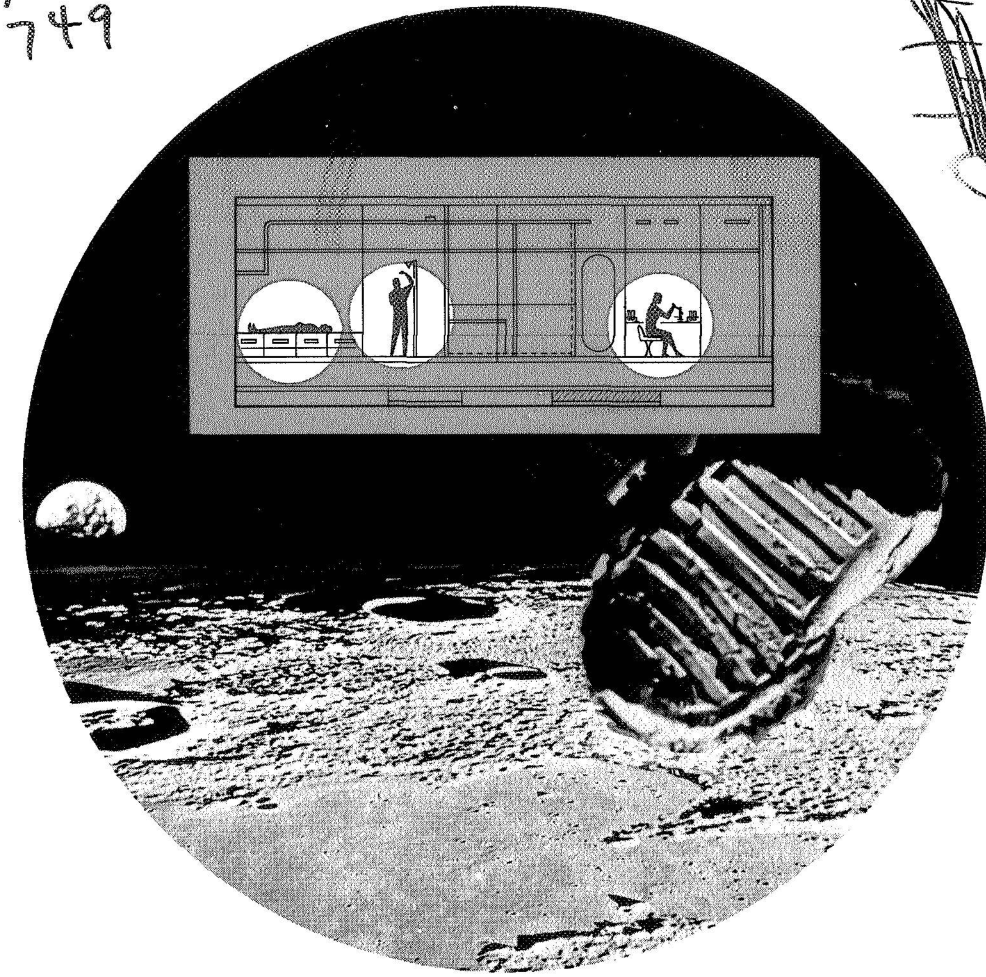
Contract NAS9-10924
DRL Line Item 7

MSC-02688
SD 71-208



ORBITING LUNAR STATION (OLS)

PHASE A FEASIBILITY AND DEFINITION STUDY

CONDENSED SUMMARY REPORT

FINAL REPORT

Space Division
North American Rockwell

APRIL 1971
Prepared by Advanced Program Engineering

12214 Lakewood Boulevard, Downey, California 90241

SD 71-208

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Approved by

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Program Manager
Orbiting Lunar Station Study

Space Division
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TECHNICAL REPORT INDEX/ABSTRACT

ACCESSION NUMBER						DOCUMENT SECURITY CLASSIFICATION	

TITLE OF DOCUMENT

ORBITING LUNAR STATION (OLS) PHASE A FEASIBILITY AND DEFINITION STUDY CONDENSED SUMMARY REPORT

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CODE	ORIGINATING AGENCY AND OTHER SOURCES	DOCUMENT NUMBER
QN085282	SPACE DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION, DOWNEY, CALIFORNIA	SD 71-208

PUBLICATION DATE	CONTRACT NUMBER
APRIL 1971	NAS9-10924

DESCRIPTIVE TERMS

*OLS STUDY OBJECTIVES, *SIGNIFICANT STUDY ASSUMPTIONS, *OLS OBJECTIVES, *OLS FUNCTIONAL, OPERATIONAL AND PERFORMANCE REQUIREMENTS, *SPACE STATION CONFIGURATION AND SYSTEM ANALYSIS DATA, *REPRESENTATIVE OLS CONFIGURATION, *DERIVATIVE OLS CONFIGURATION, *EOSS IMPLICATIONS, *FUTURE STUDY TOPICS

ABSTRACT

A CONDENSED SUMMARY OF THE ANALYSES OF THE ORBITING LUNAR STATION (OLS) PHASE A FEASIBILITY AND DEFINITION STUDY CONDUCTED BY NORTH AMERICAN ROCKWELL UNDER CONTRACT NAS9-10924 TO NASA/MSC IS CONTAINED IN THIS REPORT. THE STUDY OBJECTIVES ARE ENUMERATED, PRINCIPAL ASSUMPTIONS IDENTIFIED, SIGNIFICANT RESULTS PRESENTED, IMPLICATIONS ON THE EOSS IDENTIFIED, AND TOPICS FOR ADDITIONAL STUDY IDENTIFIED.

FOREWORD

This report presents a condensed summary of the analyses conducted by the Space Division of the North American Rockwell Corporation (NR/SD) during the Phase A Feasibility and Definition Study of an Orbiting Lunar Station. It is submitted in accordance with Article II, Item D of Contract NAS9-10924.

The study was conducted by NR/SD under the technical direction of:

L. R. Hogan, NR/SD Program Manager

R. F. Baillie, NASA/MSC Technical Director

S. S. DiMaggio, NASA/Headquarters, Program Manager

Questions pertaining to this study may be directed to any of the above.

The complete study report is compiled in six volumes for ease of presentation, handling, and reliability of the data in the report. In general, each volume is a compilation of the data generated in a specific phase of the study. The six volumes of the final report are:

Volume I - OLS Objectives

Includes operational and scientific objectives and scientific support requirements.

Volume II - Mission Operations

Includes orbit determination, crew definition, safety considerations, propellant and cargo handling, docking provisions, and an integrated operations sequence.

Volume III - OLS Performance Requirements

Presents a summary of the design criteria, mission requirements, and system and subsystem performance requirements.

Volume IV - Configuration and Systems Analysis

Presents trade studies, parametric data, and comparison matrices of OLS systems and subsystems for 4 to 12 crewmen and 12- to 33-foot diameter modules.

Volume V - Configuration Definition

Defines the representative OLS and the derivative OLS that is an adaptation of an earth orbital Modular Space Station.

Volume VI - Comparison of OLS Configurations

Presents the estimated costs and development plans of both OLS configurations and a comparison of the performance characteristics as well as the cost and schedule of the two configurations.

CONTENTS

1.0 INTRODUCTION

The Apollo missions are successfully conducting the initial phase of lunar exploration. The next phase is to significantly increase our exploration capability from orbit, and in conjunction with longer duration surface missions provide a maximum coordinated effort of extensive lunar exploration and exploitation for the benefit of mankind.

Scientific contributions will include a more thorough understanding of the origin of the moon and our solar system in general. A very important aspect of the program is to determine the lunar natural resources and their potential applications.

Technological and engineering advancements such as long-lived, multi-purpose, reusable hardware that can function effectively on and around the moon will evolve. These concepts will be applicable to or can be extrapolated to exploration and exploitation of other extraterrestrial bodies.

Operational techniques can be developed and evaluated to establish the confidence level necessary for conducting manned planetary missions.

One of the key elements defined in the Integrated Program Plan defined by the NASA for the second phase of the lunar exploration program was the Orbiting Lunar Station (OLS). The definition of the OLS, including the functions, operations, and performance requirements as well as a concept or configuration, was the purpose of this study.

The study was conducted in four phases:

PHASE I - OLS FUNCTION DEFINITION

Definition of scientific, operational, engineering and technological objectives of the lunar exploration program; functional analysis of the objectives; identification of mission, operational, and performance requirements of the OLS to accomplish the objectives.

