LIBRARY REQUEST FORM

REQUESTED BY David L. Christensen, Research Institute, UAH P. O. Box 1247, Huntsville, Ala. 35807 MAIL ADDR. BL.

SOCIAL SECURITY NR. PHONE 895-6255 DATE 17 Feb. 1970

AUTHOR (S)

TITLE Summary of Tech. Studies ALSS Apollo Projects Support System

BOOK	MAGAZINE	REPORT
EDITION	MAGAZINE TITLE	REPORT NUMBER (S) X66-14502 CR-70599
PUBLISHER		
		ISSUING AGENCY (S) Boeing
CITY	VOL.	
DATE	PAGE THRU	DATE CONTRACT NR.
CALL NR.	DATE	CLASSIFICATION

Proprietary info

REFERENCE OBTAINED FROM

LIBRARY USE ONLY

L C CARD NR. QTY TO BE ORDERED UNIT PRICE

VENDOR CHECKED BY

626302 BSC

AMSMI-R-FORM 3, 1 APR 64

LIBRARY REQUEST FORM

REQUESTED BY Dave Akens MAIL ADDR. AATS-MS-H BL 4200

SOCIAL SECURITY NR. PHONE DATE

AUTHOR (S)

TITLE

BOOK	MAGAZINE	REPORT
EDITION	MAGAZINE TITLE	REPORT NUMBER (S)
PUBLISHER		
		ISSUING AGENCY (S)
CITY	VOL.	
DATE	PAGE THRU	DATE CONTRACT NR.
CALL NR.	DATE	CLASSIFICATION

III.4

REFERENCE OBTAINED FROM

LIBRARY USE ONLY

L C CARD NR. QTY TO BE ORDERED UNIT PRICE

VENDOR CHECKED BY

626302 BSC

AMSMI-R-FORM 3, 1 APR 64

BOEING D2-83001-1

Cy 1

APOLLO LOGISTICS SUPPORT SYSTEM (ALSS) PAYLOADS

X66-14502

NASA CR 70599

Proprietary Information

SUMMARY REPORT

D2-83001-1

III 4

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

Under

CONTRACT NAS 8-11411

[redacted]

June 1965

THE BOEING COMPANY
AERO-SPACE DIVISION
SEATTLE, WASHINGTON

APOLLO LOGISTICS SUPPORT SYSTEM
(ALSS)
PAYLOADS

SUMMARY OF DETAILED TECHNICAL REPORTS
D2-83001-1

PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
UNDER
CONTRACT NAS 8-11411

JUNE 1965

THE BOEING COMPANY
AERO-SPACE DIVISION
SEATTLE, WASHINGTON

FINAL REPORTS DOCUMENT TREE

- D2-83000-1 CONDENSED SUMMARY REPORT
  - D2-83001-1 SUMMARY OF DETAILED TECHNICAL REPORTS

DETAILED TECHNICAL REPORTS

SYSTEM SPECIFICATION AND DESCRIPTION

- D2-83101-1 SYSTEM SPECIFICATION
- D2-83102-1 SYSTEM DESCRIPTION
- D2-83103-1 OPERATIONAL PLAN

TECHNICAL ANALYSIS

SUBSYSTEM DESIGN ANALYSIS

- D2-83201-1 CONFIGURATION DESIGN AND INTEGRATION
- D2-83202-1 CABIN SYSTEMS - STRUCTURES & MECHANISMS
- D2-83202-2 CABIN SYSTEMS - CREW SYSTEMS
- D2-83202-3 CABIN SYSTEMS - THERMAL CONTROL
- D2-83202-4 ENVIRONMENTAL CONTROL SUBSYSTEM
- D2-83203-1 MOBILITY SYSTEMS-VEHICULAR
- D2-83203-2 MOBILITY SYSTEMS - CRYOGENIC
- D2-83204-1 POWER SYSTEMS
- D2-83205-1 ASTRIONIC SYSTEMS- NAVIGATION & GUIDANCE
- D2-83205-2 ASTRIONIC SYSTEMS- COMMUNICATIONS- COMMAND AND CONTROL
- D2-83205-3 ASTRIONIC SYSTEMS ELECTRONICS
- D2-83207-1 TIE DOWN AND UNLOADING
- D2-83208-1 GROUND SUPPORT EQUIPMENT (REQUIREMENTS FOR)

SYSTEM AND OPERATIONAL ANALYSIS

- D2-83211-1 FUNCTIONAL ANALYSIS
- D2-83212-1 RELIABILITY & CREW SAFETY
- D2-83213-1 OPERATIONS ANALYSIS

AES/LSSM ANALYSIS

- D2-83221-1 AES/LSSM ANALYSIS AND CONCEPTUAL DESIGN
- D2-83222-1 DESIGN SPECIFICATION - MOBILITY TEST ARTICLE (MTA - BLOCK 1)

RESEARCH AND ADVANCED TECHNOLOGY

- D2-83231-1 RESEARCH AND ADVANCED TECHNOLOGY

PRELIMINARY DEVELOPMENT PLANS

- D2-83301-1 MANAGEMENT PLANS — GENERAL
- D2-83301-2 MANAGEMENT PLANS — QUALITY ASSURANCE PLAN
- D2-83301-3 MANAGEMENT PLANS — RELIABILITY AND SAFETY PLAN
- D2-83301-4 MANAGEMENT PLAN — VALUE ENGINEERING
- D2-83302-1 DESIGN PLAN
- D2-83303-1 PROCUREMENT PLAN
- D2-83304-1 MANUFACTURING PLAN
- D2-83305-1 TEST PLAN
- D2-83306-1 CREW INTEGRATION PLAN
- D2-83307-1 OPERATIONS & LOGISTICS SUPPORT PLAN
- D2-83308-1 FACILITIES PLAN
- D2-83309-1 SCHEDULE AND MANPOWER PLAN
- D2-83310-1 COST PLAN
- D2-83311-1 TECHNICAL INTEGRATION

REFERENCE PRESENTATION DOCUMENTATION

SEPTEMBER 1964 INTERIM - D2-36072-1

JANUARY 1965 INTERIM - D2-36072-2

APRIL 1965 FINAL - D2-36072-3

PREFACE

This document is a Summary Report of the major tasks performed in a 9-month preliminary design study of Apollo Logistics Support System Payloads, with major attention on a Lunar Mobile Laboratory (MOLAB). The work reported herein includes the efforts of The Boeing Company and the following subcontractor team:

Garrett Corporation - AiResearch Division
General Motors Corporation - A. C. Spark Plug Division
General Motors Corporation - Defense Research Laboratories
Radio Corporation of America - Astro-Electronics Division

Also included in this document are highlights of additional studies conducted on the operations analysis and conceptual design of a Local Scientific Survey Module (LSSM), and a proposed design for a Mobility Test Article (MTA).

Details of the technical effort, a preliminary MOLAB development plan, and conclusions and recommendations are contained in the detailed technical reports identified in the Final Reports Document Tree, Page ii.

TABLE OF CONTENTS

PAGE

TABLES

1.0 INTRODUCTION

1.1 STUDY OBJECTIVES

This document summarizes work accomplished under NASA Contract NAS 8-11411 for Marshall Space Flight Center during the period of June 27, 1964 through March 27, 1965.

The objectives of the study were to:

- Prepare a preliminary design and specification for a Mobile Lunar Laboratory (MOLAB). The MOLAB is a lunar surface vehicle concept capable of supporting a two-man 14-day scientific mission on the lunar surface, and operating within a circular area of at least 80km radius of the landing point. The MOLAB is delivered to the lunar surface as an unmanned payload of a modified LEM Descent Stage (LEM Truck) of the Apollo Logistics Support System (ALSS). Subsequently, the MOLAB crew is transported to the lunar surface by the standard Apollo/LEM, and transfers to the MOLAB. At the conclusion of the scientific mission, the crew returns to Earth via the Apollo/LEM system.

- Prepare a resource analysis which identifies the manpower, dollars, time and facilities necessary for the design, development, construction, testing and delivery of five operational MOLAB vehicles and supporting equipment.

- Utilize existing and planned Apollo hardware to the extent possible.

- Prepare a new conceptual design of an Apollo Extension System (AES) payload for lunar surface exploration. The AES payload, delivered to the lunar surface by an unmanned modified LEM, consists of a LEM-Shelter, scientific equipment, and surface and/or flying mobility aids. The focus of the study effort is a lunar surface vehicle concept (surface mobility aid), the Lunar Scientific Survey Module (LSSM). The LSSM supports short duration manned reconnaissance sorties within an 8 km radius of the LEM-Shelter.

- Initiate the definition and design of a Block I Mobility Test Article (MTA). The MTA is an Earth-based mobility test bed of the selected lunar vehicle concept. The purpose of the MTA is to perform lunar-simulation steady-state mobility tests on Earth, including soft soil and obstacle negotiation tests. The MTA design consists of the MOLAB mobility elements, battery powered, with a minimum of control, display and communication equipment in order to approach the design mass goal of 1/6 of the MOLAB mass.

To accomplish these objectives, the following tasks were directed in Section 6 of the Statement of Work, as modified by MOLAB Notes:

6.1 Review of existing conceptual designs.
6.2 Perform new conceptual design (MOLAB).
6.3 Perform conceptual subsystems design (MOLAB).
6.4 Perform integration of subsystems into a total MOLAB design.
6.5 Perform supporting development (MOLAB).
6.6 Perform operations analysis (MOLAB).
6.7 Prepare specification (MOLAB).
6.8 Prepare program plans (MOLAB).
6.9 Conduct initial design of a Block I Mobility Test Article (MTA) in accordance with MOLAB Note 030.
6.10 Perform conceptual design of Lunar Shelter/Laboratory and Small Lunar Surface Vehicle (Modified by MOLAB Note 031).

The MOLAB study encompassed three major phases as indicated in Figure 1.1-1:

- Selection of mobility concept (Tasks 6.1 and 6.2).
- Development of subsystem design concepts and integration of the subsystems into the vehicle, including supporting subsystem development and performance of mission operation analysis (Tasks 6.3, 6.4, 6.5 and 6.6).
- Preparation of system specification, and preparation of plans for performing functional tasks and identification of resources required to perform these tasks (Tasks 6.7 and 6.8).

Tasks 6.9 and 6.10 were performed as separate studies using data generated in the basic study, where applicable.

