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Lunar Base Synthesis Study

FINAL REPORT

VOLUME I
Executive Summary



Space Division
North American Rockwell

Lunar Base Synthesis Study


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Executive Summary

15 MAY 1971

APPROVED BY



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LUNAR BASE SYNTHESIS



Space Division
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<p>ABSTRACT</p> <p>A LUNAR SURFACE BASE CONCEPT HAS BEEN SYNTHESIZED BY CONSIDERING THE TOP LEVEL PROGRAM OBJECTIVES AND DERIVING HARDWARE/OPERATIONAL APPROACHES THAT BEST ACCOMPLISHED THESE OBJECTIVES. FROM THESE BROAD OBJECTIVES THE LUNAR SURFACE BASE OPERATIONAL AND DESIGN REQUIREMENTS WERE DERIVED USING A "TOP-DOWN" FUNCTIONAL ANALYSIS APPROACH. THESE REQUIREMENTS WERE FOUND TO FALL INTO TWO MAIN CATEGORIES OF SURFACE ACTIVITIES: MAIN BASE ACTIVITIES WHICH INCLUDED ASTRONOMY AND DEEP DRILLING AS WELL AS THE REGULAR LOGISTICS AND HOUSEKEEPING FUNCTIONS, AND THE SELENOLOGICAL EXPLORATIONS AT MULTIPLE SITES IN AN EXPANDED REGION AROUND THE BASE SITE. VARIOUS CONCEPTS WERE POSTULATED TO SATISFY THESE REQUIREMENTS AND THEIR RELATIVE EFFECTIVENESS EVALUATED. A LUNAR SURFACE BASE CONFIGURATION WHICH INCLUDED A MAIN BASE AND SURFACE MOBILITY SYSTEM ELEMENTS WAS DERIVED. IT WAS FOUND THAT THE MAIN BASE/MOBILITY SYSTEM CONCEPTS MUST BE INTEGRATED TO ARRIVE AT AN "OPTIMUM" BASE CONCEPT. THIS INTEGRATION INVOLVES MAINLY THE MAIN BASE/MOBILITY SYSTEM ELECTRICAL POWER AND ENVIRONMENTAL CONTROL/LIFE SUPPORT SYSTEMS. TRADEOFFS SHOWING THE BASIC OPTIONS AVAILABLE AND THEIR INFLUENCES ON THE BASE CONCEPT ARE SHOWN. THE LOGISTICS REQUIREMENTS AND OPERATIONAL CONCEPTS FOR A SELECTED LUNAR SURFACE BASE CONCEPT ARE PRESENTED. FOLLOWING THE DEFINITION OF THE OPTIMIZED LSB SHELTER, A CONCEPTUAL DESIGN OF A LUNAR SHELTER DERIVED FROM A SPECIFIED SPACE STATION MODULE IS PRESENTED. THE DEGREE OF MODIFICATION REQUIRED, INCLUDING SPECIFIC ADDITIONS FOR THE LUNAR MISSION AND ENVIRONMENT ARE IDENTIFIED. FINALLY, COST AND RESOURCE ESTIMATES ARE PRESENTED FOR THE DESIGN AND DEVELOPMENT OF EACH OF THE SHELTER CONFIGURATIONS AND FOR THE SCIENCE, MOBILITY, AND POWER SOURCE ELEMENTS OF THE LSB PROGRAM.</p>
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FOREWORD

The Lunar Base Synthesis Study was conducted by the Space Division of North American Rockwell under Contract NAS8-26145 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Program Development Directorate of the George C. Marshall Space Flight Center.

This document is Volume I, Executive Summary, which constitutes part of the final report on the study. The following additional documents comprise the entire final report:

Volume II - Mission Analysis and Lunar Base Synthesis

Part 1 - Mission Analysis

Part 2 - Lunar Base Synthesis

Volume III - Shelter Design

Part 1 - Optimized Shelter

Part 2 - Space Station Derivative Shelter

Part 3 - Support Operations and Systems

Volume IV - Cost and Resource Estimates

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INTRODUCTION

The objectives of the Lunar Base Synthesis Study were to define and analyze lunar exploration missions in order to establish the role of a semi-permanent lunar surface base (LSB) as an element of an integrated space program, and to prepare conceptual designs for two different lunar surface shelters. One shelter concept was to be optimized for the LSB mission requirements whereas the other represented a potential adaptation of a specified space station module.

The study was oriented towards a lunar surface base which would support a two- to five-year program of scientific and exploration activities in the 1980's by a crew of up to 12 men at any location on the moon which might be selected. The principal program option involved considering the operation of the LSB concurrently with an operational Orbiting Lunar Station (OLS) or without the existence of the OLS. The space station module which was designated as the candidate for adaptation to an LSB shelter configuration was the shuttle-launched Modular Space Station as defined by North American Rockwell, Space Division (NR/SD), under Contract NAS9-9953, for the Manned Spacecraft Center and documented in NR report, SD 70-546-1, January, 1971.

SCOPE AND APPROACH

The basic approach adopted for the study involved the identification of scientific and exploration activities appropriate to a single, semi-permanent base on the lunar surface from an examination of the consensus of previous studies of lunar scientific missions. A typical distribution of these activities on the lunar surface was derived from a detailed examination of several potentially desirable areas and operational/design requirements were defined to accomplish the various classes of activities.

The definition of a program encompassing these activities, the associated operational and design requirements, the logistics operational concepts, and the precursor surface and orbit missions comprised study tasks 1 and 2, Mission Analysis and Lunar Base Synthesis, respectively.

A lunar surface base configuration which included a main shelter, major science elements, and surface mobility system elements was conceptually defined. The initial design considered the probable state of the art and the operational and design requirements in arriving at a shelter configuration optimized for the spectrum of lunar surface missions. The subsystem options were identified and tradeoffs performed in arriving at the selected

configuration. The potential emergency situations were considered and the implications delineated including a maintenance and repair philosophy. Maintenance, repair and housekeeping functions were described and typical tool requirements identified.

Following the definition of the optimized LSB shelter, a conceptual design of a lunar shelter derived from the specified space station module was developed. The degree of modification required, including specific additions for the lunar mission and environment, was identified.

These two conceptual designs and the definition of the characteristics of the mobility concept and its interfaces with the shelter comprised study task 3, Shelter Design.

Cost and resource estimates were prepared for the design and development of each of the shelter configurations and for the science, mobility, and power source elements of the LSB program. The shelter development costs were generated utilizing cost estimating relationships from other space programs. Cost estimates for the science, mobility, and power source elements were primarily derived by adjusting prior studies of these elements for the recommended concept modifications and the passage of time. These cost estimates together with program schedules and milestone data comprised study task 4, Cost and Resource Estimates.

The study was accomplished and documented in an 11-month period between 15 June 1970 and 15 May 1971 as shown in Figure 1. The study results are recorded in four basic volumes. This is Volume I, an executive summary which briefly outlines the objectives, summarizes the results, conclusions and recommendations; Volume II contains a comprehensive description of the analysis and synthesis results of tasks 1 and 2; Volume III presents the LSB configurations including the conceptual designs of the optimized and derivative shelters which resulted from study task 3; and Volume IV describes the cost estimates derived in task 4.

SIGNIFICANT RESULTS AND CONCLUSIONS

MISSION REQUIREMENTS

The mission analysis task consisted of two basic elements. First, the lunar exploration and exploitation activities desired by the scientific community were compiled and analyzed utilizing a top-down approach in order to obtain a definition of experimental activities and equipment requirements. These scientific mission requirements were then analyzed and grouped into compatible sets which were used as candidate elements of the LSB program. The requirements were found to fall into two main categories of surface activities: main base activities, which included astronomy and deep drilling as well as the regular logistics and housekeeping functions, and the selenological explorations at multiple sites in an expanded region around the base site.