PHASE II - OLS SYNTHESIS DATA GENERATION

Derivation of configuration and system development and selection information.

PHASE III - OLS CONFIGURATION DEFINITION

Definition of a representative OLS utilizing the data generated in Phase II - evaluation of the adaptability of a reference Earth Orbit Space Station (EOSS) to accomplish OLS requirements, identification of required EOSS modifications, and identification of the operational or configuration changes required.

PHASE IV - OLS CONFIGURATION COMPARISONS

Comparison of the representative OLS configuration with the derivative OLS configuration including technical, cost, and schedule implications.

The results of the analyses of each phase of the study were reported in four interim reports, SD 70-518, Volumes 1, 2, 3, and 4. Updates of these reports and some regrouping of the data for more efficient presentation are contained in the final technical report, SD 71-207, Volumes I through VI.

This report presents a condensed summary of the study analyses. Included are: the study objectives, principal assumptions used in the study, the significant results of the study tasks, the potential implications on the earth orbit space station, and topics for related future studies.

2.0 STUDY OBJECTIVES

The objectives of the study as defined in the contract are listed in this section. Brief descriptions of the activities conducted in relation to each study objective are also included. The primary study objectives and their key factors and considerations that were evaluated in the study are defined below.

Refinement of the Functions to be Performed by an OLS

The OLS operational and scientific objectives were analyzed to determine the functions to be performed by the OLS in support of the Lunar Exploration Program. The procedure began with establishment of a top-level functional flow diagram considering all major OLS operations. Next, lower-level functional flows were developed for each major operation. The analysis was carried to a sufficient depth to assist in identification of OLS design and performance requirements.

Preferred OLS Orbital Parameters Determination

The orbital parameters defined were altitude, inclination, and eccentricity. Factors considered included earth to lunar logistics, experiment requirements, lunar orbit to lunar surface logistics, communications, and rescue of personnel from the lunar surface.

Orbital Science Program Development

A so-called "top-down" approach was used whereby an overall lunar exploration program was defined. Scientific objectives were established, classified by disciplines, expanded to observation requirements, and grouped into related experiments. From the total, those experiments that are feasible to accomplish from orbit were identified. The OLS accommodation requirements imposed by these orbital experiments were established by identifying the associated equipment characteristics (i.e., weight, power, volume, data handling, pointing, consumables, etc.).

Lunar Surface Scientific Program Model

In order to establish the design and support implications imposed upon the OLS to act as the center of lunar exploration operations, typical surface science sorties were developed. Logistics, communications, data handling, diagnostic laboratory facilities, as well as safety and rescue requirements for the OLS, were identified in the surface model.

OLS Crew Requirements Determination

The OLS and tug sortie scientific and operational crew requirements were established. Key crew requirement factors were crew skills, crew mix, crew responsibilities, cross training, and organizational assignments.

OLS System and Subsystem Performance Requirements Definition

In addition to the normal subsystem performance requirements (environmental control life support, electrical power, information management, guidance and control, reaction control, and environmental protection subsystems), the unique requirements imposed by other program element interfaces were also identified. Docking interfaces, cislunar shuttle capabilities, cargo and cryogenic storage and transfer, quiescent space tug berthing, scientific and communication subsatellite support, Lunar Surface Base (LSB) operations, and propellant management were all considered.

OLS System Safety and Rescue Requirements Identification

Safety and rescue analyses were used as the overriding and governing criteria throughout the entire study. Operational safety considerations included such items as provisions for the LSB crew during emergencies, standby escape and rescue space tugs, OLS contingency provisions, radiation protection to and from as well as at the OLS, and capability for rescue of personnel (in conjunction with the space tug) from the lunar surface. Design safety considerations imposed reliability/redundancy/maintainability requirements on station equipment and configuration layouts (e.g., multiple pressure volumes, multiple ingress-egress paths, physical separation of critical components and assemblies, and totally independent redundancy of life support functions).

OLS Conceptual Design Definition

Two conceptual designs were defined: A representative OLS that was unconstrained by any previous space station concept definition, and a derivative OLS that is an adaptation of an earth orbital Modular Space Station (MSS). The adaptation of the MSS to OLS use was perhaps the most significant subobjective of the study.

OLS Operations Sequence Plan Development

A mission plan model that includes delivery of OLS and supporting elements, LSB activation, crew rotations, and consumables resupply was developed to scope the total magnitude of the logistics of the Lunar Exploration Program. Earth orbital shuttle and cislunar shuttle logistics flights required to support the mission model are also included in the operations sequencing.

Definition of OLS and MSS Design and Operations Differences

A comparison between the derivative OLS and the MSS for four types of functional requirements was made: floor area, docking provisions, resupply and storage, and science support. In addition, subsystem performance requirements comparisons were made. These comparisons were made to identify unique OLS requirements and determine the necessary MSS modifications to permit incorporation of provisions for future OLS use in the basic MSS. This approach, recognized in the initial Integrated Program Plan, would allow a more efficient and less costly overall space program.

3.0 PRINCIPAL ASSUMPTIONS

The basic assumptions and guidelines required for commencement of this study were enumerated in the initial statement of work. They consisted primarily of a derivation and condensation of guidelines developed during earth orbit space station studies and gross performance characteristics of interfacing program elements. The more significant guidelines and assumptions used in this study are presented in this section.

Transportation Vehicles

The baseline booster, INT 21, placed an upper limit on the OLS lift-off weight of 195,000 pounds to a 270-nautical mile, 55-degree inclined earth orbit.

The Earth Orbit Shuttle (EOS) characteristics were modified during the study to reflect updated information from EOS studies. The EOS payload capability to a 100-nautical mile, 36-degree inclined earth orbit was assumed to be 45,000 pounds.

Space tug characteristics were assumed to be 84,615 pounds gross weight, including 60,000 pounds of propellant. The I_{sp} was 444 seconds. Roundtrip usable payload capability from lunar orbit to lunar surface was 13,000 pounds each way, or 32,000 pounds down and no return payload. The operational life of the tug was assumed to be three years or ten roundtrips to the lunar surface.

A Reusable Nuclear Shuttle (RNS) was used as the baseline cislunar shuttle in the study. The original performance data was updated during the study to reflect results of NASA studies in progress. The RNS characteristics used in this study were: 147,000 pounds delivered to lunar orbit, with no return payload, or 60,000 pounds outbound and 56,000 pounds return payload. In the "expended" mode of operation, which requires refueling in lunar orbit, the one-way payload capability was 330,000 pounds.

During the study, single and tandem Chemical Propulsion Stage (CPS-1, CPS-2) vehicles were defined for evaluation as cislunar shuttles. The single stage, CPS-1, was assumed to be capable of delivering 93,000 pounds to lunar orbit or returning 36,000 pounds, or delivering 273,000 pounds in the expended mode. CPS-2 was assumed to be capable of delivering 350,000 pounds to lunar orbit or returning 130,000 pounds. Each stage has a propellant capacity of 540,000 pounds.

The payloads for all these cislunar shuttle models were considered to be useable payload in lunar orbit. Cislunar shuttle provisions for an operational crew including their expendables were assumed to be over and above the specified payloads. Emergency and abort provisions were also excluded from the payload figures.

In Operational Condition Dates

The In Operational Condition (IOC) date of the OLS was assumed to be 1983. The earth orbit space station IOC date was assumed to be 1978. Space tug and RNS IOC dates were 1981. The Lunar Surface Base IOC was 1985.

Environmental Models

Natural environments in the lunar vicinity were as specified in NASA TMX-53865. Included were the meteoroid model and the radiation model associated with frequency, duration and magnitude of solar flares. The R-2 lunar mascon model was used in determining orbital perturbations.

Safety Considerations

A basic guideline used in this study was to provide for escape of the OLS crew to earth orbit by means other than earth or earth orbital based rescue flights. This provision was in addition to redundancy/reliability/maintainability design criteria for the OLS. The performance characteristics of the space tug permit its use as the rescue vehicle.

Rescue of surface scientific sortie personnel from lunar orbit was also a basic safety guideline. The operations sequence plan was developed in a manner to ensure one tug was available and provisioned to accomplish either lunar surface rescue or emergency earth orbit return at all times during manned surface or orbit operational periods.

The surface crew was assumed to always consist of four men. This approach permits a "buddy" system during all surface operations.