MOLAB STUDY PHASES

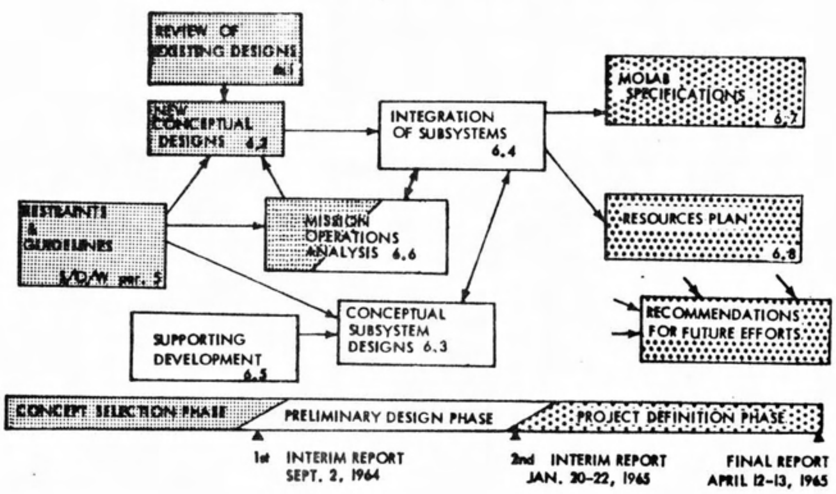


FIGURE 1.1-1

1.2 THE MOLAB CONCEPT

The MOLAB concept selected, shown in Figure 1.2-1, is a six-wheeled semiarticulated vehicle capable of traversing the lunar surface under the direct control of on-board crew members or by remote control from the Mission Control Center (MCC) at the Manned Spacecraft Center. It has the capability of supporting two astronauts for a two-week mission period with allowance for survival under emergency conditions for an additional week.

The MOLAB preliminary design that evolved during the study makes substantial use of developed Apollo components, especially in the environmental control, life support, and astrionic subsystems. In addition, a design goal was the application of state-of-the-art design technique and incorporation of developed design features. As a result of the above approach, a minimum of developmental effort is required to support the MOLAB development program.

MOLAB - BOEING MODEL 944-004

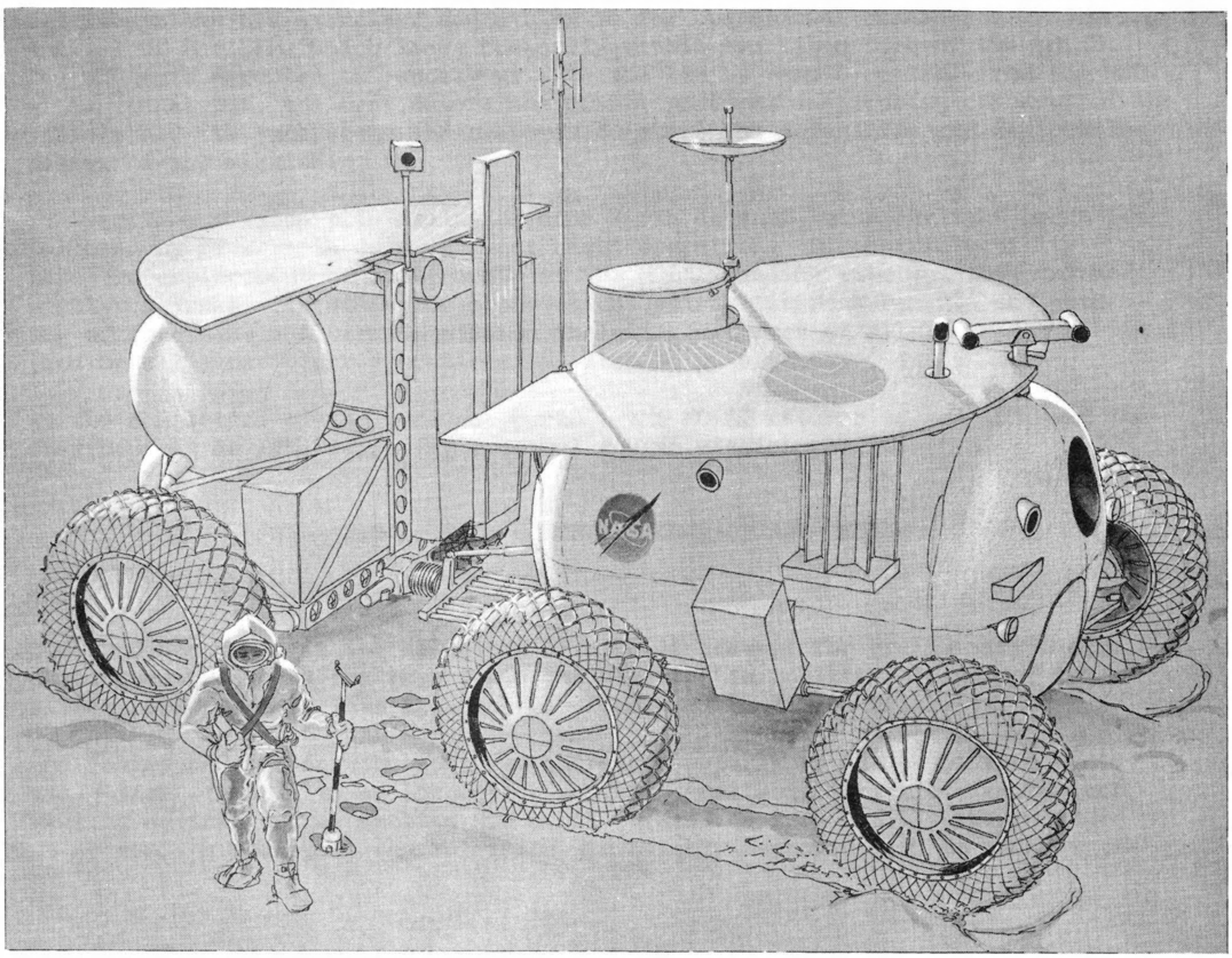


FIGURE 1.2-1

The baseline MOLAB mission plan requires a Saturn V launch of the MOLAB payload as part of an Apollo-LEM Truck spacecraft through Earth parking orbit into a lunar transfer trajectory. From this point, the Apollo Service Module provides propulsion for injection into a lunar parking orbit. The MOLAB-LEM Truck is separated from the Apollo CSM in lunar orbit and descends in an automated unmanned mode to a soft landing at the selected lunar landing site. The Command Module Crew, while in lunar orbit, monitors the MOLAB landing, performs reconnaissance and then, following a normal Apollo mission profile, returns to Earth.

After landing, MOLAB systems are activated and the vehicle is unloaded from the LEM Truck by remote command. Unloading may be accomplished in either a forward or aft direction relative to the MOLAB vehicle depending on the nature of the site as established through evaluation of TV imagery transmitted back to the MCC. During the unloading and parking operation, MOLAB subsystem operation is monitored through telemetry and evaluated at the MCC to verify system readiness. After unloading, the vehicle is parked and its subsystems are deactivated into a dormant storage mode for periods up to six months.

Prior to the launch of the MOLAB crew in a standard Apollo/LEM lunar landing spacecraft configuration, the MOLAB is activated from its storage condition and all subsystems are exercised and evaluated for operational readiness. Following arrival of the LEM, which lands nominally within two kilometers of the MOLAB, the MOLAB is directed to rendezvous with the LEM by remote control from the MCC. After rendezvous, the crew enters the MOLAB, performs engineering checkout of the vehicle and its subsystems and prepares to start the scientific and exploration phases of the mission.

The baseline mission plan calls for nine Earth days of lunar daylight operation followed by five Earth days of lunar night operation. Scientific activity involves emplacement of instruments at the MOLAB landing site and both day and night traverses with stops for observation, scientific measurements and gathering of specimens. Alternate mission including extremes of all lunar day operation or all lunar night operations may also be undertaken.

At the completion of the two-week period, the MOLAB returns to the LEM, and the crew departs in LEM, following a normal Apollo mission profile.

2.0 SYSTEM CONCEPT SELECTION AND DESIGN

2.1 CONCEPT SELECTION

The approach taken in the selection of a MOLAB concept for preliminary design development reflects the importance attached to the mobility aspects of total system performance. This approach is diagrammed in Figure 2.1-1.

The review of existing concepts was addressed chiefly to the comparison and evaluation of mobility or locomotion concepts. Although track configurations, walking devices, screw machine and multi-wheeled devices are all acknowledged as locomotion concepts, the selection was quickly narrowed down to wheel types

MOLAB CONCEPT SELECTION

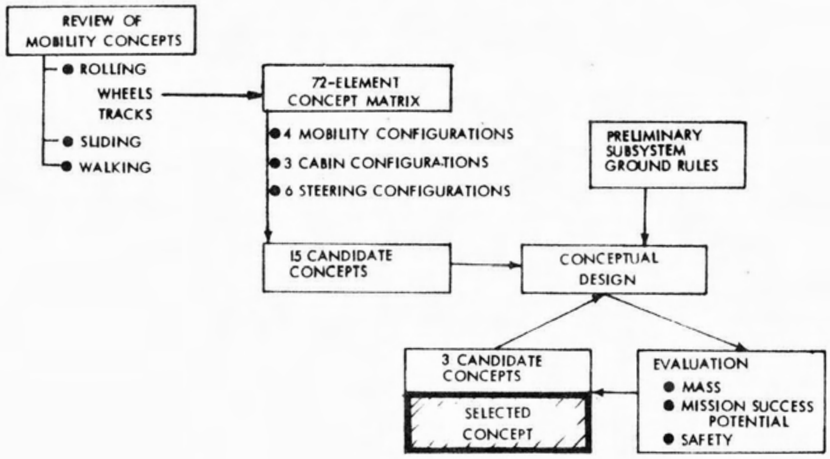


FIGURE 2.1-1

based on consideration of probable lunar surface characteristics and an assessment of power requirements and the hostility of the lunar environment to complicated linkages and sliding mechanisms.

Wheel types were then evaluated, and based on their significant draw-bar-pull-to weight (DP/W) advantage in granular soils, flexible wheels were selected in preference to rigid types. Since the DP/W ratio is only slightly improved in soft granular soils by adding more wheels, only 4- and 6-wheeled concepts were configured and analyzed.

To consider total MOLAB configuration approaches, a 72-element matrix was defined that combined three general types of cabin configuration (horizontal cylinder, vertical cylinder, and rectangular), six vehicle steering arrangements (single and double Ackermann, articulated and wagon) with each of four mobility configuration candidates (4-wheeled rigid and articulated, 6-wheeled semi-articulated and 6-wheeled fully articulated vehicles.) Preliminary screening of the matrix for internal contradictions, system complexity, and relative mass resulted in 15 feasible MOLAB concepts.

An iterative process of conceptual design and evaluation was the final step in concept selection. A uniform set of preliminary subsystem ground rules was formulated to help ensure that differences in evaluation parameters between the various configurations were representative of the concepts themselves, rather than the particular designs prepared in this study. In the first iteration, the 15 candidates were reduced to three on the basis of mass and system integration complexity evaluations. The choice of a selected concept resulted from a second iteration, with more detailed design definition of the three final candidates and refined evaluations of mission success and crew safety potential.

This second iteration included a failure mode analysis considering wheel drive failure, which indicated an advantage of the 6 x 6 mobility concepts. The advantages of the 6 x 6 articulated mobility concepts were further supported by assessing the obstacle crossing performance and locomotion efficiency in soft, undulating terrain.

The selected concept was a 6-wheeled semiarticulated vehicle with a horizontal cylindrical cabin.

2.2 DEVELOPMENT OF SYSTEM DESIGN

The approach taken in System Design was one of successive iteration through the sequence of requirements definition, design formulations and performance assessment, as illustrated in Figure 2.2-1.