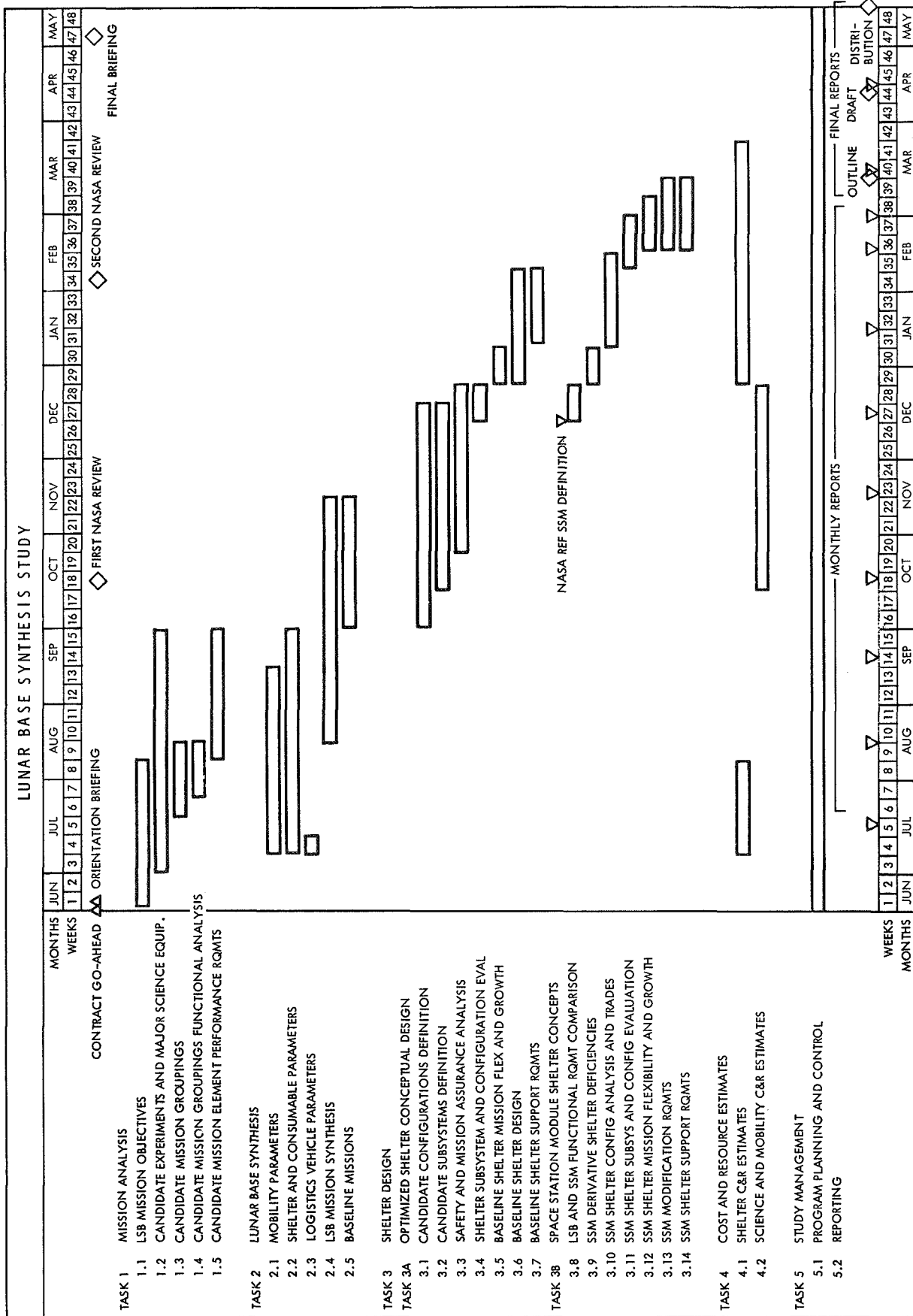


Figure 1. Lunar Base Synthesis Study

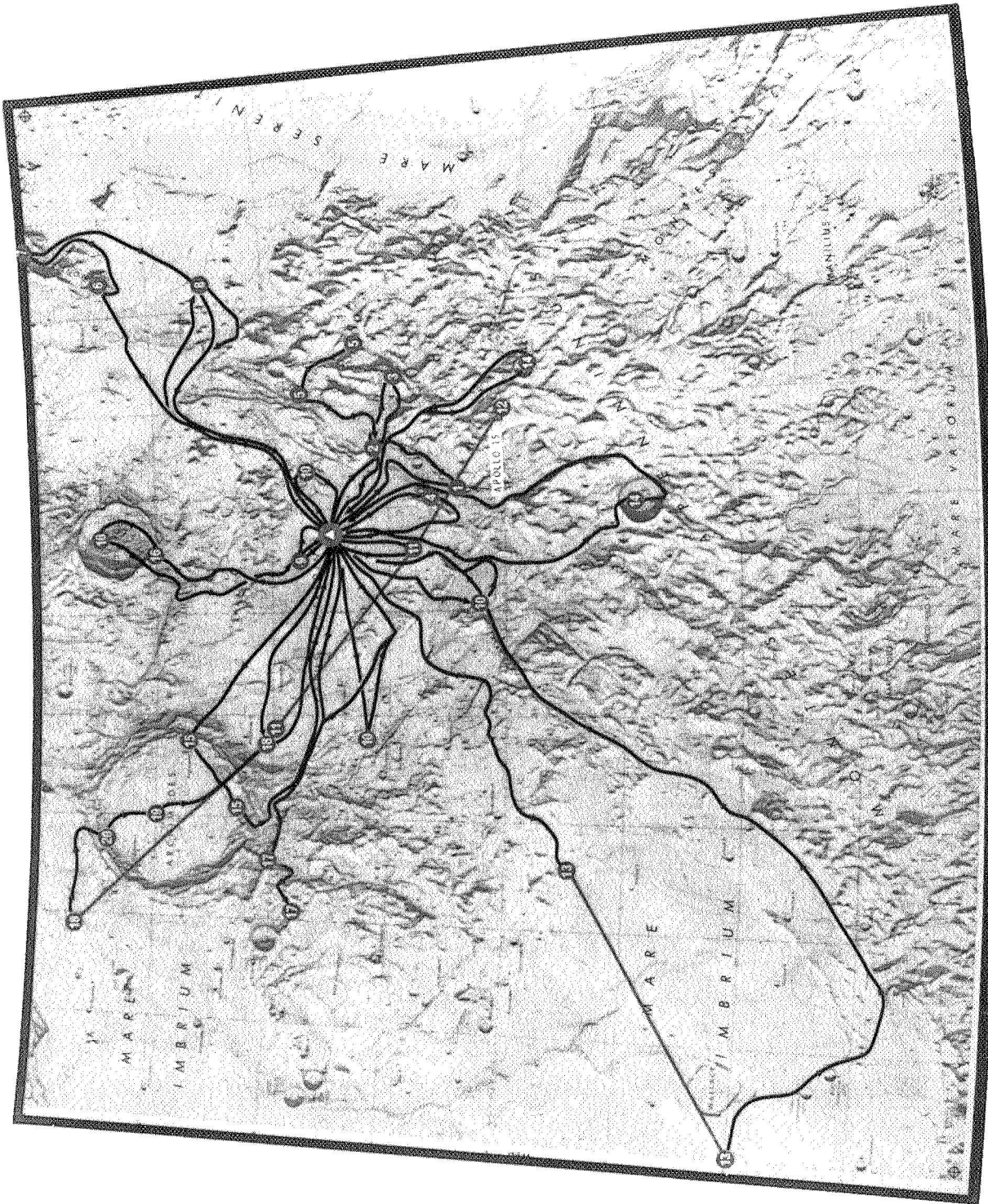


One of the major features of the analyses conducted was the selection of several actual regions on the lunar surface which were considered to be representative of potential LSB locations, and the definition of the spatial distribution of the applicable experiments in the selected regions. The purpose of this site analysis was two-fold: to evaluate the potential effectiveness of a single-site surface base in satisfying the objectives of a lunar program and to establish the influences of the site on mission requirements. Figure 2 illustrates a typical example of the scope of the site analysis and shows a region of the Apennines Mountains on the eastern edge of Mare Imbrium. The lunar features which make this area of interest for exploration are located by numbered circles and typical traverse lines are identified. Surface mobility paths to reach these features from a central base are shown. These paths were analyzed in detail to furnish parametric data for the definition of the requirements which this type of wide-ranging exploration might impose on the base and the mobility equipment. Over 100 of these sorties were analyzed and a composite model of remote sorties at a typical LSB was developed. Table 1 summarizes the results of these analyses in terms of the performance requirements for a typical sortie and for all sorties at an LSB site. The average or nominal requirements are shown as well as the requirements which encompassed 95 percent or more of the sorties analyzed and were, therefore, used as design point parameters for the mobility equipment.

A conclusion drawn from the site analyses is that the variety of lunar features which are within reach of exploration activities from a surface base can satisfy the vast majority of the objectives of the lunar program plus providing the only method of achieving those objectives requiring very long staytimes. However, the synoptic coverage obtainable in an orbital mapping program and some manned landings at features too remote for surface sorties from an LSB are also considered required in order to complete the lunar program objectives.

One of the exploration activities which requires a relatively long staytime involves the use of core drilling equipment to obtain samples of the lunar crust from depths of up to 1000 feet. Analysis of the drilling operations resulted in the performance requirements summarized in Table 2. An option is indicated for the deep drilling in that it could be conducted from inside a shelter or under EVA conditions. A large difference in the time required is indicated and the tradeoffs strongly favor providing a shirtsleeve environment for the drill and crew.