In order to ensure quick response as well as backup operations capability, it was assumed that continuous communications capability between the OLS and the lunar surface must be provided. This groundrule imposed a requirement for a lunar data relay satellite system.

Transfer of crew and cargo between the OLS and the baseline cislunar shuttle, the RNS, will be accomplished via the space tug. Radiation safety consideration led to the assumption that the RNS will never dock to the OLS.

Providing for the harboring of the LSB crew in the event of its emergency abandonment was assumed to be an OLS requirement. This requirement proved to be a governing sizing factor for some subsystem designs.

Within the OLS, double failures of equipment were considered. However, it was assumed that the probability of failure of more than one program element (e.g., OLS, space tug or LSB) at one time had an extremely low probability because of the built-in redundancy of equipment in each element. Therefore, simultaneous double element failures were not considered.

Communications

Comparisons between Earth Orbit Space Station (EOSS) data links and OLS data links were made as part of the derivation of the OLS communications requirements. It was assumed that the Tracking and Data Relay Satellite (TDRS) would be available for EOSS use and a similar lunar satellite with comparable gain/power characteristics would be available for OLS use.

The commmunications frequency was assumed to be in S-band and 30- and 85-foot parabolic antennas comparable to the present Manned Space Flight Network (MSFN) equipment would be available for OLS to earth communications.

In the preceding safety discussion it was pointed out that a lunar data relay system was required. Several concepts were evaluated only to the extent of identifying OLS design requirements. As a baseline for this study it was assumed that a three satellite system deployed in a lunar equatorial orbit would be available. One very promising lunar data relay concept, which has been proposed by Dr. R. W. Farquhar of the Goddard Space Flight Center, required only one satellite in a "halo" orbit about the L_2 libration point. This concept could result in modifications to the OLS communications concept because of the additional path loss. However, if the satellite is designed with higher gain/power characteristics than the assumed equatorial system such that the additional path loss is compensated for, there would be no impact on the OLS concept.

4.0 SIGNIFICANT RESULTS

This section presents a summary of the more significant results of the analyses conducted during the study. The subdivisions correspond to the six volumes of the technical report of the study.

4.1 OLS OBJECTIVES

There are two predominant considerations in all of the NASA's advanced planning for the Integrated Program Plan (IPP); safety and economic operation. These two factors impose a design criteria on all program elements of redundancy, long life, multiple rescue provisions, operational versatility, adaptability, commonality, reusability, and compatible interrelationships between associated program elements. In this study, two OLS concepts that meet these criteria were derived. These concepts can conduct, support and/or integrate all facets of the lunar exploration program segment of the IPP in a safe and economic manner. The following specific OLS objectives and subsequently derived support requirements reflect the key role that an OLS can perform in the lunar program.

Operational Objectives

The primary operational objectives of the OLS that were identified are:

1. The OLS will function as a control center, managing many elements of an advanced lunar program. The OLS shall have the capability to command, control, and monitor all lunar elements of the integrated program, including remote control of manned and unmanned surface or orbital vehicles.

2. The OLS will provide a local operational base for manned and unmanned lunar landing missions for the purpose of lunar exploration and exploitation.

3. The OLS will provide operational and logistic support to a lunar surface base.

4. The OLS will provide a lunar orbital facility from which remote scientific sensing and mapping of the lunar surface and atmosphere can be performed.

5. The OLS will provide laboratory facilities to support lunar surface and orbital operations including film processing, diagnostic analysis of lunar samples, control of detailed experiments and preliminary screening of scientific data.

6. The OLS will provide support of free-flying subsatellites in the lunar vicinity including servicing, data processing and command and control.

7. The OLS will provide safe crew quarters for all personnel operating in the lunar vicinity and in conjunction with the space tug, facilitate rescue of personnel from the lunar surface.

8. The OLS will incorporate autonomous operational capability to provide efficient and cost effective lunar operations.

Technological and Engineering Objectives

Several reports pertaining to advanced planetary mission concepts were reviewed in an attempt to identify potential planetary technological and engineering development evaluations that could be candidate OLS objectives. Common OLS and planetary mission items such as orbital assembly, refueling, long-duration space operations, autonomous operation and orbital science are a basic part of the OLS operation. Therefore, these items were not identified as unique OLS objectives. Other topics such as heat shield concepts, entry and exit guidance, and unmanned planetary probe ascent and descent were considered incompatible with OLS operations. However, three advanced technological and engineering objectives were considered applicable to the OLS.

1. Laser Communication - OLS communications do not require the use of a laser; however, the OLS can provide an effective test station at a sufficient range from a counterpart earth orbiting test facility to evaluate tracking and delay time characteristics proposed for deep space missions.

2. Space Vehicle Materials - The operation of the OLS beyond the earth geomagnetosphere affords a unique opportunity for duration evaluation of candidate deep space vehicle materials, insulation, thermal coatings and radiation protection concepts.

3. Lunar and Planetary Surface Shelters - In conjunction with the space tug, an evaluation of candidate shelter concepts can be conducted on the lunar surface prior to final commitment to shelter concepts and materials.

Scientific Objectives

A top-down formulation of the post-Apollo lunar exploration and exploitation program was developed. The four overall objectives of the scientific program that were identified are:

1. Improve understanding of the solar system

2. Utilize earth-moon comparison to extend knowledge of the development process of the earth

3. Exploit moon resources for both scientific and technological purposes

4. Extend man's capability in space in preparation for exploration of other planetary bodies

Scientific disciplines of astronomy, geology and geochemistry, geophysics, bioscience, aerospace medicine, lunar atmosphere, particles and fields, and geodesy and cartography were investigated to establish subobjectives which support the overall lunar exploration program. Identified lunar program subobjectives that will be directly supported by the OLS are given below.

Astronomy. Perform high-resolution radio and optical observations of solar system sources.

Geology/Geochemistry. Determine the type, form, structure, distribution and relative age of lunar surface features. Determine the physical, mineralogical, and chemical properties of lunar materials. Deduce the nature and relative importance of dynamic natural processes on the lunar surface. Study the effects of ancient or long term geologic processes. Compile a geochronology of lunar events from the early stage of formation to the present day. Construct geologic maps of the lunar surface, delineating lithologic contacts, tectonic structures, physiographic and petrographic provinces. Determine the nature of morphologic difference between the near- and far side of the moon. Locate geologically favorable sites for advanced lunar exploration/exploitation scientific facilities.

Geophysics. Determine the mass distribution and figure of the moon. Determine the physical state and composition of the lunar interior. Evaluate the internal dynamics (heat flow, circulation, creep, etc.) of the moon. Determine the earth-moon mechanical interactions.

Bioscience. None

Aerospace Medicine. None

Lunar Atmosphere. Determine the total quantity and distribution of the component species of the lunar atmosphere. Determine the principal natural atmosphere sources, loss and transport mechanisms, and their rates. Monitor atmospheric contamination resulting from lunar missions, including transport and escape rates.

Particles and Fields. Study the interaction of the solar wind with the moon. Study the fundamental physics of plasma interactions. Determine the magnetic and electric fields around, on, and within the moon as modified by the relative positions of the earth and sun. Measure the primary and secondary nuclear particles in lunar space and at the surface of the moon.

Geodesy/Cartography. Establish a three-dimensional geodetic control system over the entire lunar surface in terms of latitude, longitude and height above the chosen reference figure. Collect photogrammetric data and construct topographic maps for scientific purposes, sortie, and base site evaluation studies.

The previous scientific objectives were analyzed and 16 orbital experiments were identified. These 16 experiments were evaluated for compatibility with the potential OLS environments of contamination, acceleration, attitude/stability, electromagnetic interference, orbit, and safety. This analysis indicated that eight of the experiments could be incorporated in the OLS. The remaining eight experiments were accommodated on three free-flying subsatellites.

The equipment required to conduct the orbital experiments, including laboratory facilities and subsatellites, was identified including definition of weight, power, volume, consumables, stability, data, and environmental requirements and characteristics. Three laboratories were identified: geochemistry, data analysis, and photography. A photography laboratory is mandatory on the OLS because of the deterioration of film due to galactic radiation. Total area required to accommodate these laboratories plus the control center for operation of the experiments was approximately 300 square feet. The total required experiment sensor mounting area normal to the lunar local vertical was 110 square feet. A narrative and a master timeline for each of the orbital experiments, including those incorporated in the subsatellites, were developed. An integrated experiment program plan was developed which combines the characteristics of the equipment with the individual experiment timelines to determine the total OLS experiment support requirements. Power, data handling, and scientific crew skills profiles were generated.