DEVELOPMENT OF SYSTEM DESIGN

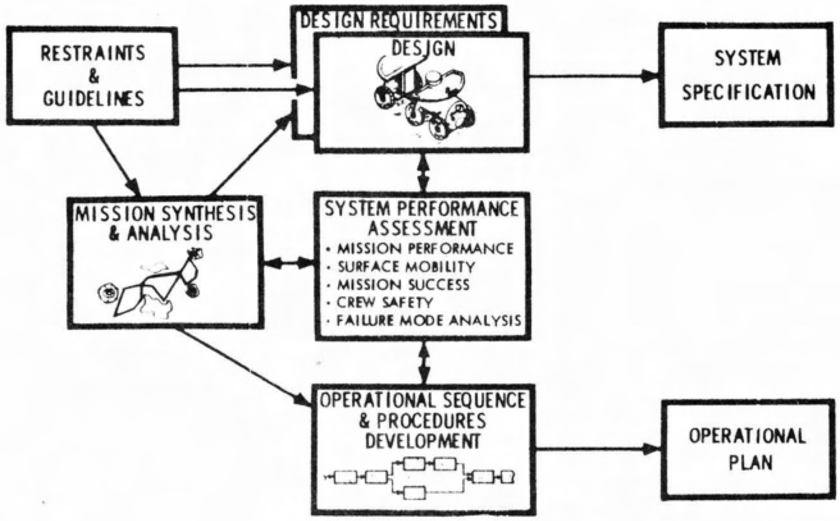


FIGURE 2.2-1

The mission operations analysis task was directed at the first and last of these considerations. Beginning with the formulation of a baseline MOLAB mission from the system and mission restraints and guidelines, initial system and subsystem design and performance requirements were established through system functional analysis. As the design definition progressed, the system performance assessment effort provided guidance for design optimization. In addition, baseline MOLAB performance data influenced the updating of mission analysis work and the study of mission variations.

Continuing baseline mission refinement included the analysis of operational procedures necessary to define an operational plan. This work was influenced both by the analysis and synthesis of mission objectives and requirements, and by the MOLAB baseline vehicle performance and design characteristics.

2.3 MOLAB DESIGN FEATURES

The MOLAB concept developed is a 6-wheeled semiarticulated configuration with a 4-wheeled Ackermann-steered forward unit (cabin) which houses the crew, and a 2-wheeled aft unit which supports major equipment items. The two units are connectioned by a flexible frame which provides pitch and roll freedom. Aft unit steering is accomplished through a hinged joint at the aft end of the flexible frame. All six wheels are individually powered and braked.

The cabin consists of an inner pressure shell and an outer shell. Passive thermal control is provided by surface coatings and by insulation between the two shells. Meteoroid protection is provided by the combination of the inner and outer shells and the insulation between them. The cabin is divided into a crew compartment and an airlock for crew ingress and egress. It houses the majority of operational subsystem equipment. The cabin also provides facilities for basic crew functions including food preparation, personal hygiene, sleeping and resting, and waste disposal.

The aft unit carries fuel cells, cryogenic tanks, core drill equipment, drive control electronics and a Lunar Flying Vehicle (LFV). Meteoroid protection is provided by individual shields as required.

This configuration, Boeing Model 944-004, is illustrated in Figure 2.3-1 deployed for the operational mode.

MOLAB - BOEING MODEL 944 - 004

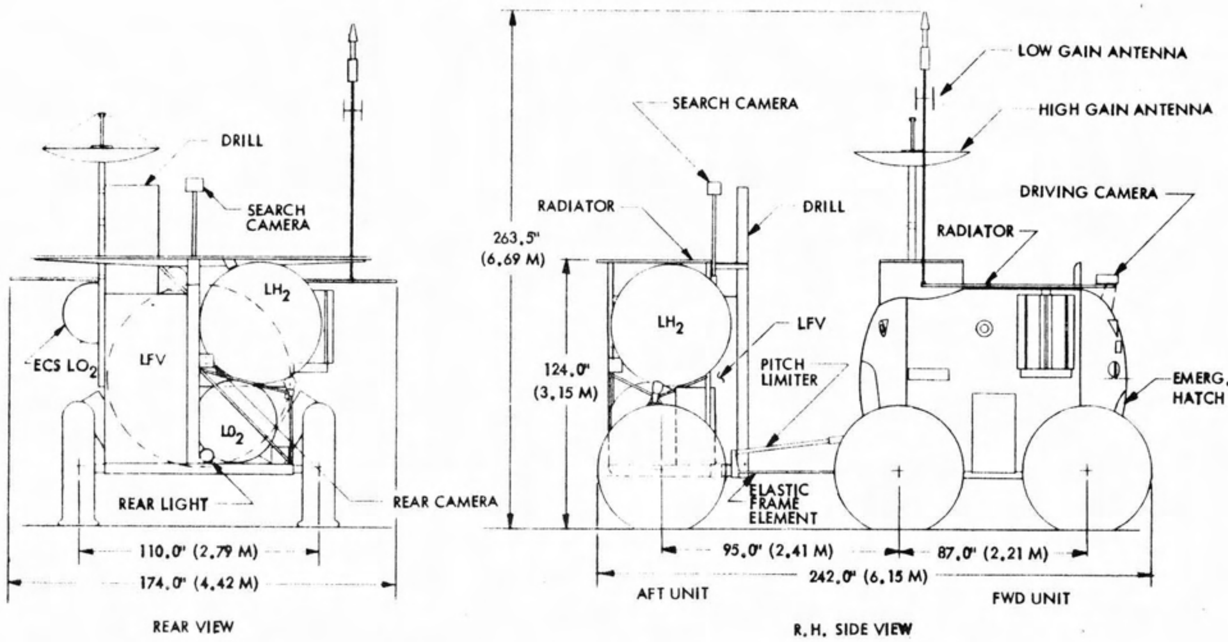


FIGURE 2.3-1

The performance summary is shown in Table 2.3-1 and the mass summary in Tables 2.3-2 and 2.3-3.

PERFORMANCE SUMMARY

RANGE (NOMINAL MISSION)		396 KM (INCL RESERVES)
DRAWBAR PULL/WEIGHT RATIO (K_ϕ = 0.5, n = 0.5 ϕ = 32°)		0.55
MAXIMUM VELOCITY	- LEVEL COMPACTED SOILS	16 KM/HR
	- MARIA	9.8 KM/HR
	- AT MINIMUM TURN RADIUS	10.8 KM/HR
MINIMUM TURNING RADIUS		7.2 M (23.5 FT.)
STATIC STABILITY	- SIDE SLOPE	42°
	- LONGITUDINAL SLOPE	57°
(1) LOCOMOTION ENERGY	- MARIA	0.34 KW-HR/KM
	- UPLANDS	0.39 KW-HR/KM
(2) OBSTACLE CAPABILITY	- STEP UP	194 CM (76.5 IN)
	- CREVICE WIDTH	194 CM (76.5 IN)
	STRADDLE HEIGHT-WIDTH	61 CM X 241 CM (24 IN X 95 IN)

(1) AVERAGE
(2) AT WORST AXLE LOADING

TABLE 2.3-1

PAYLOAD MASS SUMMARY

		(KG)	(LBM)
1.	CABIN SYSTEM	947	(2086)
2.	MOBILITY	825	(1813)
3.	POWER	292	(643)
4.	ASTRIONICS	210	(464)
5.	SCIENTIFIC EQUIPMENT	340	(750)
6.	UNLOADING & TIE-DOWN	126	(280)
7.	LUNAR FLYING VEHICLE (DRY) & SUPPORT EQUIPMENT	182	(400)
8.	MOLAB EXPENDABLES	526	(1160)
	Δ W FOR ITERATED GROSS WEIGHT ①	77	(170)
	TOTAL PAYLOAD MASS (WET) ②	3525	(7766)
	TARGET	2948	(6500)

① TO ADJUST GROSS WEIGHT SENSITIVE SUBSYSTEMS TO ACTUAL VEHICLE MASS.
② MOLAB WET, LFV DRY

TABLE 2.3-2

OPERATIONAL MASS SUMMARY

	KG	(LBM)
TOTAL PAYLOAD MASS (LESS LFV FUEL)	3525	(7766)
LFV FUEL	284	(626)
TOTAL MOLAB/LFV MASS	3809	(8392)
SCIENTIFIC EQUIPMENT EXCLUDED ①	-23	(-50)
DEPLOYMENT & TIE-DOWN SYSTEM EXCLUDED	-126	(-280)
TOTAL UNMANNED VEHICLE AT DEPLOYMENT	3660	(8062)
SUITED CREW WITH BACKPACKS	227	(500)
SPARE PRESSURE SUITS ②	27	(60)
FOOD ②	25	(56)
HYDROGEN BOIL-OFF ③	-20	(-44)
TOTAL MOLAB MASS AT START OF LUNAR TRAVERSE	3919	(8634)

① EQUIPMENT LEFT AT LEM/TRUCK LANDING SITE
② CARRIED ABOARD MANNED LEM
③ AFTER 6 MONTHS STORAGE

TABLE 2.3-3

3.0 MOLAB DESIGN AND INTEGRATION

Following selection of the MOLAB concept and a selection of baseline subsystem concepts, a functional analysis was conducted in order to define system and subsystem interfaces and design requirements. This early analysis focused attention on the fundamental mission objectives and requirements of the MOLAB mission, and provided the basis for an orderly establishment of specific subsystem criteria. Additional factors considered in subsystem design evolution included system reliability, crew safety, weight, technological risk, cost, simplicity and human factors. Major consideration was given to the application of hardware currently available or under development, especially that hardware being developed for the Apollo and Gemini Programs.

3.1 DESIGN APPROACH

3.1.1 System Functional Requirements

A principal constraint on system design is the specification of the Saturn V launch vehicle and a modified Apollo/LEM spacecraft as the lunar surface payload delivery system. The spacecraft adapter section of the launch vehicle establishes the volumetric packaging constraints. Figure 3.1-1 shows the MOLAB within that envelope.

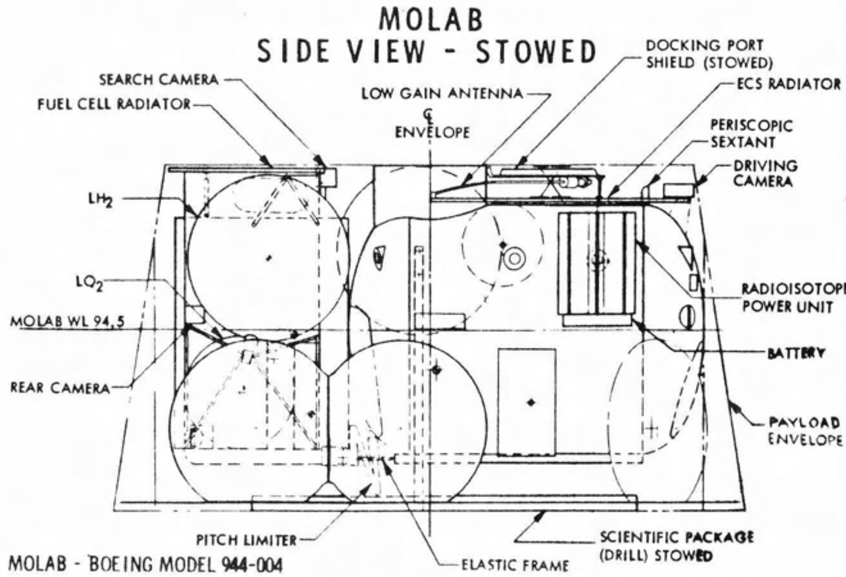


FIGURE 3.1-1

The modified LEM descent stage imposes the constraint of permissable mass. Although the mass target of 2948 kg was not attainable without penalizing the mission, system masses were held within range of the capability of the payload delivery system.