The lunar surface provides some unique characteristics for astronomy programs. The stable surface, slow rotational rate, shielding from earth-generated interference on the backside, and sharp occulting edges are advantageous for a wide range of astronomical observations. These are in addition to the advantage of no interfering atmosphere which is inherent in any space-based astronomy. Because of these advantages, an observatory mission was defined for the LSB which incorporated seven telescopes; two in the optical band, four for radio frequencies, and one X-ray. The nominal performance requirements are shown in Table 3. These elements are significant



HADLEY RILLE

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Figure 2

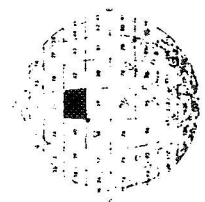


Table 1. Nominal Remote Sortie Performance Requirements

For Each LSB Site	Parameters *	
	A	B
Map travel distance	3440 statute miles	3963 statute miles
Consumables	2000 pounds	3000 pounds
Adjusted travel distance	4210 statute miles	4850 statute miles
Science time (6.5 work hours/day)	330 days	470 days
Duration (driving, maint. and repair, overhaul)	836 days	1150 days
Distance on rough terrain	2300 statute miles	2650 statute miles
Distance on smooth terrain	1910 statute miles	2200 statute miles
Distance on 0-10° slopes	4082 statute miles	4701 statute miles
Distance on 11-30° slopes	116 statute miles	135 statute miles
Distance on 31° + slopes	11.6 statute miles	13.5 statute miles
Number of sorties	12.6	20
Number of traverses	3.2	5
Number of experiment sites	17.4	27
Number of experiments	115	134
Travel on experiment sites	462 statute miles	549 statute miles
Return payload (rocks)	2716 pounds	3285 pounds
Return payload (cores)	3755 pounds	5410 pounds
Payload weight	3608 pounds	3608 pounds
Payload power	1-3000 watts	1-3000 watts
Payload volume	9055 cubic feet	9055 cubic feet
Drill holes (10 feet deep)	110	150
Drill holes (100 feet deep)	16	24
Flyer missions	10	10
For Each Remote Sortie		
Payload weight	1140 pounds	1468 pounds
Payload power	1-3000 watts	1-3000 watts
Payload volume	100 cubic feet	123 cubic feet
Map travel distance	274 statute miles	700 statute miles
Adjusted travel distance	335 statute miles	855 statute miles
Sortie science time (6.5 work hours/day)	26.2 days	40 days
Sortie duration	48.6 days	90 days
Radial distance from shelter	106.5 statute miles	230 statute miles
Distance on rough terrain	183 statute miles	467 statute miles
Distance on smooth terrain	152 statute miles	388 statute miles
Distance on 0-10° slopes	325 statute miles	828 statute miles
Distance on 11-30° slopes	9.4 statute miles	24 statute miles
Distance on 31° + slopes	.94 statute miles	2.4 statute miles
Travel on experiment sites	26.6 statute miles	100 statute miles
Science time on experiment sites	19.1 days	37.3 days
Sample return (cores and rocks)	517 pounds	705 pounds
Data rate (bps)	.7 - 10 ⁴	.7 - 10 ⁴
Consumables	159 pounds	238 pounds
Drill holes (10 feet deep)	8.7	12
Drill holes (100 feet deep)	1.3	2
Flyer range (statute miles)	3	5
Flyer flights/sortie (4 sorties/LSB)	2	2
Crew size	4	4
*A Nominal parameters (averaged over five LSB sites)		
B Design point parameters (95 percent values or maximum)		

Table 2. Nominal Drilling Operations Performance Requirements

Parameters	Shallow Drilling	Intermediate Drilling	Deep Drilling
Hole depth (feet)	5 - 20	100	1000
Drill design	Rotary percussive	Diamond rotary	Diamond rotary
Operating mode	Manual	semi-automatic	semi-automatic
Penetration rate (feet/hour)	20	4	4
Number of holes per LSB site	110	22	2
Crew support	1	2	2
Consumables	0	0	0
Bit life (feet)	unknown	125	125
Drill weight (lb)	25*	300*	4200*
Power (kw)	.3 - 1.35	5.0	3.5 - 14.0
Volume (ft. ³)	1.5 - 13	8 - 35	360
Core weight (lb)	7 - 28	138	1385
Drill diameter (inches)	2	2	2
Core diameter (inches)	1.25	1.25	1.25
Core barrel length (feet)	5	5	10
Data rate (bps)	0	0	0
Nominal duration per hole	1.5 hours EVA	10 days, EVA	72 days, EVA 50 days, IVA
Contingency factor	2.0	2.0	2.5, EVA; 2.0, IVA
Expected duration per hole	3 hours	20 days	180 days, EVA 100 days, IVA
Hole pattern	5 shallow/1 intermediate	3 intermediate/1 deep	2/LSB site
Crew size	1	2	2
Requires separate power supply - *power supply not included			

Table 3. Nominal Observatory Performance Requirements

Parameters	X-Ray Telescope	Radio Telescopes	Optical Telescopes
Number of telescopes	1	4	2
Frequency	$2 \times 10^{18} - 6 \times 10^{20}$ Hz (1-200 kev)	$3 \times 10^5 - 5 \times 10^8$ Hz	$3 \times 10^{12} - 3 \times 10^{16}$ Hz (1-1000 microns and 900-10,000 A)
Duration	>5 years	>5 years	5 years
Consumables	1 pound/day (photo plates)	1000 pounds (tapes)	1600 pounds/year each (film)
Power (watts)	20	25	4000
Weight (pounds)	3564	12,423	44,055
Detectors (lb)	400	480	310
Crew support			
Assy and calibration	200 MH	550 MH	780 MH
Operation	2 MH/day	0*	5 MH/day
Volume (ft ³)	3106	1919	801
Data Rate (bps)	104	300 with 10^5 peaks	3.24×10^6 optical
Preferred location			
Longitude	0 - 360°	0-360°, .3-1.2 MHz 100°E-100°W, 5-500 MHz	90 - 100°
Latitude	0°	0°	-5 to ±3° or 90°
Surface geometry	100 km crater 1 km walls smooth floor	30 x 60 km smooth area	Smooth, flat bedrock surface; smooth, low horizon
Site stability	1 cm/km maximum displacement over 50 km for 7 days	None	.5 μ/sec maximum for 14 days 5 cps minimum
Site lighting for optimum operation	Day and night	Day and night	Night only
Telescope pointing	±90° horizontal and vertical	±60° E-W ±80° N-S	±90° horizontal, 45 - 90° vertical
Directional alignment	Polar axis tube assembly parallel to lunar axis	E-W parallel interferometer antennas	E-W primary telescope axis, polar axis parallel to lunar axis (1.3 m)
Crew size (men/mo)	.59	1.07	2.14

*Data transmission and analysis support required at shelter

drivers on the LSB program in terms of weight, power, manpower, and data handling, as well as requiring extensive development effort themselves. It remains a decision for the future to decide whether the scientific benefits justify the cost.

A scientific program was synthesized combining the above major elements and a selection of relatively minor experiments from several disciplines which could benefit from or support the lunar program, and the composite design criteria for the base shelter and mobility equipment were defined.

LSB CONCEPTS

Various concepts were postulated to satisfy the derived mission requirements and their relative effectiveness evaluated. A lunar surface base configuration was derived which included a main base and surface mobility system elements.

The remote sorties involve both travel to a site or locale and travel at the site. In addition, the activities at the main shelter require multiple trips to outlying elements of the installations there. An examination of the constraints imposed by EVA operations and lunar driving conditions led to the conclusion that the mobility equipment which is used for these local trips should provide a shirtsleeve environment and habitability provisions to permit an overnight working trip for two men. For the longer trips of up to 90 days for a sortie to a remote site, much larger living quarters are required. The mobility concept which was selected to satisfy these requirements, as well as the base construction and logistics requirements, is shown conceptually in Figure 3. The concept involves a prime mover vehicle with shirtsleeve habitability provisions for two men, capable of autonomous operations for up to 48 hours away from a shelter, and providing interfaces for attachments to accomplish the construction and logistics tasks. For the long sorties, two prime movers are utilized to provide redundancy, "back-out" control, and two 2-man vehicles for local exploration when the remote locale is reached. A mobile shelter is included in the train which provides the additional habitable volume and subsystems to support the four-man sortie crew for the sortie duration. Additional vehicles may be included in the train to transport other major equipment elements required for the particular mission, e.g., a lunar flyer.

Power for the sortie equipment is provided by a mobile power supply unit. Detailed trade studies of the options for supplying the power for the widely dispersed elements of the LSB led to the selection of a modular, mobile concept utilizing a radioisotope powered organic rankine system. It was found that the power tended to follow the men, i.e., when the sortie crew left the main base, the base power needs decreased by essentially the same amount as the sortie crew needed to take with them. Therefore, the base power is provided from a bus which is energized from a number of the modular units, one of which can be unplugged and taken along for the sortie. Figure 4 illustrates the concept.