A lunar surface program model was developed. Site distributions were analyzed and a list of 26 potential scientific exploration sites were identified. Three of these sites were considered for space tug lunar surface sortie missions and the scientific equipment and operational requirements identified in order to establish a realistic payload/logistics model for OLS support operations. A space tug lunar surface sortie scientific payload of 2000 pounds per sortie, including support equipment, was defined as nominal.

4.2 MISSION OPERATIONS AND PAYLOAD ANALYSIS

Orbit Determination

A comprehensive study was conducted to determine the optimum lunar orbit for the OLS. Analysis indicated that the preferred OLS orbit is a polar inclination, 60-nautical mile altitude, circular orbit.

The primary reasons for the selection of the polar inclination were two-fold.

1. Tug landers based at a polar orbit OLS can descend to any surface site and return to the OLS without costly plane changes, thus permitting substantial payload gain or tug propellant savings. Opportunities for such minimum delta-V coplanar descent and ascent are available approximately every 14 days.

2. The majority of the lunar orbit science experiments require viewing of the entire lunar surface. Only a polar or near polar orbit can satisfy this requirement.

Factors not favorable for a polar inclination were: higher worst-case TEI delta-V for emergency earth return, and fewer cislunar shuttle TLI opportunities with maximum or near-maximum payload to lunar orbit. However, neither factor offers significant disadvantages. The worst-case TEI and EOI delta-V's from polar orbit are within the capabilities of currently envisioned tug-lander sizes; the maximum payload mission opportunities to polar orbit occur every 54.6 days and were determined to be adequate in the development of the operations sequence plan.

The OLS orbit altitude of 60 nautical miles was recommended primarily to provide adequate margin of safety for the optimized lunar approach hyperbola perilune altitude of 40 nautical miles for a 60-nautical mile final orbit. A more absolute lower limit of 40-nautical mile OLS orbit was established by the tug ascent safety requirement. This involves tug burnout at the perilune of a 10 x 30-nautical mile altitude (948.5 x 968.5-nautical mile radius) elliptic orbit to allow for slightly premature thrust cutoff without resulting in an impact ellipse. An increment of 10 nautical miles above the 30-nautical mile apolune provides for phasing transfer to the OLS, thus establishing the 40-nautical mile altitude lower limit.

Orbit perturbation did not appear to be sensitive to altitude for polar orbit. The tradeoff between landing mission payload capability and cislunar shuttle payload capability showed little sensitivity to the OLS altitude. All OLS attached science experiments were compatible with the 60-nautical mile altitude.

The circular orbit was selected for the OLS. No advantage for eccentric orbit was uncovered and a number of disadvantages were identified.

Crew Activities

OLS crew requirements were synthesized based upon evaluation of required skills, functional responsibilities, and time estimates of the various operational tasks. The analyses indicated that a crew of eight was required. Although organizationally the crew makeup appears to be four scientific personnel and four station operations personnel, the equivalent manpower division was five scientific and three operational crewmen. This crew time allocation results from the analysis of task times as well as the selection of and cross training in crew skills that was defined.

Autonomous Operations

The primary reasons for inclusion of an OLS in the lunar exploration program were to provide both economic and safe lunar operations. That is, the OLS can provide a local centralized base of operations which is relatively independent of earth operations in all day-to-day activities as well as most of the contingency operations. This role of the OLS in lunar operations in turn imposes a mandatory requirement upon the OLS to be as autonomous as possible. Functions such as mission planning (short range), experiment scheduling, system status monitoring, maintenance, repair, servicing, checkout, calibration, flight command and control, communications, and rescue operations can and should be performed by the OLS.

The level of autonomy of the OLS that was desired and the implementation approach were derived. Partial autonomy was preferred. It provides for on-board operations that are independent of real-time earth-based support, but earth-based support on an as-required basis was recommended. Incremental installation and activation were recommended. The functional requirements imposed upon the OLS by inclusion of autonomous operations were identified. The primary areas affected were the reliability/redundancy design criteria for all spacecraft equipment and the degree of sophistication and automation of the Information Subsystem (ISS).

Safety and Rescue

Safety and rescue related ground rules enumerated in Section 3.0 of this report and related operational and design requirements imposed upon the OLS were derived. OLS system safety and OLS safety and rescue support were treated separately. OLS system safety deals with OLS operational safety requirements inherent to safe operation of the OLS and its crew. OLS safety and rescue support deals with additional OLS operational considerations and requirements related to the safety of other lunar program elements such as the tug and the lunar surface base.

Some of the major design implications identified were:

1. Two separately pressurizable volumes, with interfacing hatches are required

2. Multiple airlocks are required to support potential IVA/EVA activity

3. The OLS must be capable of supporting 12 additional crewmen for up to 55 days in the event of a failure requiring rescue of the LSB crew

4. One space tug shall be provisioned at all times for either escape to earth orbit or rescue of lunar surface personnel

Operations Sequencing

A baseline model was developed for a nominal sequence of operations from initial delivery of the OLS in lunar orbit to completion of a 10-year OLS program. These plans were derived to assist in the identification of OLS design requirements such as normal and contingency consumables storage, crew rotation schedules, propellant storage, and maximum crew accommodation requirements. The basis of these plans is as follows. The OLS is initially placed in operation in 1983. The nominal crew size is eight men. During the first six months of operation, surface mapping and other precursor operations are performed in orbit prior to beginning surface sorties with a space tug lunar lander. During the following 2-1/2-year period, a total of eight scientific surface sorties are performed. The LSB is delivered to the lunar surface at the OLS 3-year point and is operated with a 12-man crew for approximately five years. After LSB deactivation, the OLS continues orbital operations to the end of the 10-year period.

Logistics resupply requirements to support the OLS, tug sorties, and the LSB were developed employing data derived from the concurrent space tug and LSB studies in progress at NR. Operational interfaces were determined through close coordination of these companion studies. The performance of the RNS shuttle, CPS shuttle, and the tug lander were obtained from the OLS guidelines discussed in Section 3.0 of this report.

An integrated plan generated from consideration of the logistics requirements and operational interfaces with the other space program elements is presented. These operations plans are based upon the RNS cislunar shuttle. Delta effects upon logistics supply and mission planning resulting from the use of the Chemical Propulsion Stage (CPS) as the cislunar shuttle are also discussed. Figure 4-1 presents a cumulative plot of the total payload required to be delivered to lunar orbit over the 10-year period of OLS operation. The traffic model including earth orbit shuttle flights is presented in Table 4-1.

Propellant Management

A vital operational aspect of an integrated lunar exploration program in the 1980's is a propellant management plan for providing tug propellant and OLS cryogenics resupply in a timely and efficient manner. Approximately 55 percent of the payload weight delivered to lunar orbit on the cislunar shuttle will be tug propellant, and an additional 5 percent will be OLS cryogenics (LH_2, LO_2, and LN_2). Based upon the operations sequence model developed in this study, propellant requirements and propellant management concepts were evaluated. Propellant resupply logistics were reviewed, the need for a lunar orbital propellant depot evaluated, and a module for delivery of propellant to lunar orbit was defined. The main conclusions reached were:

1. No lunar orbiting propellant depot is required to store space tug propellants.

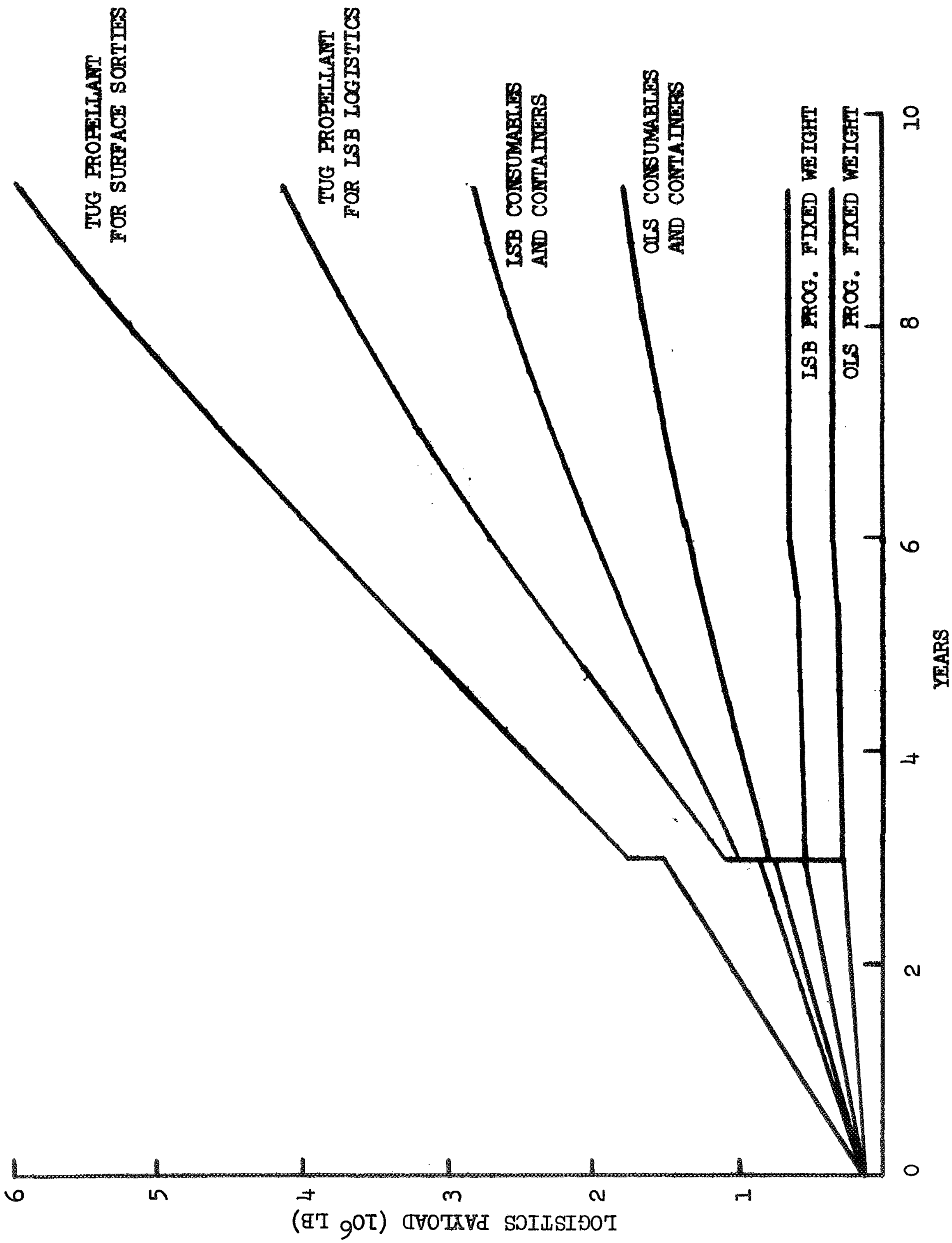

Figure 4-1. Cumulative Payload to Lunar Orbit

Table 4-1. Lunar Program Traffic Model - Number of Flights

Program Year	Earth Orbit			EO-LO RNS	Tug Roundtrips - Lunar Orbit to Surf.	
	INT-21	EOS	Tug		Sorties	To LSB
0	1	21	20	2		
1		32	32	3	2	
2		44	44	4	3	
3		44	44	4	3	1/2
4	1	89	88	8	3	4
5		77	77	7	4	3
6		80	80	7	3	3
7		66	66	6	3	3
8		77	77	7	3	4
9		65	65	6	3	1-1/2
10		9	9	1	1	
Total	2	604	602	55	28	19

EOS Earth Orbit Shuttle
EO Earth Orbit
LO Lunar Orbit
RNS Reusable Nuclear Stage

2. A 77,000-pound capacity propellant module can be used to transport cryogenics to lunar orbit and subsequently transfer cryogenics directly to the tugs and to the OLS.

3. The propellant modules can be disposed of by deorbiting them to the lunar surface with an expenditure of approximately 1200 pounds of propellant, or they can be returned to earth.

Docking Operations and Payload Accommodation Studies

Based upon the operations sequence model of this study, concepts for cargo transport and storage were developed. Worst-case storage requirements were identified, resupply procedures were developed, and docking operations were defined. The primary conclusions were:

1. A "pantry" module is not required to store OLS cargo.

2. OLS and tug sortie supplies can be transported to lunar orbit in a common cargo module; i.e., a dual-support cargo module.

3. LSB supplies are transported independently in dedicated cargo modules.

4. A total of four operational docking ports are required.

5. OLS cargo storage capacity requirements were based upon the combination of a study guideline and provisions for harboring the LSB crew in the event emergency abandonment is necessary. Normal operations storage facilities are commensurate with the study guideline of 180 days of operation without resupply. Contingency life support provisions for the LSB crew for up to 55 days were an additional requirement.

4.3 OLS PERFORMANCE REQUIREMENTS

In the functional analysis task, the scientific and operational objectives were analyzed, and the supporting OLS functions were identified. Systems analyses were then performed to determine the OLS preliminary design criteria, including subsystems functional and performance requirements supporting these identified OLS objectives and functions. These requirements, which include OLS overall design criteria, mission operational requirements, and subsystem and provisions requirements, were derived. As the objectives, functions, and operational modes of the OLS are similar in many respects to those of the Earth Orbit Space Station (EOSS), the EOSS Performance Specification, SD 70-510-1, dated July 1970, was employed as a baseline model and checklist in the determination and documentation of the OLS system requirements. The EOSS design criteria, operational requirements, and subsystems requirements were reviewed by the OLS personnel and adopted, rejected, or modified into applicable OLS requirements. These requirements were then supplemented with the addition of requirements unique to the lunar orbit operations and/or required to support OLS objectives. The results of these analyses were compiled into an OLS preliminary design requirements document.

4.4 OLS CONFIGURATION AND SUBSYSTEM SYNTHESIS

Parametric data, trade studies and comparison matrices were developed for various OLS configurations and subsystem options. No configuration design or subsystem concept selections were made as the analyses were limited intentionally to comparisons of concepts and design approaches. The data presented were utilized, however, to select design configurations and subsystems concepts for the representative OLS (20 to 33-foot diameter vehicle) and the derivative OLS (based on the MSS).

OLS Parametric Configuration Studies

The configurational design studies investigated OLS concepts for crew sizes of 4, 8, and 12 men which would satisfy the OLS program objectives, operational criteria, and structural performance requirements. Structural parameters which were varied during these analyses were:

Basic vehicle diameter - 12, 15, 22, and 33 feet

Floor orientation - transverse and longitudinal

In these studies, conical, flat, and toroidal pressure bulkhead shapes were considered. Floor arrangement drawings were prepared for each of the above parametric combinations of diameter, floor orientation, and crew size. A weights analysis was performed for each of these OLS concepts.

OLS Subsystems Concepts

Parametric data, trade studies and comparison matrices for OLS subsystems concepts were developed for the following subsystems:

1. Environmental Control and Life Support (ECLSS)
2. Electrical Power (EPS)
3. Information (ISS)
4. Guidance and Control (G&C)
5. Reaction Control (RCS)
6. Environmental Protection (ENPS)

Subsystem synthesis parameters considered in the analyses were:

1. Initial, development, and resupply relative cost data
2. Initial and resupply weights
3. Safety and reliability
4. Maintenance and repair considerations
5. Power requirements
6. Heat rejection requirements
7. Volumetric requirements

Wherever applicable, data for these parameters were compiled for various functional concepts capable of satisfying the OLS subsystem functional and performance requirements. Where appropriate, the data are presented parametrically as a function of crew size (4 to 12 men) and vehicle diameter (12 to 33 feet). In many cases, trade data generated in the EOSS study were directly applicable and were also included.

4.5 OLS CONFIGURATION DEFINITION

Two OLS configurations were derived which meet the performance requirements derived previously in the study. A representative OLS configuration that was constrained to be within 20 to 33 feet in diameter and was based upon the configuration and subsystem synthesis data was derived. A derivative OLS which was an adaptation of the modular space station, defined by NR in January, 1971, was also defined.

Representative OLS Configuration Definition

Layouts of the principal structural elements (core module, power module, and experiments module) were made for the representative OLS configuration. Mass properties data including a weights statement were also calculated. A summary of the characteristics of this configuration is given below.