Key mission performance constraints include provision for up to six months unattended storage subsequent to delivery and prior to the manned mission; provision for both manned and unmanned unloading and operation during lunar day and lunar night conditions; and the provision for a two-man, 14-day mission characterized by traverses of several hundred kilometers with frequent extravehicular astronaut activity.

Specific design and performance constraints established by NASA include the provision for carrying a Lunar Flying Vehicle as an auxiliary mobility device; the use of H_2-O_2 fuel cells for primary power generation; and the provision for a 340 kg inventory of scientific equipment, including a 30-meter drill.

Implicit throughout the design guidelines was the goal to provide compatibility with the Apollo communications and command and control facilities, and to make maximum use of Apollo developments wherever possible.

Analysis of the MOLAB mission has led to the definition of requirements for each phase of the mission. The significant phases are: storage, activation and checkout, remote driving and manned operation. Within these phases, the following paragraphs describe significant functional sub-phase considerations.

Table 3.1-1 summarizes the critical performance requirements for survival in the lunar environment during the lunar storage period. Specific functions are identified that are pertinent to the subsystem definition and the specific requirements identified. Control of equipment temperature, protection against damage by meteoroids, maintenance of minimal internal atmospheric pressure and long term cryogenic storage are key functions required during the 6-month storage period to prevent degradation of the MOLAB and its ability to perform the planned mission.

CRITICAL PERFORMANCE REQUIREMENTS

SURVIVE LUNAR ENVIRONMENT

STORAGE

FUNCTION	MECHANIZATION	REQUIREMENT	BASIS FOR REQUIREMENT
PROVIDE TEMP CONTROL	HEAT FROM RPU ACTIVE ECS COOLING SYSTEM PASSIVE THERMAL CONTROL	ELECTRONICS (+40°F)-(+140°F) FUEL CELL (-40°F) - (+250°F) BATTERY (+40° F) - (+120° F)	EQUIPMENT REQUIREMENTS
PROVIDE METEOROID PROTECTION	METEOROID SHIELD PLUS PRESSURE SHELL	99% PROBABILITY OF SURVIVAL WITH 80% CONFIDENCE	ANNEX H OF SOW AS MODIFIED BY MOLAB NOTES 9 AND 11.
PROVIDE CABIN PRESSURE	ECS SUBSYSTEM	0.2 PSIA	EFFECT OF LONG TERM HARD VACUUM ON MATERIALS AVOID CORONA DISCHARGE
PROVIDE LONG TERM CRYOGENIC STORAGE	CRYOGENIC TANKS	6 MONTHS STORAGE UNDER LUNAR SURFACE CONDITIONS	MOLAB MISSION PLAN

TABLE 3.1-1

Table 3.1-2 summarizes the critical performance requirements for verification of system readiness. Measurement of subsystem status, conversion and processing of data, downlink communication, decoding and routing of commands are key functions in the verification sequence.

CRITICAL PERFORMANCE REQUIREMENTS
VERIFY SYSTEM READINESS

FUNCTION	MECHANIZATION	REQUIREMENT	BASIS FOR REQUIREMENTS
MEASURE SUBSYSTEM RESPONSES	TRANSDUCERS AND SIGNAL CONDITIONERS	OUTPUTS ANALOG - 0-40 MV, O-5V DIGITAL - PARALLEL & SERIAL	COMPATIBILITY WITH TELEMETRY SUBSYSTEM
CONVERT & PROCESS DATA	PCMTE SUBSYSTEM	51.2 KB/SEC DATA RATE (24 KB/SEC RQMT IDENTIFIED)	VOLUME OF DATA REQUIRED PLUS GROWTH (BASED ON MANNED OPERATION)
DOWNLINK COMMUNI - CATION	S-BAND WITH DIRECTIONAL ANTENNA	500 KC	TV-TM MULTIPLEX
DECODE & ROUTE COMMANDS	COMMAND AND CONTROL SUBSYSTEM	3 LEVELS OF VERIFICATION	MINIMIZE HAZARDS FROM COMMAND ERROR

TABLE 3.1-2

Remote driving of the MOLAB is accomplished through control of the mobility subsystems from the Mission Control Center. Critical functions involved in remote controlled closure of the MOLAB on the LEM include: sensing of obstacles; determination of azimuth; downlink communication; and decoding, routing, and execution of velocity and heading commands. The resulting critical performance requirements are shown in Table 3.1-3.

CRITICAL PERFORMANCE REQUIREMENTS
REMOTE DRIVING - CLOSURE ON LEM

FUNCTION	MECHANIZATION	REQUIREMENT	BASIS FOR REQUIREMENT
SENSE OBSTACLES	STEREO TV	DETECT AT 10M 0.25 M. BUMPS 1.0M HOLES	SAFE STOPS AT 5.0 KM/HR.
DETERMINE POSITION AND AZIMUTH	DSIF TRACKING	INITIAL POSITION 400 X 2800 M.	AVAILABLE WITH RANGE CODE
	DEAD RECKONING	ACCURACY 1.0%	ACCURACY REQD FOR MANNED TRAVERSE
	VHF RDF	2.0 KM RANGE	ADEQUATE FOR FINAL CLOSURE
	SEARCH TV-STAR	± 1.0 DEGREES	ADEQUATE FOR 10 KM TRAVERSE
DOWNLINK COMMUNI - CATION	DIRECTIONAL ANT WITH S-BAND	500 KC	TV RESOLUTION TV-TM MULTIPLEX
VELOCITY & HEADING			
DECODE AND ROUTE CMMDS	C&C SUBSYSTEM	CONFIRM BY PERFECT SUB-BIT MATCH	RISK REDUCTION
EXECUTE COMMANDS	CLOSED LOOP DRIVE CONTROLLER SUBSYSTEM	MINIMIZE DELAY CORRECTING PERTURBATIONS	6.0 SEC. TOTAL 2 WAY RESPONSE TIME

TABLE 3.1-3

Critical functions identified for the provision of habitable environment are: conditioning of cabin atmosphere, provision of pressure suit atmosphere, passive temperature control of cabin, and meteoroid protection. Table 3.1-4 lists the critical performance requirements established from the functional analysis.

CRITICAL PERFORMANCE REQUIREMENTS
PROVIDE HABITABLE ENVIRONMENT

FUNCTION	MECHANIZATION	REQUIREMENT	BASIS FOR REQUIREMENT
PROVIDE CONDITIONED CABIN ATMOSPHERE	ECS SUBSYSTEM	75 ± 10° F TEMP 5.0 PSI PURE O_2 CO_2 P.P. BELOW 8 mm Hg REL. HUMID 50% ± 20%	CREW METABOLIC REQTS AND COMFORT MINIMIZE LEAK RATE AND CABIN & TANKAGE WEIGHT
PROVIDE PRESSURE SUIT ATMOSPHERE	SUIT LOOP ECS SUBSYSTEM	SAME AS CABIN	PROVIDE FOR PRESSURE SUIT OPERATION WITHOUT PORTABLE L.S.S.
PROVIDE PASSIVE TEMPERATURE CONTROL	PROTECTIVE COATINGS INSULATION	75° ± F TEMP	MINIMIZE ECS COOLING SUBSYSTEM WEIGHT
PROVIDE METEOROID PROTECTION	METEOROID SHIELD PLUS PRESSURE SHELL	SURVIVE ENVT SPECIFIED IN ANNEX H OF SOW AND MOLAB NOTES 9 AND 11	BASED ON STORAGE PERIOD REQUIREMENTS

TABLE 3.1-4

The function of the MOLAB mobility system is to provide a mobile platform capable of negotiating the postulated soils, slopes, and obstalces in the lunar environment with maximum safety and without undue discomfort to the crew or damage to the equipment. The evaluation of mobility performance in soft soils was based on analytical and experimental methods developed by Dr. M. G. Bekker of GM DRL for the purpose of evaluating vehicle/terrain systems in off-the-road locomotion. Mobility analyses were based on the requirements defined by surface characteristics described in Annex A, Engineering Lunar Model Surface (ELMS), and Annex G, Obstacle Criteria, of the Statement of Work.

3.1.2 Subsystem Design Development

The general approach for integrating the subsystem design into the overall system design is depicted in Figure 3.1-2. As discussed in previous paragraphs, subsystem restraints and guidelines were delineated and analyzed through a complete system functional analysis in conjuction with the development of the general configuration of the vehicle. Tasks were identified and defined as the basic trade studies necessary to define detailed subsystem requirements. Maximum application was made of study reports in allied areas made available by NASA. Also, an informal data exchange was established with MSFC specialists to permit MSFC participation in trade study reviews. As the trade studies evolved, conceptual subsystem requirements and designs were developed.

SUBSYSTEM DESIGN

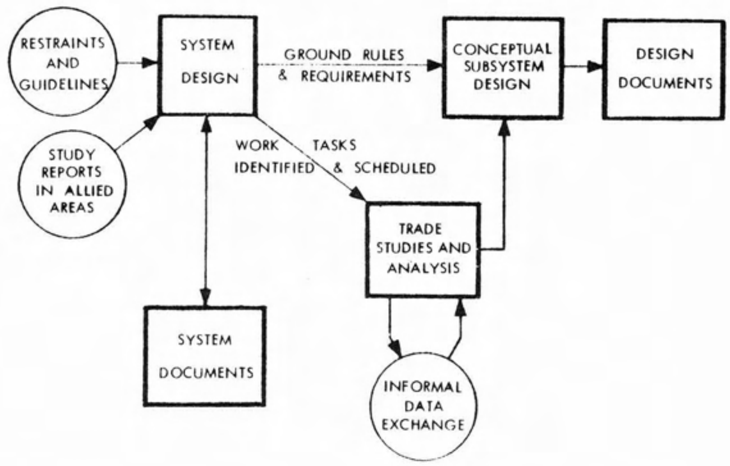


FIGURE 3.1-2

3.2 CABIN SYSTEMS

3.2.1 MOLAB Structure

The MOLAB structure as discussed in this section includes the primary and secondary structure of the forward unit cabin and associated equipment supports and the aft unit structure above the chassis frame.

The primary function of the cabin structural system is to: contain the necessary atmosphere for the crew, provide insulation against both heat and cold, support internal and external equipment, transmit loads from the mobility system into the cabin structure, provide continuity of structure during transit to and for landing on the lunar surface, provide means for egress and ingress, and provide vision for the crew. The primary function of the aft unit structure is to provide support for the equipment and attachment to the mobility system. The structure is designed to satisfy the specific requirements of thermal and meteoroid protection, pressure, vibration, and loads resulting from launch, midcourse correction, lunar landing, and lunar surface traverse accelerations.