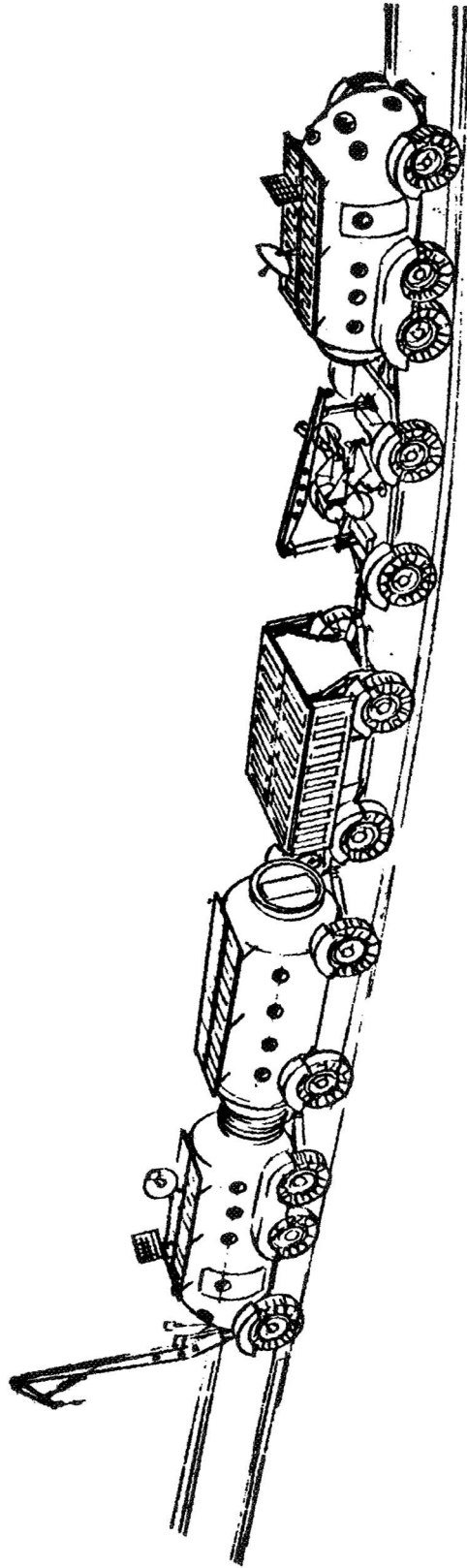


Figure 3. Sortie Mobility Concept

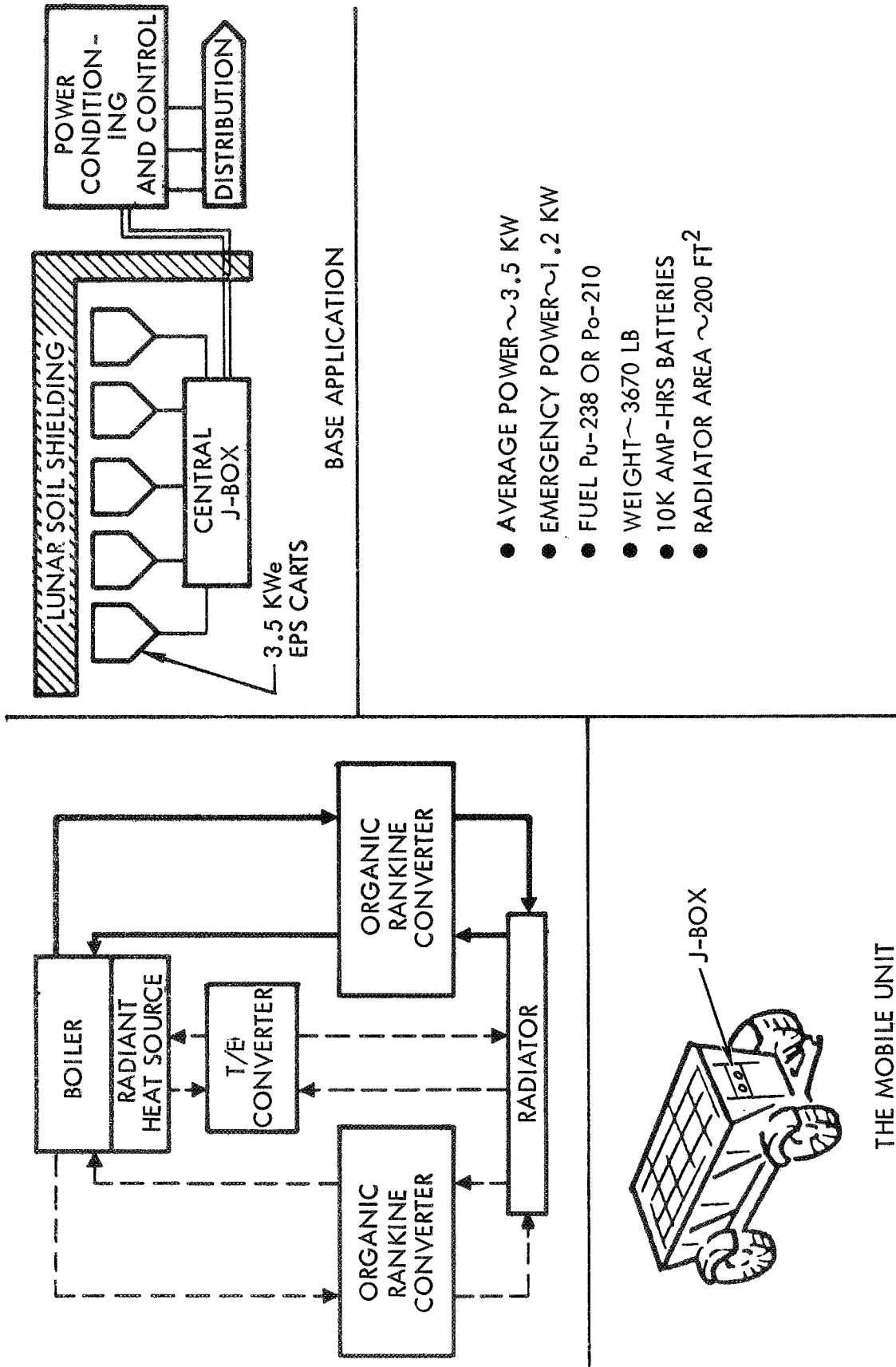


Figure 4. Electrical Power Module Concept

The high cost of transportation of equipment and supplies to the lunar surface provides a strong driver to minimize the expenditure of consumables. The selected mass conservation concept is illustrated in Figure 5, and is based on a consideration of the interfaces between the main base and mobile sortie shelters. The basic approach is that both shelters utilize the same water recovery and carbon dioxide reduction processes but that in order to minimize the power constraints on the mobile equipment, all electrolysis to recover oxygen and hydrogen is done at the main base only.

A large percentage of the crew metabolic budget is expended while performing EVA and is therefore outside the influence of the recovery systems in the shelters. The present portable life support system (PLSS) design does not provide for any recovery of either the oxygen consumed or the water used for cooling. However, advanced PLSS concepts are under study which show promise of being regenerable in the shelter such that the carbon dioxide and water can be processed by the shelter recovery systems. It was assumed that these, or similar concepts, would be implemented by the LSB era because of the importance of mass conservation to the LSB.

Four basic options can be visualized for communications between the elements of the LSB beyond the horizon: (1) surface waves, (2) repeaters at line-of-sight intervals, (3) satellite relays, and (4) earth relay. Earth relay is a clear choice if LSB operations are confined to the near side. Surface waves may be useful for low bandwidth (voice) communication with some remote elements but require very large antennas. If the base is an appreciable distance around on the backside, a satellite relay system will be required for communication with earth and can provide the surface-to-surface relay also. The concept of a relay satellite in a halo orbit around the L_2 libration point, as proposed by R. W. Farquhar of Goddard Space Flight Center, appears promising for this application. A location on the limb, although desirable in many other ways, probably presents the worst situation for communications because of the libration effects. Repeaters operating in the VHF band at line-of-sight intervals are a feasible approach for this region and were included in the LSB communication concept even though they represent a weight penalty and an operational complication.

An analysis of the issues and trades associated with sizing the shelter module resulted in the selection of an optimized baseline shelter composed of eight modules of identical overall size and shape (15-foot diameter by 30-foot cylinder). All have the same basic construction although two are modified to incorporate airlocks and two have an end bulkhead which can be opened completely. Figure 6 illustrates the overall LSB concept as it might be installed on the lunar surface. This representative complex embodies most of the site selection and arrangement criteria. The logistics vehicle landing site is removed from the other elements to minimize potential damage, and the deep drilling site is separated from vibration-sensitive base elements.

The main shelter is covered with lunar soil for environmental protection and the arrangement of modules provides two exits from each pressure volume for safety. A garage module provides a shirtsleeve environment for