1. The core module is 27 feet in diameter with an overall length of 60.83 feet. The internal arrangement consists of four transverse circular decks with toroidal end pressure bulkheads and two separate pressure volumes. Unpressurized volumes are provided in the upper and lower torus regions for cryogenic storage.

2. A four-element rollout solar array of 10,000 square feet is accommodated on a cylindrical power module. When mated at launch, the overall length of the power and core modules is 94.25 feet.

3. Four passive docking ports are located on the cylindrical portion of the core module plus two active neuter docking cones at each end. Passive side docking ports are employed to eliminate the need for large boost fairings. At anytime after boost to earth orbit, these passive ports can be modified by the addition of active/active docking adapters. Four of these are defined as necessary to satisfy OLS operational docking requirements.

4. An experiment module 15 feet in diameter and 22 feet long (EOS compatible) is docked at the +Z axis port of the experiments deck to physically accommodate those science experiments requiring an unrestricted field of view while body mounted to the OLS. The experiment module also incorporates a separate compartment which functions as an airlock and subsatellite servicing hangar.

A summary of the representative OLS weight statement is presented below:

1. The total OLS dry weight is 107,475 pounds, consisting of an 85,155-pound core module, an 11,320-pound power module, and an 11,000-pound experiment module.

2. The total OLS inert weight is 129,375 pounds, including 21,900 pounds of inert fluids.

3. The total OLS maximum in lunar orbit weight is 157,625 pounds including 26,650 pounds of consumables and 1600 pounds for a crew of eight.

A concept for delivery of the representative OLS to lunar orbit was developed. Single and two-stage Chemical Propulsion Stages (CPS-1; CPS-2) and a Reusable Nuclear Shuttle (RNS) were considered as candidate Cislunar Shuttles (CLS). Also, operation of CPS-1 and the RNS in an "expended" mode (refueled in lunar orbit) was considered. The baseline delivery concept was to use the RNS as the CLS and to deliver the total assemblage of OLS modules, consumables, crew, and one space tug by means of two RNS flights.

Representative OLS Subsystem Definition

A concept definition of each representative OLS subsystem was made. The trade studies and rationale for selection are summarized for each subsystem subassembly. The more significant assembly and subassembly selections of each OLS subsystem are summarized below.

Environmental Control/Life Support Subsystem. A high-pressure nitrogen system is included in the emergency supply assembly. The emergency earth-based reaction time for the OLS is 30 days as compared to only two days for an Earth Orbit Space Station (EOSS). Resupply weights and costs were the primary factors in selecting a laundry for the OLS. All other ECLSS functions are accomplished in a manner similar to the EOSS concepts.

Electrical Power Subsystem. A 10,000-square foot solar array was selected as the primary power source. The major influences were weight and cost. The energy storage concept is regnerative fuel cells. Initial and resupply weights were the prime drivers in the selection of this concept. Premanning, emergency, and eclipse power are supplied by open-loop fuel cells. This approach provides a completely independent power source which also will produce potable water during emergency periods.

Information Subsystem. The only unique concept in the Information Subsystem as compared to the EOSS is the high-gain antenna subassemblies. Phased arrays are preferred over parabolic dishes primarily because of the lower maintenance requirement and the capability for simultaneous multiple communication links. An antenna subassembly is also included on the power module in order to eliminate communication dead zones that would occur if antennas were restricted solely to the OLS core module.

Guidance and Control. Attitude control is provided by the combination of the Reaction Control System and Control Moment Gyros (CMG). The CMG's are comparable to those of the EOSS. The navigation requirements of the OLS require the inclusion of a landmark tracker and a radar altimeter. A strap-down system was selected as the inertial reference assembly primarily because of the reliability and, if necessary, ease of maintenance. Operational science experiment considerations require that the OLS be maintained in a local level orientation. The selected assembly of OLS modules was based upon CMG sizing, RCS impulse requirements, thermal constraints, and experiment sensor viewing requirements.

Reaction Control Subsystem. An H_2/O_2 propulsion system, with cryogenic storage, was selected primarily because of a smaller required mass as compared to the other candidate concepts and for commonality with the propellants of the space tug.

Environmental Protection Subsystem.

a. Radiation Protection. Based upon the NASA defined solar flare event model (TMX 53865), it is mandatory that a radiation shelter be included in the OLS. An area that includes the secondary control center, backup galley, and a hygienic facility is enclosed primarily within a water jacket that contains 16,000 pounds of water.

b. Thermal Protection. The thermal environment in lunar orbit (in the subsolar region) is significantly more severe than in earth orbit. An active external radiator system operating at an effective temperature of 70 F was selected. A heat pump is required and also a thermal capacitor (the water of the radiation shield) is used in order to achieve adequate heat rejection with the available effective radiator area and with reasonable α_S/ϵ values for the control coating.

c. Meteoroid Protection. The differences in the meteoroid environments between the OLS and the EOSS are negligible. Therefore, the same concepts are used. The governing factor in selecting the thickness of the micrometeoroid bumper was manufacturing, handling, and maintenance considerations rather than the meteoroid environment.

Derivative OLS Definition

The derivative OLS configuration, which was an adaptation of the earth orbital Modular Space Station, is discussed in Section 5.0, Implications Concerning the EOSS. In general, the MSS is adaptable to OLS use by employing a combination of modules of the 6-man and 12-man MSS configurations. Eight mandatory changes were identified. Only the strengthening of structure in the MSS core modules in the area of the side docking ports concerns primary structure. The most significant change to the secondary structure was incorporation of a radiation protection shelter for the OLS crew.

Five highly desirable changes were also identified for OLS use. Three of these are currently being evaluated as part of the NR Phase B effort on the MSS. Ten changes to the basic MSS which would facilitate conversion to OLS use were recommended. The most significant recommendation was the strengthening of the primary structure of MSS core modules in the area of the side docking ports.

4.6 COMPARISON OF OLS CONFIGURATIONS

Both the representative and the derivative OLS configurations were designed to meet all operational and performance requirements that were identified in this study. However, there are some characteristics and/or capabilities that are significantly different between the two concepts.

The total on-orbit weight of the derivative OLS was approximately 65,000 pounds greater than the representative OLS concept. Structural, electrical power, environmental control, and docking provisions differences were primarily the reasons for the increased weight. For example, the derivative OLS uses batteries and battery chargers as the energy storage concept. This concept is approximately 12,000 pounds heavier than the regenerative fuel cell energy storage concept used in the representative OLS. The increase in the number of docking ports required for assembly, and consequently, the increased atmospheric leakage, results in additional O_2/N_2 storage requirements of another 4530 pounds.

Phased arrays were selected for the representative OLS. This concept can track multiple targets simultaneously. The parabolic antennas on the derivative OLS, which are adequate, can track only one target at a time.

The mass distribution of the derivative OLS results in approximately a 20 percent increase in RCS impulse requirements as compared to the representative OLS. This, in turn, requires larger storage capacity on the derivative OLS concept.

5.0 IMPLICATIONS CONCERNING EOSS

A summary of the analyses and definition of the modifications to an earth orbiting Modular Space Station (MSS) required to permit operation in lunar orbit as the derivative OLS is presented. The MSS concept considered was the preferred baseline concept as documented in MSC 02464, Volume 1, the MSS Definition Document, and in PDS-71-1, the MSS 2nd Quarterly Review Briefing Booklet. Mandatory changes to the MSS modules are identified. Recommended changes to the baseline MSS which would either facilitate conversion to OLS use or enhance operations as an OLS without significantly penalizing the MSS are also identified.

Functional Requirements Analysis

A comparison was made between the derivative OLS and the MSS for four types of functional requirements; i.e., floor area, docking provisions, resupply and storage, and science support. The baseline MSS used for comparison purposes was the 6-man configuration. Significant conclusions which were made are:

1. Modules must be added to enlarge the 6-man MSS concept to meet the increased OLS floor space requirements.

2. The MSS C1 and C2 core modules do not provide adequate assembly ports for the additional modules required for OLS use.

3. MSS cryogenic storage is inadequate to meet the requirements of the OLS.

Performance Requirements Comparison

A performance requirements comparison was made (e.g., power, consumables, stability, data handling, impulse, etc.) between the OLS subsystems and the 6-man MSS subsystems. Significant results of these analyses are:

1. The 6-man MSS solar array is insufficient to meet OLS primary power requirements.

2. Additional crew quarters and medical facility space are required for the OLS.

3. The ECLSS equipment of the 6-man MSS must be resized for the 8-man OLS.

4. A radiation storm shelter which provides 16.6 gm/cm^2 of shielding, must be incorporated.

5. High pressure nitrogen and increased high pressure oxygen storage for emergency leakage makeup is required uniquely by the OLS.