3.2.1.1 Studies

The development of the structural configuration resulted from design layout and analytical studies. The analytical studies were primarily concerned with: derivation of detail structural criteria; stress and thermal analyses on the cabin pressurized shell, insulation and exterior skin, and typical attachments for equipment and the mobility subsystem; dynamic analyses to determine response spectral densities; radiation analyses for local shielding requirements; and evaluation and selection of structural materials.

Weight trade layouts and analyses were made on such specific items as windows, hatches, bulkhead location, and attachments to interfacing subsystems, particularly the mobility and tie-down subsystems.

3.2.1.2 Structure Description

The cabin portion of the forward unit, Figure 3.2-1, is a two-compartment horizontal cylinder with elliptical dome ends. It is the pressure vessel within which the astronauts operate in a shirt sleeve environment. The cabin wall structure consists of a primary pressure shell outside of which are layers of glasswool and superinsulation and an outer non-structural shell. Passive thermal control is provided by an outer surface coating with a low absorptance to emittance ratio and the superinsulation. Meteoroid protection is afforded by the outer, thin "bumper", the glasswool filled space and the inner pressure shell.

CABIN STRUCTURE

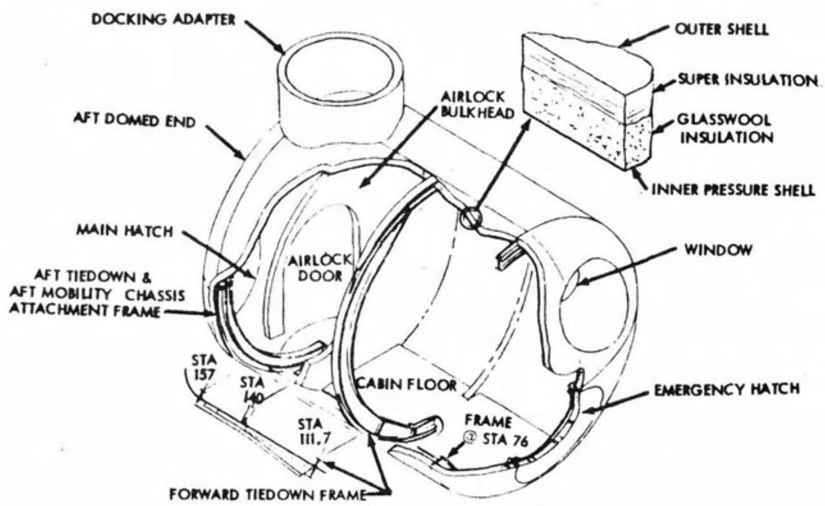


FIGURE 3.2-1

The MOLAB cabin contains approximately 8.2 cubic meters (290 cubic feet) total internal volume and is arranged with a flat bulkhead separating the crew compartment and airlock. The airlock located at the aft end of the horizontal cylinder consists of approximately 2.26 cubic meters (80 cubic feet). The main entry hatch is located in the aft end dome and an emergency hatch is located in the forward end dome.

The cylindrical shell, end domes, circumferential rings for dome and airlock bulkhead attachment, hatch and window reinforcement, and local hard point attachments constitute a 2219 aluminum pressure section. The airlock bulkhead is of honeycomb construction and is located to distribute part of the docking adapter loads to the shell structure. The hatch in the airlock bulkhead is silicone and rubber impregnated dacron cloth, with an environmental-barrier type zipper molded to shape.

The aft unit structure, Figure 3.2-2, is a lightweight flat bed chassis frame with a center truss to which is attached the radiator support beams. Tubular elements provide lateral support to the vertical truss and the hydrogen tank.

AFT UNIT STRUCTURE

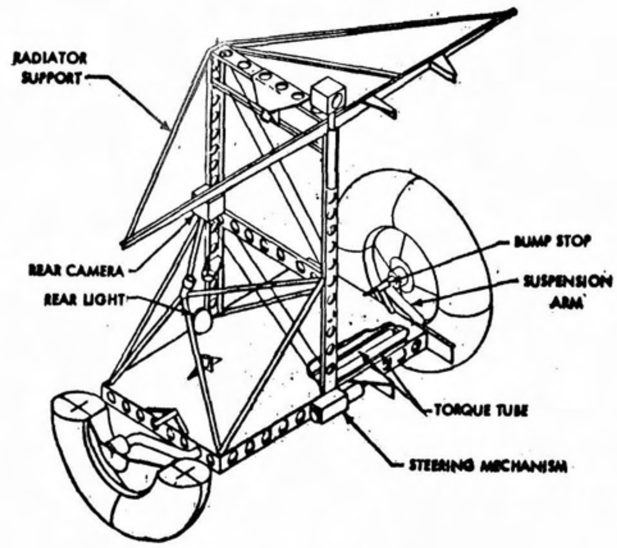


FIGURE 3.2-2

The structural subsystem will not require additional basic research. Routine design and test development will generally be required; specifically, however, emphasis on hatch and seal, lubrication and mechanisms, and thermal coatings will be necessary. Instigation of development on these specific items prior to the hardware acquisition phase would improve the confidence of producing structure with integrity at minimum cost and mass.

3.2.2 Cabin Arrangement and Crew Accommodations

The MOLAB cabin, which includes the crew accommodation provisions, life support system, and subsystem components, is arranged to provide for maximum utilization of the available space and volume. To accomplish an optimum cabin arrangement, the major guidelines considered were minimum space requirements for crew seats and restraints; redundant usage of space, work areas, and equipment; and close proximity of related or interdependent subsystem components.

The primary objective in the design and arrangement of the cabin interior was for shirt-sleeve operation with the pressure suited requirements as an emergency mode only.

Restraint and support is required at both seats to support the crewman during the lunar traverse maneuvers and provide adequate protection against the acceleration vectors.

3.2.2.1 Studies

Cabin interior configuration and arrangement studies, which included various sizes and shapes of airlocks, location of major components, and sizes, shapes, and location of hatches, were accomplished. Using a full scale wooden mockup, ingress, egress and compartment interior arrangement evaluations were conducted with subject in shirt-sleeve and in pressurized spacesuits.

Design studies of various seating arrangements and seat/restraint configurations were performed before the seat and harness concept was determined to be acceptable. Conventional fixed seats do not permit an efficient use of the limited cabin volume because of the space they require.

3.2.2.2 Description

The airlock will accommodate two crewmen in pressure suits and portable life support systems and provides, in an emergency mode, sufficient free space to allow both crewmen to don their pressure suits. The crew compartment incorporates side-by-side seating with the driving station and command console on the left side and observer's station on the right.

The two crew members are supported and restrained at their primary duty stations by dual restraint straps installed at each crew position between floor and ceiling in a manner to provide back support at an angle of approximately 0.17 radians (10 degrees). Lap belts and shoulder harnesses are attached for body restraint. A fabric material or netting is sewn between each set of harnesses and will conform to the back contour. The incorporation of a rigid seat with the harness system provides a seat which can be used with or without the body restraint straps. When using the seat without body restraint, the crewman is able to lean forward and to the side or stand easily. Seat adjustment to accommodate from a 5th to a 95th percentile man is provided at the MOLAB driver's position only.

The harness system concept was selected in preference to a conventional seat to reduce weight and for more efficient utilization of space. With the use of quick disconnect type fittings, the MOLAB driver's harness system may be removed and the seat pan rotated to its stowed position. This space is then made available for standing, donning or doffing suits, access to surrounding equipment, or for stowing equipment.

The right side of the cabin, Figure 3.2-3, includes the observer's station with a worktable located in front of the crewman's seat. The observer's seat is primarily a cabinet in which the urine storage tank, personal equipment, tape recorder, and film storage are located. Provisions for the installation of the periscopic sextant are in the ceiling between the crewmen. The sextant will normally be stowed elsewhere when not in use. Other cabinets and subsystem equipment such as communications, power distribution unit, and scientific equipment storage are located on the side wall to allow maximum usable floor areas. A fold-down seat which is also used as a toilet facility is installed on the side wall. The sleeping accommodations are two stowable hammocks which are installed, extending through the center bulkhead hatchway.

The left side of the cabin, Figure 3.2-4, includes the driver's station with display and control panels arranged directly forward of the seated position. The manual driving controller is positioned on the left-hand console at normal armrest height and location. The environmental control system, which includes, for emergency use, several manually operated controls, is located behind the left console to keep the lengths of control runs to a minimum. The storage area behind the driver's station also includes the reserve water tank, a cabinet for stowing the folded spare pressure suit after each drying, the two portable life support systems, and the coordinate heading platform. A folding seat is provided in the airlock for use when donning a pressure suit.

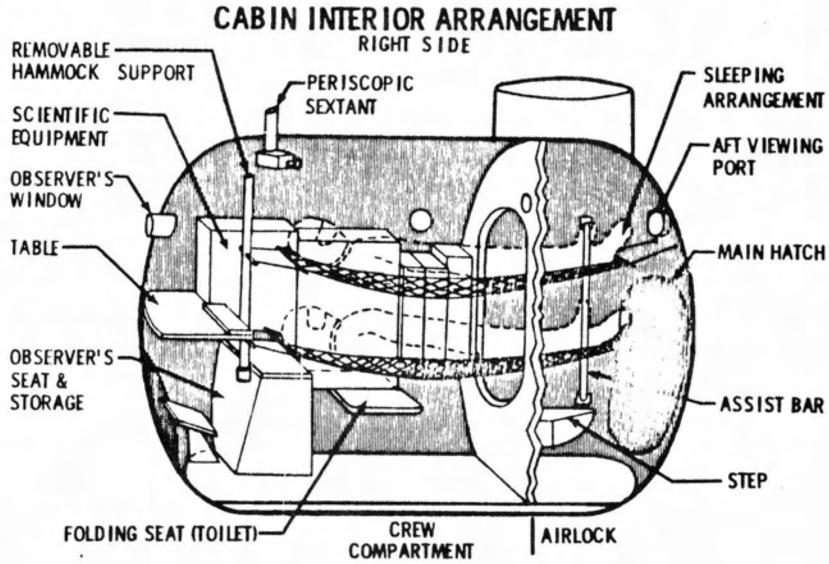


FIGURE 3.2-3

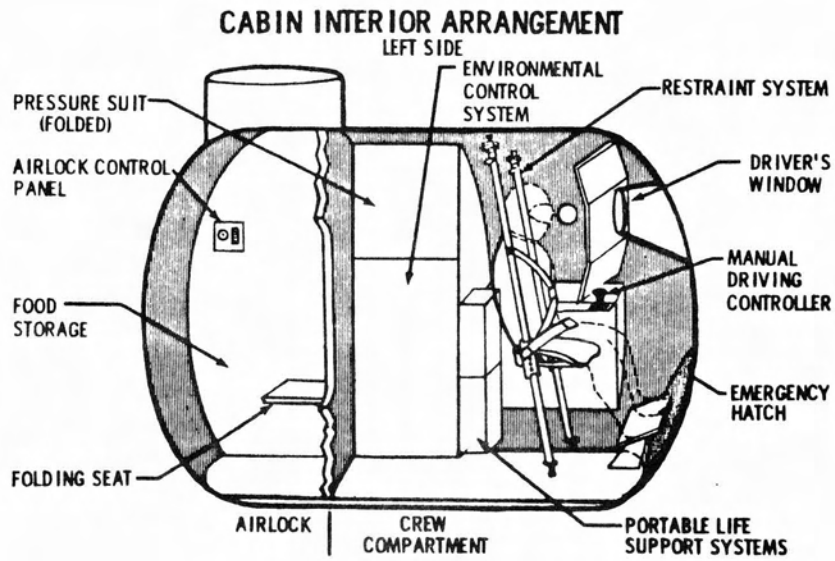


FIGURE 3.2-4

3.2.3 Vision Capabilities

External vision provisions include a driver's window, an observer's port and vision ports on the left-hand side, right-hand side and rear of the cabin. A viewing port is also provided in the airlock bulkhead.

