permanent landing site (and transporting it to a discarded equipment storage area) or selecting and preparing new site.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 32 (4 crew, 24 day surface stay)

1. Continue science applications experiments in Lunar planetology, life sciences, material sciences, and Lunar resource development.
2. Additional effort required for crater dating and deep drilling.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing sites for next two missions by either removing spent descent stage from permanent landing site (and transporting it to a discarded equipment storage area) or selecting and preparing new sites.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Year 2004

Mission 34 (4 crew, 24 day surface stay)

1. Offload the nuclear power plant from the previous unmanned lander.
2. Emplace reactor at a location some distance from the base's pressurized modules, connect interfaces to the power distribution system, perform system checks, and startup the system.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 36 (4 crew, 24 day surface stay)

1. Unload oxygen mining equipment (primarily mining vehicles, loaders, and haulers) from the previous mission's unmanned lander.
2. Checkout the vehicle systems.
3. Begin preliminary mining operations to acquire a stockpile of feedstock material prior to the arrival of the primary oxygen extraction facility.
4. Service Geochemical Materials Lab.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research in geochemical and materials processing laboratory.
8. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 38 (4 crew, 24 day surface stay)

1. Unload the oxygen production plant from Mission 37 lander.
2. Emplace plant at location in protected area near the landing field.
3. Checkout systems prior to startup, startup the plant, and correct startup operational problems.
4. Service Life Science Facility.
5. Preventive maintenance, resupply, and logistics tasks.
6. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
7. Continue research in geochemical and materials processing laboratory.

Mission 38 (Continued)

8. Prepare landing site for next mission by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new site.
9. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 39 (4 crew, 24 day surface stay)

1. Continue previous manned efforts in developing the first full-scale Lunar resource utilization project, as well as science applications experiments in Lunar planetology, life sciences, and material sciences activities.
2. Preventive maintenance, resupply, and logistics tasks.
3. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
4. Continue research in geochemical and materials processing laboratory.
5. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
6. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Year 2005

Mission 42 (4 crew, 180 day surface stay)

This mission represents the beginning of a permanently manned Lunar base. Crew stay times extend to a half year and the base population grows after the next manned mission to 8 personnel.

1. Unload the previous mission's unmanned lander.
2. Deploy a second communications relay station.
3. Berth a module interface node and a logistics module in the pressurized module complex.
4. Crew time is occupied by science and technology applications experiments.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
7. Begin preparation of landing/launch site for Reusable Lander.
8. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 44 (4 crew, 180 day surface stay)

1. Offload the previous unmanned lander of a liquid oxygen tank truck and oxygen refueling facilities.
2. Install propellant depot/refueling facility in a location close to the landing pads near the full-scale oxygen production plant. This facility is needed to load liquid oxygen into the reusable Lunar lander that begins operation in 2006.
3. Crew time is occupied by science and technology applications experiments.
4. Continue startup operation of Oxygen production plant.
5. Service Geochemical Materials Lab.
6. Preventive maintenance, resupply, and logistics tasks.
7. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
8. Continue research in geochemical and materials processing laboratory.
9. Prepare landing sites for next two missions by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new sites.
10. Continue preparation of Reusable Lander landing/launch site.
11. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 46 (4 crew, 180 day surface stay)

1. Unload the second life science research facility, and the last module in the first quad of pressurized modules, from the Mission 45 unmanned lander.
2. Install to complete the race track pattern.
3. Crew time is occupied by science and technology applications experiments.
4. Continue startup activities on oxygen production plant.
5. Service Life Science Facility.
6. Preventive maintenance, resupply, and logistics tasks.
7. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
8. Continue research in geochemical and materials processing laboratory.
9. Prepare landing site for next mission by either removing spent descent stages from permanent landing sites (and transporting them to a discarded equipment storage area) or selecting and preparing new site.
10. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).

Mission 47 (4 crew, 180 day surface stay)

1. Crew time is occupied by science and technology applications experiments.
2. Continue oxygen production plant operation.
3. Preventive maintenance, resupply, and logistics tasks.
4. Continue lunar science and field geology exploration using the unpressurized rovers, collecting samples of significant scientific interest for return to the geochemical laboratory and if warranted, to Earth.
5. Continue research in geochemical and materials processing laboratory.
6. Continue preparation of Reusable Lander landing/launch site.
7. Recharge all regenerative fuel cells on surface vehicles before departure (or leave on charging cycle).