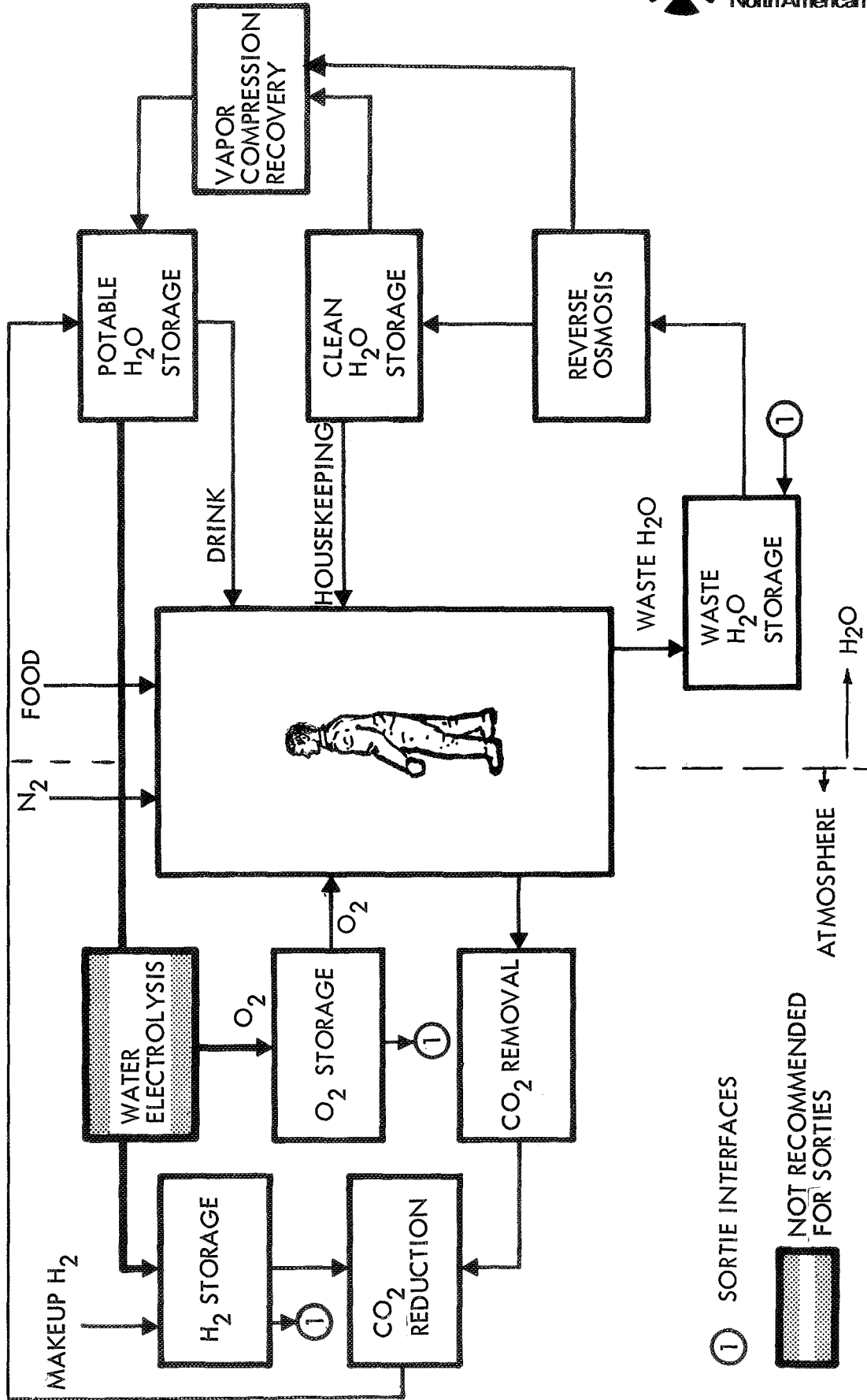


Figure 5. Mass Conservation Concept

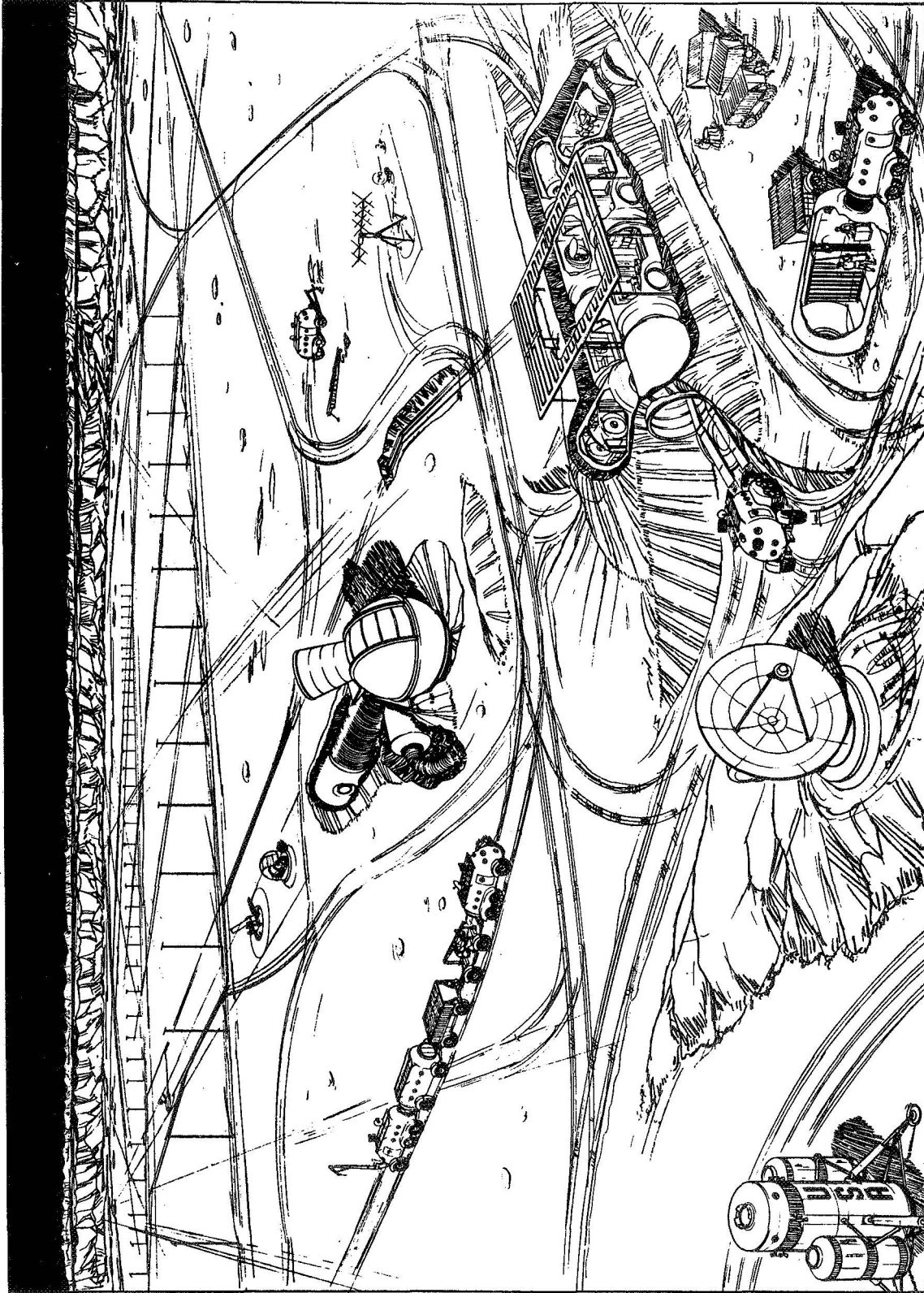


Figure 6. Overall LSB Concept

maintenance of the mobility equipment and a similar module provides a drive-in warehouse for storage of resupply items. Two airlocks provide redundant exits and are of two different sizes so that the pumpdown and ingress/egress penalties can be minimized. Expansion for a larger base can be achieved by utilizing standard side hatches capped-off in this version and/or pressurizable connectors as indicated for the large telescope. Individual modules can be deactivated when a sortie crew is in the field, thus conserving the power without degrading the remaining module functions.

The LSB concept shown in Figure 6 provides a pictorial summary of the requirements imposed on an LSB and provides a baseline for the planning activities. It is not the only arrangement nor necessarily the recommended one. A detailed examination of the potential for adaptation of modules from a shuttle-launched modular space station (MSS) to form an LSB indicated the approach to be highly feasible. It is important that the design and development of the MSS recognize the modules' eventual use on the lunar surface in order to minimize the modifications required, but the compromises to the earth orbital space station mission appear to be minimal. In general, the subsystem and configuration modifications required for the LSB mission involve deletion of those elements required for the free-space mission but superfluous for a fixed location on the surface protected by lunar soil. Typical deletions include the attitude control system, guidance and navigation equipment, and meteoroid protection.

There are some functions which are unique to operations on the lunar surface, e.g., EVA, dust control, and mobility vehicle maintenance, and it was determined that these functions could be grouped and supported by two new modules which are similar to each other. Figure 7 illustrates an arrangement of seven MSS modules with the drive-in garage/airlock module and drive-in warehouse/airlock module, which provides capabilities essentially identical to the baseline configuration and was used for planning. Table 4 compares some of the key characteristics of the two shelter configurations.