3.2.3.1 Studies

Studies conducted investigated window sizes and locations, and considered approaches such as fiber optic viewing ports and multiple lens optic systems. From the standpoint of weight, complexity, meteoroid protection, thermal effects, light transmission and field of view, the configuration described in 3.2.3.2 below was chosen.

3.2.3.2 Description

The driver's window is 0.41 meter (16 inches) in diameter and is recessed in a conical structural section in the forward dome. From the normal eye position, a 0.68 radian (40 degree) conical field of view is available. The observer's window is a 10 cm (4.0 inch) diameter viewing port located forward of the observer and provides a view from the seated position. By moving the eye closer up, down or to the side, the total viewing angle for either window is increased. Side and rear vision is obtained by the use of similar viewing ports located on each side of the crew compartment and in the aft dome above the main hatch.

The windows and viewing ports are designed as multipane assemblies with a fused silica glass outer panel for meteoroid shielding and thermal insulation, and laminated inner panes of fully-tempered alumino-silicate glass. The inner laminated panes are pressure sealed such that a positive seal is maintained if either of the laminates is broken. For the viewing port assemblies, that segment of the tubular housing extending outside the cabin pressure shell will be of non-metallic material to reduce conduction of heat.

During the storage period and when external vision is not required, the viewing ports and windows will be covered with external manually removable plug-type covers.

3.2.4 Displays and Controls

Essential displays and controls are segregated according to function, and presented to the driver to allow complete MOLAB operation by one astronaut. Priority of display and control location is determined by space availability, functional reach, vision and multiple crew use. The panel lighting concept utilizes flood lights with individual lights for push button switch function and malfunction indications. The television monitor, communications panels, and camera controls are located between the driver and observer to provide access to both crew members.

3.2.4.1 Studies

Evaluation was made to determine the degree of override control required on the display and control panels based on subsystem failure modes and effects analyses. The panel configuration is conservative in display and switching function provisions as redundancy is provided by telemetry and Earth control on all subsystems.

3.2.4.2 Description

Display and control priorities have established a grouping concept under the general headings of navigation and guidance, locomotion (or driving), communications, environmental control, and electrical power.

Navigation and guidance displays and controls have been located above, below and to the left of the driver's window to provide an easy means of relating such data with the external terrain. These include the guidance alignment and navigation control panels on the lower forward console, the combined directional gyro/RDF displays on the upper forward console and the velocity and elapsed time indicators on the forward instrument panel.

The primary environmental control and electrical power displays and controls have been located in an operational format to maintain interface relationship of subsystems and provide ready access for override control under out-of-tolerance operating conditions.

Driving controls have been located forward of the manual drive controller for ease of access to control functions and for display of turn indication near the driver's window.

The manual drive controller, located at the MOLAB driver's left hand, incorporates power, brakes, and turn control functions as well as switching operations for reverse and skid steering. Actuation of the skid steering switch provides emergency steering by applying brakes to all wheels on one side of the vehicle and power applied to all wheels on the opposite side.

Multiple selection displays have been incorporated in the interest of weight saving and panel space economy. Lighted push-buttons for timed operational sequencing have been used and due to their recessed nature eliminate inadvertent operation.

3.2.5 Environmental Control Subsystem

The environmental control subsystem provides atmosphere control and thermal control for the cabin and thermal control for elements of the aft unit.

Cabin ECS

A 100 percent pure oxygen atmosphere is controlled to a nominal pressure of 3.45 N/cm^2 abs (5.0 psia) during the manned mode of operation except that during airlock depressurization the crew compartment pressure does not exceed 5.03 N/cm^2 abs (7.3 psia). A nominal pressure of 0.138 N/cm^2 abs (0.2 psia) is maintained in the cabin during the storage mode. It is anticipated that long term storage (6 months) at a low pressure of 0.138 N/cm^2 abs (0.2 psia) will:

- Prevent long term material degradation which might result from such exposure to a hard vacuum.
- Give greater latitude in material selection.
- Ease the problem of qualification testing for storage.
- Permit greater utilization of Apollo components.

Carbon dioxide partial pressure is maintained below 0.107 N/cm^2 abs (8.0 mm Hg absolute) while the relative humidity in the cabin is controlled to 50 ± 20%. Trace contaminants are maintained at safe levels. These safe levels are tentatively set for each contaminant at one-fifth of industrial threshold limit values.

The cabin thermal control element maintains the cabin atmosphere temperature between 292°K and 303°K (525°R and 545°R) during the manned mode of operation. Equipment temperature is maintained between 278°K and 333°K (500°R and 600°R) during both the storage and manned modes.

Aft Unit Thermal Control

During fuel cell operation:

- A fluid coolant is provided to maintain required fuel cell temperatures below 366°K (660°R).
- Fuel cell reactants temperature are controlled within 255°K and 366°K (460°R and 660°R).
- A heat exchanger is provided with temperature capability for condensing and collecting water from the fuel cell. The drive controller-inverter temperature is maintained between 278°K and 333°K (500°R and 600°R) during operation.

Temperatures within the fuel cell-drive controller compartment is maintained within 249°K to 366°K (440°R to 660°R) during the storage mode.

3.2.5.1 Analysis

Due to extreme temperatures of the lunar environment, emphasis was placed on determination of the heat transfer through the cabin walls. A thermal analysis conducted on the cabin configuration, using a specially programmed computer, determined the heat flux through all known cabin penetrations and structure and component supports. The total heat flux as well as the cumulative transferred heat for the vehicle parallel to the ecliptic plane and facing east is shown on Figure 3.2-5. Except for solar radiation transmitted through the forward window, the results are not significantly different for other vehicle orientations.

The analysis assumed the vehicle is located with a 0.192 radian (11°) hill on either side of the vehicle. Further analysis would be required to determine the heat flux if other lunar terrain conditions are assumed. The internal cabin wall temperatures ranged from 288°K (518°R) at lunar night to 300°K (540°R) during the lunar noon period with normal heating and cooling except the inner window surface temperature which was 276°K (497°R) during the lunar night. The steady state internal temperature dropped to 104°K (187°R) without heating during the lunar night, and rose to 317°K (571°R) without cooling during the lunar day. The analysis revealed that only 15 watts cooling was required during the lunar day and 114 watts heating during the lunar night to maintain a 297°K (+75°F) cabin temperature during the manned operation mode.

In addition to the cabin heat leak, the normal mode of operation is characterized by various degrees of activity of the crew and various rates of power usage which combine with the external thermal conditions to create a wide variation in heat loads for the ECS to manage. A further capability which greatly exceeds other space vehicle requirements is the conservation of oxygen during a great number of entries and egresses from the vehicle. As indicated by the activity profile, 36 depressurizations of the airlock are required.

In contrast with the Gemini and Apollo systems, the dominant mode of activity of the crew will be in a shirt-sleeve environment rather than in pressurized suits. Only during extravehicular activities and emergencies will the Apollo suits be used. Therefore, an efficient ECS for both shirt-sleeve and suited operation is required.

Because of the relationship of the MOLAB Program to the Apollo and LEM Programs, a maximum use of Apollo and LEM components is desired. New components, or modified Apollo components, are employed only where analysis showed significant weight savings could be achieved. Over 50 percent of the ECS components are existing Apollo units.

CABIN WALL HEAT FLUX

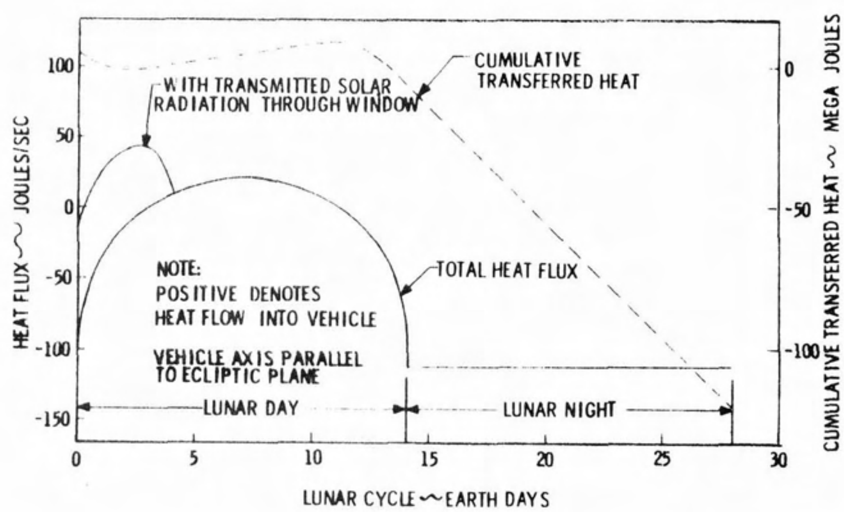


FIGURE 3.2-5

3.2.5.2 System Description

A combination of passive and active thermal control provisions are used to maintain MOLAB cabin and aft unit elements within required temperature limits.

Passive provisions include such items as insulation, low conductance structural connections and spectrally selective thermal coatings. These passive provisions are effectively used to reduce the heat transfer rate to (or from) temperature critical elements from (or to) the lunar environment.

The active fluid transport circuit rejects heat through the horizontal radiators plus water boilers when required. Heat is added in the cabin by the heat transport circuit by picking up heat radiated from the radioisotope power unit by means of a radiant heat receiver. A small electric heater provides heat to the fuel cell-drive controller compartment when required.

Cabin ECS

The system for providing control of the internal environment of the MOLAB cabin is as follows:

- The Suit Loop provides the atmosphere processing to permit the crew to be pressurized whether the cabin is pressurized or depressurized. CO_2, humidity, and trace contamination control are provided for the cabin as well as for spacesuit operation inside the vehicle. Lithium hydroxide has been selected for CO_2 control because of its simplicity and proven reliability.

- Cabin Temperature Control is provided by a heat exchanger plus an Apollo fan, with a redundant heat exchanger-fan provided in the airlock. The heat exchangers, arranged in parallel with the suit heat exchanger, will also control humidity, and will utilize lunar gravity for moisture separation.

- Cabin Pressure Control utilizes a suit demand pressure regulator, a cabin demand pressure regulator, and a flood valve. In addition, a remote-control shut-off valve and low pressure control valve are inserted in the oxygen supply line for the storage mode pressure regulation. Cabin and airlock pressure relief valves are provided.

- Airlock Depressurization is provided by a small high-speed vane pump which pumps 80% of the airlock oxygen into the crew compartment. Currently available pumps operate at speeds up to 20,000 rpm, indicating a small, lightweight unit for this application.