6. OLS module heat rejection requirements exceed those of MSS modules which, coupled with the high lunar infrared radiation, requires additional radiator area and necessitates use of a thermal capacitor to store heat during subsolar portions of the lunar orbit.

7. More stringent OLS navigational accuracy requirements necessitate addition of a landmark tracker and a radar altimeter to the MSS G&C subsystem.

8. Larger OLS total impulse requirements require resizing of MSS Reaction Control Subsystem (RCS) accumulators and the cryogenic tank storage facility.

9. The side docking provisions on the core module must be strengthened to accommodate the bending loads that will be experienced during translunar and lunar orbit insertion thrust maneuvers.

The requirement for strengthening the primary structure of the core module was a result of development of a concept for delivery of the derivative OLS to lunar orbit. The three candidate Cislunar Shuttles (CLS) considered were CPS-1, CPS-2, and RNS operated in round trip and expended modes. Both assembled and disassembled arrays of modules were considered in the delivery concepts. The baseline concept was to use two RNS flights operated in a round trip mode. The RNS payload capability permitted delivery of a partially assembled OLS on one flight, provided the primary structure of the core modules were strengthened. The primary limitation on use of the CPS as the CLS was the thrust level, which induced bending moments six times as great as the RNS. All three cislunar shuttle concepts could be used for delivery of an unassembled OLS.

MSS Conversion Modifications

Based on analysis of the functional and performance requirements comparison data, the changes to the MSS concept which were absolutely required to allow its use in lunar orbit as the derivative OLS were defined. These modifications are:

1. Reconfiguration of the MSS Cargo Modules (CM's) into OLS Cryogenic Storage Modules (CSM's) to conform to the increased OLS cryogenic storage requirements.

2. Installation of a solar flare nuclear radiation shelter surrounding the secondary control center in MSS Control Center Module 1 (CCM1) and incorporation of a hygiene facility within the shelter.

3. Incorporation of high pressure GN_2 and GO_2 storage tanks in the two reconfigured core modules for OLS emergency N_2/O_2 leakage makeup and O_2 metabolic consumption.

4. Addition of a laundry to the MSS Galley Module (GM).

5. Installation of an additional high gain parabolic antenna subassembly boom mounted on the Power Module (PM) above the solar array to meet the OLS continuous communications requirements.

6. Addition of a landmark tracker and a radar altimeter in OLS Core Module 1B, derived from MSS Core Module 1 (C1) to meet the more stringent OLS navigation requirements.

7. Addition of RCS hydrogen accumulators in OLS Core Modules 1A and 1B (both derived from MSS Core Module C1) that are required because of the larger OLS impulse requirements.

8. Addition of (a) heat pumps to MSS Crew Quarters Modules (CQM's) 1 and 3; (b) a thermal capacitor (the water in the radiation shelter in CCM1 is used to fill this requirement); and (c) additional radiator area added to the converted MSS CM's, which is required to satisfy OLS heat rejection requirements.

9. Reinforcement of the side docking structure to the OLS Core Modules to withstand the bending moments during translunar and lunar orbit insertion thrust maneuvers.

Some additional MSS modifications which would be desirable, but are not absolutely required, are also identified and described. All of the suggested desirable changes are believed cost effective; however, some of these changes would incur development costs not otherwise present in the derivative OLS program. Major desired changes are:

1. Revise the MSS Power Module (PM) by removing the MSS cryogenic storage tanks from the power boom and replacing the MSS batteries and battery chargers with a regenerative fuel cell energy storage system.

2. Further reconfigure the OLS cryogenic storage modules 1 and 2, both of which are derived from MSS CM's to house all OLS cryogens and high pressure nitrogen.

3. Change the MSS electrical power system from a double to a single ac voltage distribution concept.

4. Remove excess RCS engine clusters from the OLS core modules (at the mated ends of the modules) and replace the high pressure nitrogen tanks with gaseous oxygen and hydrogen accumulator tanks.

5. Resize the oxygen, hydrogen, and nitrogen cryogenic storage tanks to optimize them for OLS use.

Derivative OLS Configuration Definition

The derivative OLS is composed of modified MSS modules together with the OLS dual support cargo module (DSCM) and the OLS experiment module (XM) plus two space tugs. The MSS modules employed are:

1. The 12-man Power Module (PM)
2. Two No. 1 Core Modules (C1)
3. Control Center Module No. 1 (CCM1)
4. The 12-man version of Control Center Module No. 2 (CCM2)
5. The 12-man Galley Module (GM)
6. Crew Quarters Module No. 1 (CQM1)
7. The 12-man Crew Quarters Module No. 3 (CQM3)
8. Two Cargo Modules (CM's) modified to cryogenic storage modules (CSM's)

The structural changes required in each of the parent MSS modules were identified in layout drawings. A weights analysis of the derivative OLS was made and a weight statement developed. The derivative OLS gross weight is 223,104 pounds. A comparison of the weight of each OLS module with that of its parent MSS module was made. Also calculated were derivative OLS mass properties.

The derivative OLS subsystems were defined. The structures, electrical power, information, reaction control, and the micrometeoroid protection portion of the environmental protection subsystems are very similar to the MSS subsystems. The environmental control and life support, guidance and control, and the thermal and radiation protection portions of the environmental protection subsystems were modified to more closely resemble the representative OLS subsystems concepts.

Recommended MSS Design Modifications

Some in-line design change modifications to the MSS were recommended. These are proposed changes to the basic MSS which would facilitate adaptation of the MSS to OLS use without significantly affecting MSS performance or cost. Some of these changes would also enhance the performance of the MSS. These recommendations cataloged per their parent MSS subsystem areas are listed below.

Structures Subsystem. Strengthen the primary structure surrounding the side docking ports in the Core Module to meet OLS requirements. This would be a difficult and expensive change to make once the MSS core module is constructed. Incorporation of this change will increase the structural weight of the core module by approximately 1000 pounds.

Environmental Control/Life Support Subsystem. Use the regenerable charcoal concept in the trace contaminant control system if the technology supports the initiation of MSS development. A significant program weight reduction could be realized. In the case of the OLS, a weight reduction of the order of 12,000 pounds, over a 10-year period, can be achieved.

Add a dishwasher to the MSS. Resupply and trash weight considerations make a dishwasher highly desirable for the OLS. It is believed that to a lesser degree, a total program weight reduction could also be realized with a dishwasher on the MSS.

Resize the MSS equipment for an eight-man crew to facilitate OLS conversion. The resized MSS equipment could be operated at either a reduced rate or only 18 hours per day.

Electrical Power Subsystem. Substitute Regenerative Fuel Cells (RFC) for batteries and battery chargers on the MSS. A significant decrease in total program weight can be realized.

Incorporate a single ac voltage distribution concept in the MSS. Use of a single, standard voltage system will reduce susceptibility to corona effects and switching transients and result in an overall weight reduction by simplifying the inverter-regulator design.

Information Subsystem. Incorporate a third parabolic antenna to be mounted to the power boom. Although continuous communication capability is not a requirement on the MSS, this added antenna would eliminate the signal blockage caused by the shadow effect of the solar arrays. This concept would enhance MSS operation and facilitate conversion to OLS use which requires the third antenna

Guidance and Control Subsystem. Add a landmark tracker and a radar altimeter. This equipment is required to satify the tighter OLS navigation accuracy requirements and would enhance MSS performance.

Reaction Control Subsystem. There were no recommended changes to the Reaction Control Subsystem of the MSS.

Environmental Protection Subsystem. A detailed analysis and design of the MSS meteoroid protection concept has not been conducted yet. However, it is anticipated that no modifications would be identified because the environments are very similar as are the area-time products of the two designs.

Incorporate a thermal capacitor and a heat pump. Although the MSS does not require these items, their addition would reduce the required radiator area, decrease the sensitivity to thermal control coating degradation, and facilitate adaptation to OLS use.

The only useful radiator area for heat rejection on the OLS modules is between nadir + 120° and nadir + 240°. Segment the radiators on the MSS modules such that the radiators between 120 and 240 degrees can be isolated from the remainder of the circumferential radiator system.