Table 4. Comparison of Shelter Configurations

Characteristic	MSS Derivative	Optimized Baseline
Dry weight (pounds)	84,500	59,500
Total volume (cubic feet)	44,500	41,600
Living volume (cubic feet)	34,500	25,900
Floor area (square feet)	3,600	2,800
Number of modules	9	8

RESOURCE REQUIREMENTS

The planning effort included the preparation of hardware trees, work breakdown structures, program development schedules, hardware utilization lists, and program cost estimates. The costs for the two shelter concepts were derived utilizing parametric cost estimating techniques based upon cost

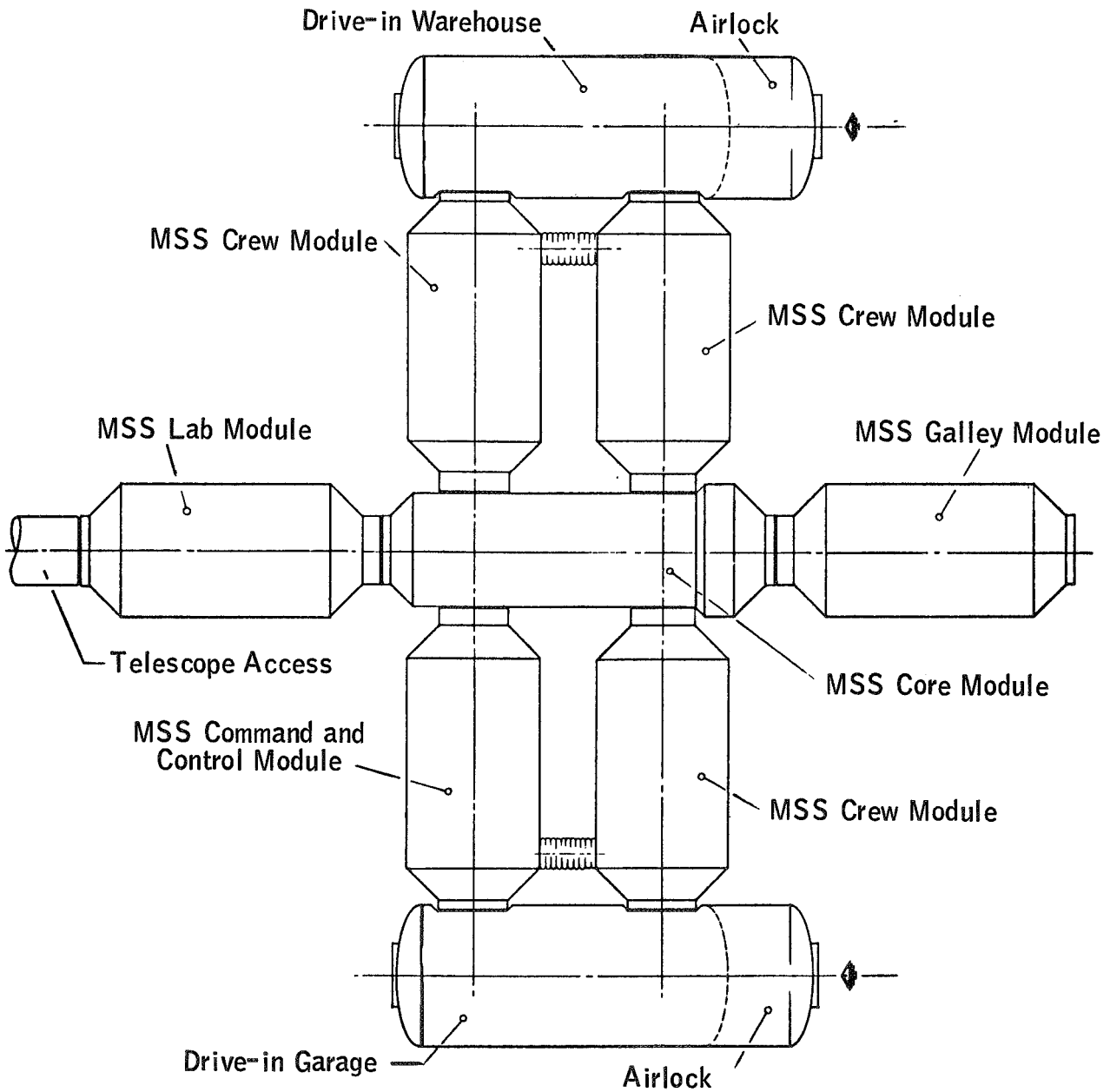


Figure 7. MSS Derivative LSB Shelter

estimating relationships from other space programs. One of the key ground rules utilized was that the LSB program would follow the Earth Orbit Space Station (EOSS) project in time, and hardware development and state-of-the-art advancements anticipated to be made by that program were incorporated. The Phase D go-ahead was assumed to occur in GFY 79 to support a first launch in January, 1985.

The costs for the science, mobility and power source equipments were compiled primarily from previously generated lunar mission study data, updated and adjusted for the concepts selected in this study.

The summary cost estimates for the two shelter options and the science, mobility, and power source equipments are shown in Table 5. As shown, the cost savings from utilizing the MSS modules are a small percentage of the total cost and the two program options can be considered essentially equivalent in cost. This result stems basically from two factors: (1) the baseline shelter estimates assumed utilization of space station technology and subsystems and incorporated the cost savings resulting from the advanced state of development, and (2) the shelter configuration utilizing the MSS modules involves more structural configurations and one more module than the baseline configuration which was able to standardize on one basic structure. It should also be noted that the shelter costs represent only about one third of the total. Another third is attributable to the science equipment cost, about one fourth to the mobility, and the remainder to the power source.

Table 5. LSB Program Summary Costs

Cost Element	Optimized Baseline	MSS Derivative
Shelter project	\$ 876.0 M	\$ 861.2 M
LSB science equipment	833.0	833.0
Mobility equipment	645.5	645.5
Electrical power source equipment	191.2	191.2
Total	\$2545.7 M	\$2530.9 M

In the science costs, approximately 83 percent of the estimate is for equipment to support the astronomy experiments. Figure 8 indicates the relative distribution of the total science costs and shows that just ten elements comprise almost 87 percent of the total, while approximately 120 other items make up only about 13 percent.

The significant cost elements in the mobility equipment are the four prime movers and two mobile shelters which comprise nearly 87 percent of the total, apportioned approximately equally between the two types of equipment. The additional powered trailers, appendages for the prime mover, and lunar flyers contribute only 13 percent of the total.

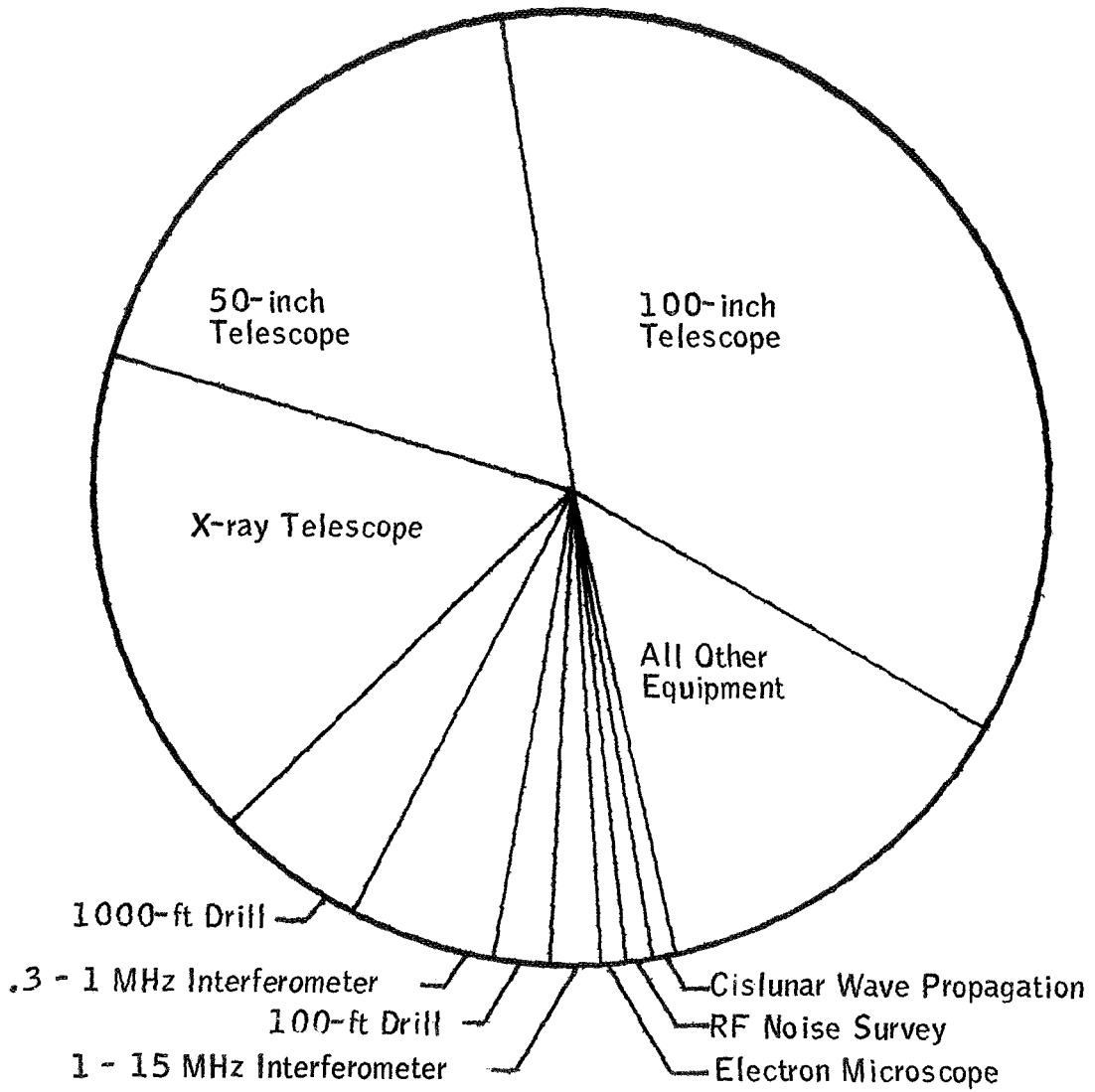


Figure 8. Scientific Equipment Cost Distribution

INTEGRATED PLAN INTERFACES

The LSB interfaces with all elements of an integrated space plan to some degree. No direct operational interface with the EOSS is visualized at this time but, as indicated in the preceding section, significant cost savings to the LSB program are anticipated from utilizing the subsystems and technological know-how developed for the EOSS program.