- The Cabin Fluid Heat Transport Loop utilizes a mixture (approximately eutectic) of ethylene glycol and water to transfer the suit loop, cabin, and electronic heat loads to the radiator, or water boiler heat sink. An arrangement of valves and bypasses also permits simultaneous cabin heating and dehumidification for the lunar night condition. The effects of fluid freezing or overheating on the ECS is avoided by the use of a radiator area selector valve. When cabin heating is required, part of the heat transport fluid flow is bypassed through the isotope heater and on into the cabin heat exchanger. The remaining flow passes into the suit loop heat exchanger (for dehumidification) and through the electronic system cold plates. Both streams then merge and pass through the radiator, or a part of it, as determined by the area selector valve.

Aft Unit Thermal Control

The aft unit cooling system is a separate glycol-water loop with a radiator and water boiler for supplementary heat sink. An Apollo dual pump package and Apollo water boiler control elements provide the basis for system design. New components are the fuel cell water condenser and water boiler, both of which take advantage of lunar gravity for phase separation and fluid transfer. A small 10-watt heater prevents excessively low fuel cell and drive controller-inverter temperature during lunar night storage periods.

The temperature controls are similar to those of the cabin glycol loop except for higher settings consistent with the fuel cell requirements.

3.2.6 Life Support

The life support elements of crew systems must provide for the needs of the crew in terms of: food, water, waste management, clothing including the extravehicular spacesuits, medical and personal hygiene items, and trace contaminant control.

3.2.6.1 Analysis

Representative crew task metabolic rates based on Earth gravity conditions were adjusted to the values shown on Table 3.2-1. The adjustments were made according to the estimated influence of lunar gravity conditions, spacesuits and the capabilities of the portable life support system.

METABOLIC RATES

	JOULES/SEC	(BTU/HR)
SLEEP	94	(320)
OFF DUTY	117	(400)
SHIRT SLEEVE DUTY (NON DRIVING)	146	(500)
SUITED DUTY (NON DRIVING)	146	(500)
DRIVING (SHIRT SLEEVE)	205	(700)
DRIVING (SUITED)	205	(700)
DRIVING (SUITED, PRESSURIZED)	264	(900)
EXTRAVEHICULAR	469	(1600)

TABLE 3.2-1

The metabolic rates of the crew while performing various tasks establish the quantity of food, water and oxygen required as well as the capacity of associated equipment such as the CO_2 removal and humidity control equipment. Such interfaces are illustrated on Figure 3.2-6.

METABOLIC RATE INTERFACES

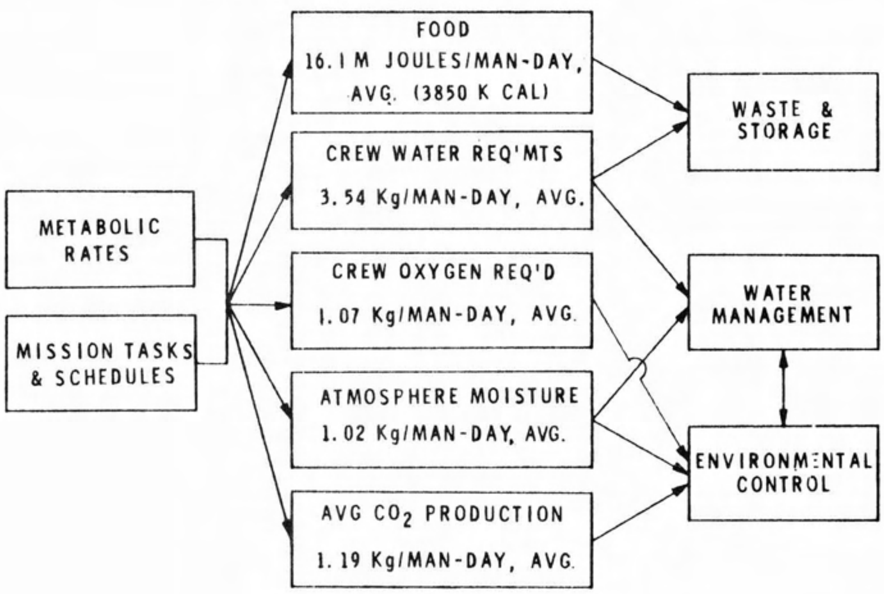


FIGURE 3.2-6

3.2.6.2 Description

Water Management - The MOLAB water concept uses the water produced by the fuel cell and an on-board initial supply as potable water. The steam produced by the fuel cell is condensed in the aft unit and transferred to the cabin main storage tank. The potable water is used for crew drinking, food reconstitution and cooling. Water conservation is practiced by using the humidity control condensate water for cooling and recharging the portable life support system. Urine is collected for emergency cooling for the first week of the manned mission after which it is used with humidity water for vehicle cooling thru the water boiler.

Waste Management - The Apollo waste management concept has been selected. Putrescible material is sealed in plastic bags with disinfectant and the bags kneaded by hand before storage.

Trace Contaminant Control - Control of trace contaminants in the MOLAB atmosphere will be accomplished in two ways. First, the quantity of contaminants will be minimized by careful selection of materials. Second, the contaminants in the atmosphere will be removed or destroyed until their concentration is below man's tolerance level. The normal charcoal filters in the atmosphere conditioning system will remove many contaminants; others will be removed by oxidation in a catalytic burner. Special chemical filters upstream from the catalytic burner will remove those contaminants whose products of oxidation are toxic. In designing the contaminant control equipment, the effects of atmospheric leakage will be considered. As atmosphere is lost from the vehicle, so also are lost the contaminants and the remaining contaminants will be diluted by make-up oxygen.

Food, Clothing, Medical, Personal Hygiene - These items are government furnished for the MOLAB. They do affect the MOLAB mission and design and must be considered. As an example, the type of food dictates the amounts of hot and cold water needed for food reconstitution. The spacesuit or extravehicular clothing very significantly affects the lunar surface activities of the MOLAB crew. By restricting physical motions, by limiting total allowable energy expenditure, by reducing manual dexterity and by limiting the time available for surface activities, the spacesuit assembly determines many of the boundary conditions of extravehicular mission activities.

3.3 MOBILITY AND CRYOGENIC STORAGE

3.3.1 Mobility Systems

The MOLAB mobility system provides a mobile platform capable of negotiating the postulated soils, slopes and obstacles in the lunar environment with maximum safety and without undue discomfort to the crew or damage to the equipment. It consists of a four-wheeled forward unit and a two-wheeled aft unit coupled together by means of a flexible frame allowing pitch and roll motion of the aft unit relative to the forward unit. Steering is accomplished by a combination of Ackermann steering of the front wheels and, simultaneously, articulated steering of the aft unit.

The specific restraints used in the preliminary design included: mobility capability over as wide a range of lunar surface conditions as possible (surface characteristics of the Engineering Lunar Model Surface were used), and the capability of traveling at least 6 km per hour in soft soils ($K_\phi = 0.5$, $N = 0.5$) and up to 16 km per hour on level compact soils ($K_\phi = 6$, $N - 1.25$).

Consistent with dimensional restraints (ALSS payload envelope), environment, human tolerance, and mission requirements, specific design criteria were established for the mobility components. These criteria were related to dimensions, loads, accelerations, operational life, spring rate, jounce, rebound, damping rate, drive arrangement, braking, declutching, speed-torque, steering limits, pitch limits and roll limits.

3.3.1.1 Studies

Analytical studies performed included:

- Tractive performance
- Motion resistance
- Drawbar pull
- Gradeability
- Drive torque
- Power requirements
- Locomotion energy
- Pitch stability
- Component stress analyses
- Drive system (Motor and controller)
  - Efficiency
  - Thermal
  - Inverter reliability

Most of the mobility performance computations were performed with the aid of a digital computer. In addition, data for the preliminary design of the suspension and damping components were obtained by a dynamic analysis programmed on an analog computer. A second objective was to determine allowable speeds as a function of terrain roughness and the determination of energy absorbed by the suspension dampers at various vehicle speeds.

A 1/3 scale model test program was conducted to aid in the evaluation of MOLAB obstacle mobility. The main objectives of these experiments were to establish maximum performance capabilities over prescribed obstacles, optimize the flexible frame design, and determine the effect of wheel load distribution.

The mobility system, shown in Figure 3.3-1, incorporates flexible wire frame wheels, individual wheel drive mechanisms, steering mechanisms, and the chassis frame.

The wheels are 1.52 meters (60 inches) in diameter and consist of a wheel disc to which is welded a flexible wire outer frame. The wire cloth covering closes the wheel to soil particles and provides a continuous bearing surface. The wear resistant tread serves to protect the wheel covering from abrasion and provides a gripping tread for traction.

The individual wheel-drive assemblies include a single stage spur gear reduction, harmonic drive, disc-type service brake, band-type parking or emergency brake, declutching mechanism, electric motor and radiator. A single stage spur gear reduction connects the electric motor shaft to the wave generator of a harmonic drive which connects to and drives the wheel. The service brake is located at the input end of the harmonic drive. A parking or emergency brake, independent of the wheel drive, is a spring-actuated band brake acting on the wheel hub. The declutching of the wheel is accomplished by disengaging the harmonic drive flexspline teeth from the circular spline.

The electric motors are of the three-phase squirrel cage induction type (passively cooled). Two liquid cooled controller-inverters each service the three wheels on one side. The electric drive system is capable of producing a maximum wheel torque of 560 meter-Newtons (759 pound-feet) at a wheel speed of approximately 2 RPM. A closed loop control system will govern wheel speeds for manual, auto-drive, and remote modes of operation.