If the recommendation for changing the energy storage concept from batteries and battery chargers to regenerative fuel cells is incorporated, the power boom radiators have to be resized. A total of 425 square feet with at least 280 square feet on the antilunar side of the boom is required.

There were no recommended MSS radiation protection modifications to facilitate the adaptation to OLS use. Incorporation of the storm shelter provisions that are a unique requirement of the OLS would unduly penalize the MSS and are not warranted.

6.0 ADDITIONAL EFFORT

OLS Phase A study effort is believed complete; however, during the course of the Phase A study there were identified interfacing operations and supporting elements of the total lunar exploration program which could be further refined. If these studies were to be conducted prior to a Phase B OLS study, results would be greatly enhanced.

Following are the items of additional effort proposed for future study with a brief discussion of the benefits to be obtained. The first three additional efforts discussed relate to the OLS/space tug interface and deal with logistics resupply, docking operations, and sortie consumables requirements. The second group of two efforts are concerned with the total integration of consumables requirements for all lunar program elements and the generation of cislunar shuttle payload delivery synthesis performance data and procedures. The next item deals with the determination of practical and feasible means for resupplying propellants to lunar orbit. The last item is a detailed study of the use of "orbits" about the L_2 libration point as a staging point for more efficient delivery of payload to lunar orbit and as the location for a communications data relay satellite system.

OLS/Tug Interface Studies

Many of the operational and design requirements derived during the OLS study were based upon a logistics operations sequence model developed for the entire lunar exploration program. The model, of course, is as viable as the inputs to the model, which included payload and propellant performance characteristics for the tug. Conversely, conceptual requirements were identified which would impact the design and operations of the tug. A pre-Phase A study has been completed for the tug in which preferred concepts were optimized for earth orbital operations. More detailed design analyses are required to delineate the total conversion required to adapt one of the preferred configurations for use as a lunar lander tug. Such tug design features as a bottom-mounted crew module, swing out engines, landing gear kit with articulating legs, side-mounted cargo pods for cargo transport and "pantry" use are among those modifications that require further investigation. Also engine sizing, cargo off-loading, and the method of transferring cargo pods to the tug in lunar orbit, and expending the pods on the lunar surface require additional analysis to establish feasibility and design for optimum support to the lunar program.

The initial buildup of the OLS in lunar orbit, the subsequent resupply of consumables to lunar orbit, conduct of lunar lander tug sortie missions, and the potential conduct of rescue missions, require considerable tug docking and undocking activity. Both of the OLS design concepts evaluated in this Phase A study (modular and basic core module) utilize modules and tugs docked laterally to a central core module. The resulting total station configurations provide restricted space for tug maneuvering during docking operations, and impose attitude alignment requirements which may in turn require more sophisticated docking aids than are currently in operational use or in design. The latter might be particularly aggravated in those cases where the tug is docking a long module (such as a 50-foot long propellant module) to the OLS or to another tug. It is proposed that tug flight dynamics simulations be conducted to determine the capability of the tug (using state-of-the-art operational procedures and hardware) to meet the requirements imposed by the OLS program, and to define docking aids design requirements, where necessary, to overcome identified deficiencies in tug docking flight dynamics capability.

For purposes of the OLS Phase A study a "typical" space tug lunar surface sortie mission was derived in terms of science objectives, experiment payload requirements, total mission duration, and potential landing sites. This typical OLS space tug sortie mission was utilized as the model for logistics resupply purposes for each of the 28 sorties incorporated in the ten-year OLS operations sequence model. Although this was considered adequate to support the Phase A conceptual design of the OLS, future studies of a total integrated lunar exploration program will require more detailed analyses of various unique space tug sortie missions. It is recommended that further effort be expended in this area, with emphasis placed on landing site selection, individual sortie mission experiment and payload requirements, and equipment and crew operations on the lunar surface (including cargo off-loading and cargo pod disposal).

<u>OLS/Cislunar Shuttle Interface Studies</u>

The operations sequence model developed as part of the OLS study program, and discussed previously, was based upon the RNS cislunar shuttle performance defined in the OLS contract guidelines. The logistics payload transported to lunar orbit on each RNS flight, the frequency of flights, the crew rotation schedule, and the number of Earth Orbit Shuttle (EOS) flights to support each cislunar shuttle flight, are sensitive to the cislunar shuttle performance module used. Also, the lunar program logistics requirements will undoubtedly vary during the ensuing years, prior to the initiation of the lunar program. It is believed that a valuable tool for future use in lunar mission planning and design studies would be provided by the generation of cislunar shuttle parametric performance data which can readily accommodate changes in logistics requirements and cislunar shuttle (CLS) performance models. Among the desired parameters are CLS payload, CLS payload-to-propellant ratio, specific impulse, flight frequency, number of EOS support flights, and crew rotation size.

The cislunar shuttle is a key element in the total integrated lunar program, both from the standpoint of initial delivery of lunar program elements (tugs, LSB, and OLS) to lunar orbit and as a logistics vehicle for consumables resupply. A variety of payloads (in terms of size, shape, and type) must be carried by the CLS in order to effectively fulfill its support role in the total lunar program. The manner in which payloads are supported on the CLS can: (1) determine the number of flights required to deliver a given payload (e.g., the derivative OLS configuration) to the lunar orbit; (2) influence the structural design of the station modules and resupply modules; and (3) impact logistics supply operations in earth orbit and lunar orbit.

A study of various design methods, and associated operational procedures, for attaching modules to candidate cislunar shuttles (both chemical and nuclear propulsion), based upon the best available CLS configurational arrangement and structural design information, will add greatly to the fund of data required to significantly refine the current logistics operations plans. In addition, the results of such a study will undoubtedly establish new and/or modified design requirements for the CLS.

Propellant Module Design Concepts

One of the significant results of the OLS Phase A study program was the conclusion that a lunar orbiting propellant depot was not required to support the integrated lunar exploration program. The need for a propellant depot was avoided by the utilization of a propellant module for (1) transport of cryogenics to lunar orbit, and (2) transfer of cryogenics directly to the tugs and the OLS cryogenics tanks. The importance of cryogenics resupply in the overall logistics scheme is apparent from the realization that approximately 60 percent of the total payload delivered to lunar orbit is comprised of cryogenics, most of which are tug propellants. This percentage increases to approximately 69 percent if the propellant module weight is included.

The propellant module concept selected in the OLS study, required a module of approximately 77,000 pounds cryogenics capacity with the capability to transfer these cryogenics to other elements. Some type of self-contained positive expulsion device probably would provide the simplest means for transferring cryogenics, at least from an operational standpoint. Other means involving dynamic principles (module rotation) are potential viable options. Due to the major logistics role required of the propellant module (comparable to that played by the cislunar shuttle), it is recommended that a design and operations study be initiated to define and evaluate in more depth all technical aspects of a lunar program logistics propellant module. One option that should be considered is the possibility of oversizing the tanks of the CPS to carry OLS and tug cryogens.

Halo Orbits About the L_2 Libration Point

The work of Dr. R. W. Farquhar of the Goddard Space Flight Center has indicated several potential uses of the unique characteristics associated with the libration point on the earth-moon centerline that is beyond the moon (L_2). Recognizing the problems and limitations of placing elements at L_2 or attempting to maintain an element offset from L_2, Dr Farquhar has proposed orbiting this point in a halo orbit that is sufficient to provide continuous line-of-sight communications with earth. As mentioned previously in this report, this technique appears very attractive as a means to provide continuous communications capability with any point on the lunar surface via an earth link. Additional analyses including this technique are required to define the preferred lunar data relay satellite concept.

In NASA GSFC report X-551-70-449, December 1970, Dr. Farquhar further expanded the utilization of the halo orbit concept to provide a staging point for lunar logistics operations. Using his lunar flyby technique (use of the moon's gravitational force to assist in the retro maneuver of the cislunar shuttle) a preliminary analysis of just the affect on the payloads of the RNS shuttle model used in this study indicated that the usable payload in lunar orbit per RNS flight could be as high as 204,100 pounds, which is more than sufficient for two surface sorties per RNS resupply. The conventional TEI-LOI approach with the RNS delivered 161,500 pounds to lunar orbit permitting only one tug surface sortie per RNS resupply flight. It is recommended that additional studies including operational considerations and optimization of shuttle vehicles be conducted on the lunar resupply concept of using the L_2 halo orbit as a staging point.