The logistics support of the LSB was examined to determine the potential influences that the LSB might exert. It was found that the combination of the Earth Orbital Shuttle (EOS), a cislunar shuttle, and a suitably sized manned lunar landing tug could provide the initial buildup and resupply support required. All LSB elements could be sized to be compatible with the payload dimensional and weight constraints of the EOS although the propellant tank sets for the lunar tug might have to be topped-off by a second EOS delivery. A potential EOS constraint on the LSB was identified in that the desired LSB buildup schedule requires delivery of approximately 300,000 pounds to the lunar surface in a sequence of manned and unmanned flights over a period of about six months. Adding to this the tugs, tug propellant, and supporting elements results in a requirement for six cislunar shuttle flights with an aggregate payload about three times the surface payload. It does not appear that the presently visualized EOS fleet can support this cislunar flight rate and some alternates will have to be explored for the buildup phase. The subsequent resupply flights are at intervals which can easily be supported.

Figure 9 summarizes the LSB operational program for the two optional programs, i.e., with a concurrent Orbiting Lunar Station (OLS) and without the OLS. The principal differences between the options are found in the choice and sizing of the cislunar shuttle. If there is no concurrent OLS resupply requirement, the cislunar shuttle needs only to meet the needs of the LSB. The estimated resupply payload required to be delivered to the LSB is shown in Figure 10 as a function of the interval between logistics flights. Also shown is the crew member staytime utilizing the approach that half the crew rotates each time. Consideration of this staytime and the logistics costs led to the selection of the nominal resupply interval as six sidereal months (164 days) as indicated for the no-OLS option in Figure 9. The resulting 328-day staytime was felt to be a maximum allowable even though a longer interval might be desirable to lower logistics costs. The cislunar shuttle is somewhat inefficiently utilized at this interval in the sense that, utilizing the characteristics of the reusable nuclear shuttle for the cislunar flight, it would be operating off-loaded.

If there is a concurrent OLS, the cislunar shuttle must support both operations. Based on the results of the study of the OLS which was conducted by North American Rockwell (NR) for the Manned Spacecraft Center (MSC) concurrently with this study, resupply flights are required to the OLS at four sidereal month intervals (109 days). When these requirements are integrated with those of the LSB, a cislunar flight is scheduled every 109 days with every third one supporting only the OLS. The LSB crew staytimes remain as before and the only impact is the somewhat minor one of adapting the warehousing

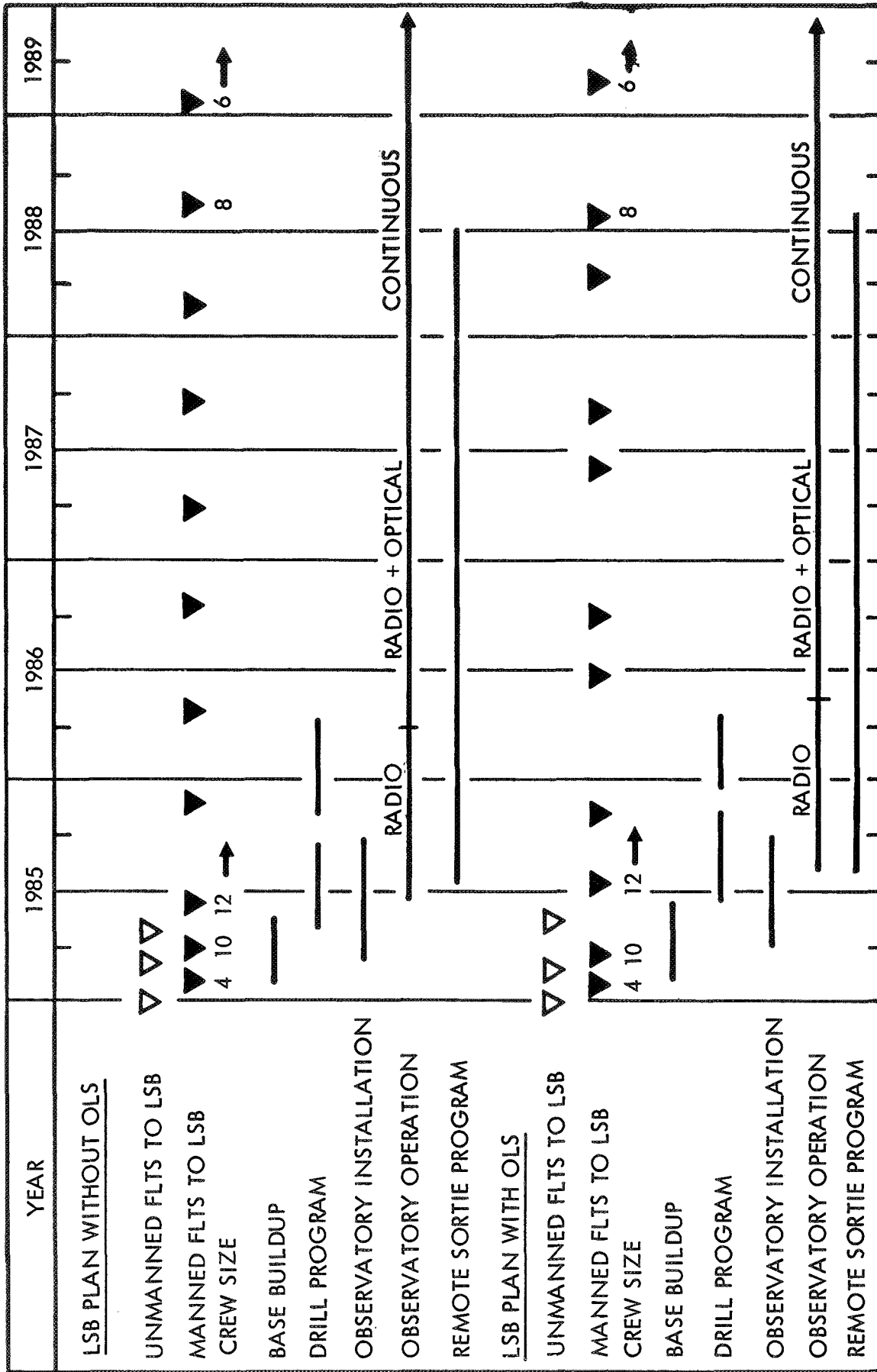


Figure 9. Lunar Program Summary

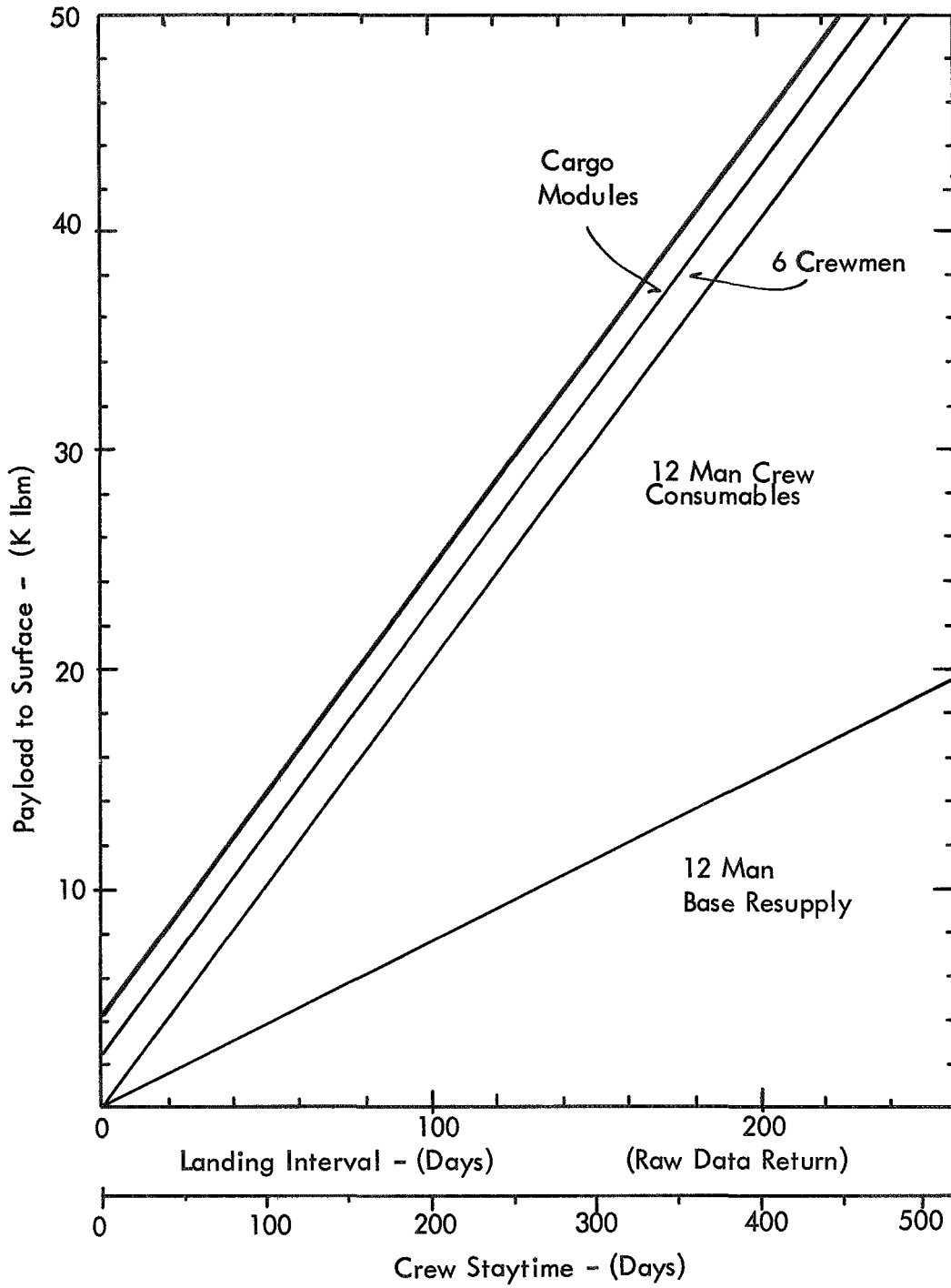


Figure 10. LSB Resupply Requirements

to alternating four and eight sidereal month intervals. The high cislunar payloads required for the flights which support both the OLS and the LSB led to the identification of the Chemical Interorbital Shuttle (CIS), as it is presently sized, as the cislunar shuttle for this program option.

No other strong interfaces with the OLS were identified in this study. From a lunar exploration program standpoint, it appears to provide an optimal way to conduct short surface sorties with the lunar landing tug to widely separated locations on the moon, and can also provide the synoptic coverage required for some scientific objectives.

The characteristics of the lunar landing tug were scaled to match the LSB requirements within the projected constraints of the cislunar shuttle. An adaptation of a concept derived in the concurrent NR study of the reusable space tug for MSC to accomplish the high-energy geosynchronous mission, was utilized as a baseline for this study. The concept involves a small reusable tug which can utilize the propellants from a larger, expendable tank set until they are exhausted, then stage the tank set on the lunar surface, and return only the basic tug to lunar orbit to pick up a new tank set and the LSB cargo from the cislunar shuttle. The cargo is mounted in matched pairs on the sides of the tug for easier removal on the surface. A tug with about 12,000 pounds of propellant in the basic stage and a tank set with approximately 67,000 pounds capacity appears to meet the LSB requirements and represents only a small increase over the version sized for the geosynchronous missions.

RECOMMENDATIONS

INTEGRATED PLAN DEVELOPMENT

One of the more significant conclusions of the study is that there can be significant cost-savings in the development of an LSB by incorporating the subsystems and technology from the EOSS development. Further savings can be achieved if the configuration adopted for the EOSS maintains compatibility with eventual use in a lunar surface environment. Specifically, this includes utilizing small modules, longitudinal floors, and sufficient head room to permit horizontal deployment and occupancy in a one-sixth gravity field. Modules sized to be compatible with the EOS cargo bay, i.e., 15-foot diameter, will be optimal for LSB application.

In general, it was found that the strongest influence on the cislunar shuttle resulting from the LSB program occurred during the initial buildup phase. Further study of concepts which would permit a high rate of cargo transfer for a few months without compromising the subsequent stretched-out resupply appears to be warranted.

The LSB program can be a significant driver on the tug concept if it is determined that a single configuration should be utilized for both earth orbit and lunar landing missions. The delivery of multiple large modules to the

lunar surface imposes unique requirements on the tug structure, thermal control, navigation and control as well as potentially affecting the overall configurational arrangement. The expendable tank set concept appears most desirable for the lunar surface applications.

SUPPORTING RESEARCH AND TECHNOLOGY/ADVANCED RESEARCH AND TECHNOLOGY

No outstanding advancements in the state of the art were found to be required to implement the LSB concepts described. As indicated above, the LSB will benefit from the development accomplished on the other elements of the integrated space program, particularly the EOSS. Some areas which appear to be unique to lunar missions (and perhaps planetary) and which could benefit from supporting research and technology/advanced research and technology are shown in Table 6.

LUNAR SURFACE BASE

The planning effort on this study indicated that the LSB project Phase B effort would not need to be initiated until GFY 77 to support a January, 1985 initial launch. However, there appear to be areas which are associated with the LSB definition and could be studied in somewhat more depth than the scope of this study permitted. Typical examples of these studies include:

1. Additional site analyses to narrow the choices and to determine what supporting sites might be required
2. Further definition of the mobility equipment concepts identified to bring them to the same definition level as the shelter
3. Further definition of the major science element, i.e., telescopes and drills, with the same purpose as above
4. Definition of a data relay satellite for deployment in a Halo orbit around the L_2 libration point
5. Evaluation of the hardware and program impacts of potential concepts for oxygen recovery from lunar rocks
6. Development of a concept for a simulated LSB to be deployed in a selected earth location for investigation of operational and hardware concepts

It should be emphasized that none of the above are considered to be constraints to the initiation of the LSB project Phase B, but will provide conceptual and parametric data on additional "building-blocks" of the integrated plan for utilization in programmatic decisions in the same way as the Lunar Base Synthesis Study has.

Table 6. SRT/ART Requirements Summary
Lunar Surface Base

Subsystem	Functional Requirement	State of the Art	Known Current Work	Needed SRT/ART	Criticality
<u>Electronics and Control</u>					
Navigation	Navigation on lunar surface sorties under day and night conditions with total position errors < 1 mile	Apollo CSM and LM guidance systems. Lunar rover accuracy is about 7 percent of distance traveled	Lunar Rover (Apollo 15)	Development of navigation system mechanization	Affects capability to conduct lunar surface exploration
Communications	Voice and data (1.6 MHz bandwidth) relay over the lunar horizon utilizing lightweight, self-powered, deployable relay units	Microwave relays	None	Development of lightweight, self-deploying masts, VHF relay electronics and power supply	Affects capability to communicate with remote elements
<u>Power Generation</u>					
Organic Rankine Converter	Lightweight, long-life conversion with about 3.5 kwe output	Feasibility demonstrated	Research studies	Demonstration of reliability and longevity	Provides basic power conversion capability
Thermoelectric Converter	Lightweight, long-life conversion with about 1.2 kwe output	SNAP-27	GE multi-100 watt Multiple research studies	Configuration and materials development for cascaded SiGe/PbTe system	Provides backup power conversion capability
<u>Nuclear Systems</u>					
Radioisotope Heat Source	Low radiation, 5 - 10 year life heat source with 7.5 kwt minimum output	SNAP-27	SNAP-8. Technology studies for 25 kwt sources	Configuration and materials development	Provides heat source for power generation
<u>Materials and Structures</u>					
Shelter Modules	Lightweight, permanent foundations utilizing indigenous materials	Portland cement, various plastics	None	Develop binder material to form lunar concrete using lunar rocks	Provides solid foundations for shelters and science equipment
Mobility Vehicles	Flexible, pressurizable connector to permit shirtsleeve transfer from mobility vehicle to shelter	STEM and related feasibility and technology studies	None	Develop configuration and materials	Provides shirtsleeve transfer and minimizes EVA
Mobility Vehicles	Shock energy dissipation	Lunar Rover	Lunar Rover	Develop shock absorber compatible with lunar environment	Affects ride quality of mobile equipment
EVA Systems	Lightweight durable pressure garment with high mobility capable of multiple reuses in the lunar dust environment	Apollo PGA	NASA space activity suit; Northrup Space Labs suit materials	Develop configuration and materials	Affects accomplishment of EVA
EVA Systems	Regenerable PLSS to minimize consumables	Apollo PLSS	Technology studies of advanced PLSS	Develop configuration and materials to absorb CO ₂ and cooling water and permit regeneration in the shelter	Affects mass conservation
Scientific Equipment	Lightweight, diffraction-limited mirrors for optical telescopes	OAO	EOSS experiments' program research studies	Develop segmented mirror and adjustment mechanization	Affects astronomy objective accomplishment
Scientific Equipment	Alignment of multi-element radio telescope arrays	Smaller arrays have been routinely aligned on earth	None	Develop methodology for mechanical and electrical alignment in lunar environment	Affects astronomy objective accomplishment
Scientific Equipment	Uncooled drilling to depths up to 1000 feet	Feasibility demonstrations to 100 feet with rotary bit	Technology studies	Develop uncooled rotary bit design capable of being replaced without removing drill string	Affects geology/geochemistry objective accomplishment
Consumables	Oxygen resupply	Conceptual design	Research studies have been performed	Develop process and configuration to obtain oxygen from lunar material	Affects resupply requirements