MOLAB MOBILITY SYSTEM LAYOUT

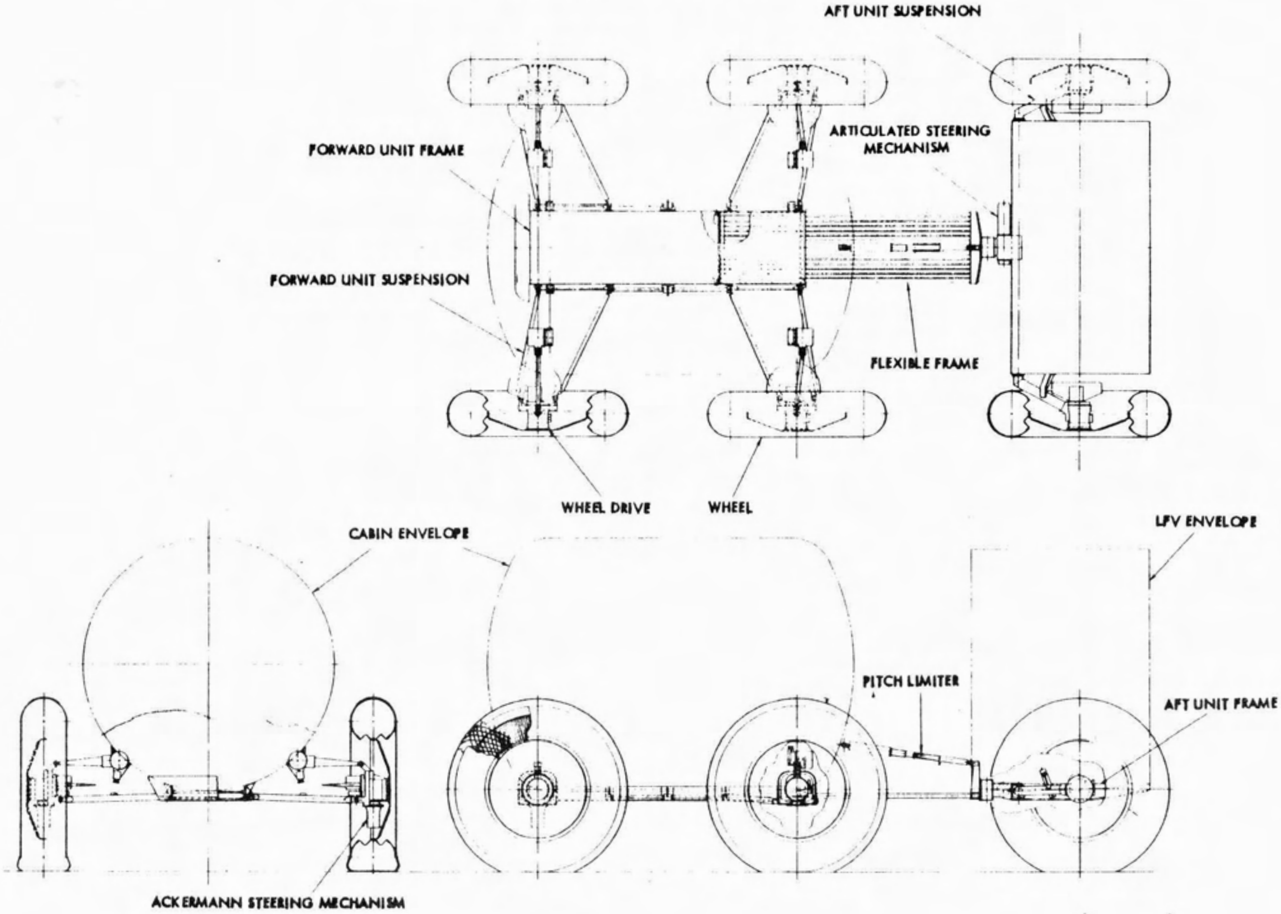


FIGURE 3.3-1

Ackermann steering is accomplished by a motor and harmonic drive reduction unit located on the king pin centerline of the two forward wheels. The articulated steering mechanism for the aft unit consists of a motor-gear reducer driving the segment gear, attached to the flexible frame, through a ball screw-nut assembly.

The chassis frame consists of a forward-unit frame providing support for the cabin and forward-unit suspension, an aft-unit frame providing support of aft-unit equipment and suspension, and a flexible frame and pitch limiter located between the forward and aft units.

Each of the four forward-unit suspensions consists of a lower suspension arm, to which one end of the longitudinal torsion bar is anchored, an upper suspension arm which is fixed to a rotary damper, and a wheel drive mounting bracket to which the outboard ends of the upper and lower arms are attached. The inboard end of the lower suspension arm is attached to the forward-unit frame.

Each of the two aft-unit suspensions include a trailing arm, traverse torsion bar spring element and rotary damper. The trailing arm, which carries all of the suspension loads, is rigidly attached to the drive motor mounting bracket and mounted in bearings on the aft-unit bed.

The flexible frame consists of twelve thin-walled titanium tubes fixed at the cabin unit by guides and spacer bars and at the aft end by the pitch limiter bracket. The pitch limiter controls the relative movement between the forward and aft units by a linear motion device which limits pitch motion to ± 15 degrees.

3.3.2 Cryogenic Storage

The MOLAB vehicle has cryogens stored in three spherical, low heat leak tanks; one oxygen and one hydrogen tank for fuel cell reactants and a separate tank for life support and cabin pressurization oxygen. The hydrogen tank is vented during storage while the oxygen tanks are non-vented. All cryogens are stored at subcritical pressure.

The requirements shown in Table 3.3-1 are those to support the baseline mission.

CRYOGEN REQUIREMENTS

FUEL CELL	O_2 (kg)	H_2 (kg)	ECS	O_2 (kg)
USABLE CRYOGEN	191.5	23.9	CREW BREATHING	25.6
UNAVAILABLE	1.6	0.4	PLSS CHARGING	13.8
MASS LOSS DURING 180 DAY STORAGE (VENT LOSS)	--	20.0	CABIN LEAKAGE	33.9
MISCELLANEOUS (LEAKAGE & USAGE TOLERANCE)	0.3	0.1	AIRLOCK OPERATION	6.8
			CABIN DECOMPRESSION	6.0
			UNAVAILABLE	.7
			MISCELLANEOUS (LEAKAGE AND USAGE TOLERANCE)	.6
	193.4	44.4		87.5

TABLE 3.3-1

3.3.2.1 Analysis

The objective of passive storage for the cryogens was established early in the study on the premise that passive devices (no moving parts) are inherently more reliable than active devices (moving parts). The determination of the feasibility and practicality of such passive storage was the primary analytical effort. The utilization of heat pumps and semipassive approaches were briefly investigated. However, once the satisfactory utilization of the passive storage concept was reasonably established, no further work was done on other approaches.

Analysis of tank designs typical of those required for MOLAB plus review of development test results on other programs established the following:

- It is feasible to store liquid hydrogen and liquid oxygen up to six months on the lunar surface in the quantities required for MOLAB.
- Passive low heat leak tanks required for the storage of these cryogens can be developed within the MOLAB time scale.

On Figure 3.3-2 is shown a comparison of the flat specimen thermal conductivity values of three insulations available today. Also shown is the value used for MOLAB tank analysis, which is considered conservative. However, additional development effort is required to develop better fabrication techniques to achieve the low heat leak in a repeatable manner on actual tanks.

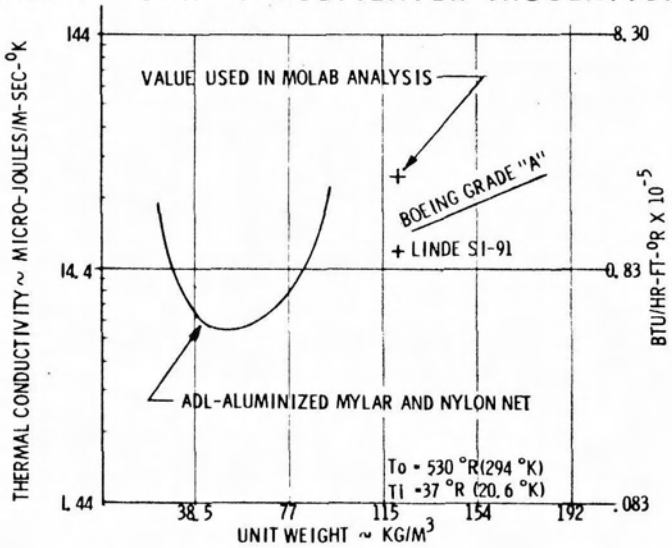


FIGURE 3.3-2

3.3.2.2 Description

The conceptual tank design is illustrated on Figure 3.3-3. An inner pressure shell is concentrically supported in a hard, outer vacuum shell by slender metallic tension rods. The rod sizes and angles were selected to withstand the loads imposed during MOLAB lunar landing. The rod arrangement depicted was primarily selected to facilitate assembly of the outer shell. Thermal insulation is located in the vacuum space between the inner and outer shells. A meteoroid shield is provided external to the outer vacuum shell.

A single probe assembly combines instrumentation, wiring and service lines and fittings into one unit and one installation. Valving for servicing and operation is presently planned to be incorporated into this assembly.

TYPICAL TANK DESIGN

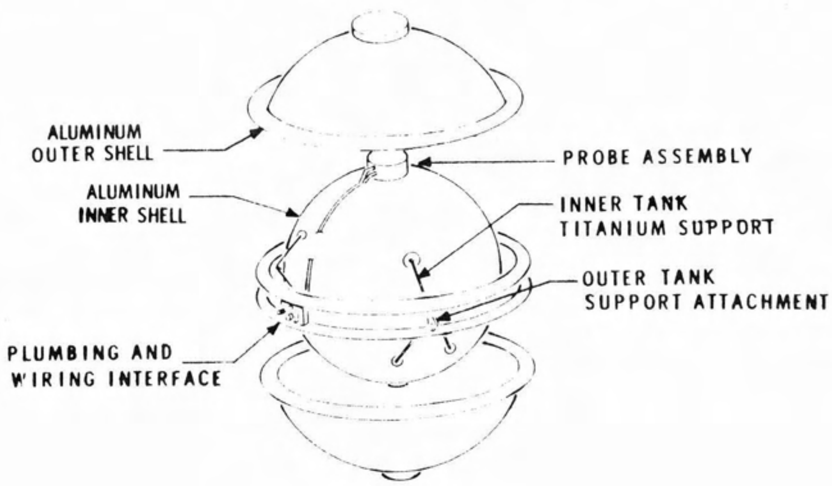


FIGURE 3.3-3

The significant parameters affecting tank design are shown on Table 3.3-2.

CRYOGEN TANK PARAMETERS

	FUEL CELL		ECS	
	OXYGEN	HYDROGEN	OXYGEN	
LOAD AT FILLING - KILOGRAMS	193.4	44.4	87.5	
INITIAL ULLAGE - PERCENT	22.0	23.0	24.0	
FILL TOLERANCE - PERCENT	0.5	0.5	0.5	
TANK VOLUME TOLERANCE - PERCENT	1.5	1.5	1.5	
TEMPERATURE AT FILL - °K	90.2	20.5	90.2	
PRESSURE AT FILL - N/cm^2 ABS.	10.1	10.1	10.1	(1)
TEMPERATURE AFTER 180 DAYS STORAGE - °K	124.0	29.4	129.8	
PRESSURE AFTER 180 DAYS STORAGE - N/cm^2 ABS.	123.8	76.2	166.5	(2)
ULLAGE AT VENT - PERCENT	5.0	5.0	--	
HEATER SIZE - WATTS	100.0	25.0	130.0	
TANK INSIDE DIAMETER AT FILL - cm	73.9	116.6	57.7	
INSULATION THICKNESS - cm	3.81	6.35	3.81	
HEAT THROUGH 180 DAYS STORAGE - MEGA-JOULES	11.3	12.3	6.0	(3)

(1) 14.7, 14.7, 14.7 PSIA
(2) 179, 110, 241 PSIA
(3) 10.7, 11.6, 5.7×10^3 BTU

TABLE 3.3-2

The oxygen tanks are initially filled with saturated liquid. During the storage period, the heat leak builds up the tank pressure to a predetermined maximum value without venting gas to space.

As the temperature of the fuel cell oxygen increases in the tank, the overall mass density of the fluid remains constant since no oxygen is used during the

storage period unless the fuel cells are started. At the end of the six-month storage period, the tank has reached its design ullage and pressure. With the starting of the fuel cells, an electric heater is used to bring the system up to pressure if it is not achieved during the storage period and to maintain system pressure as cold gas is drawn off for fuel cell operation.

The ECS tank operates similarly to the fuel cell tank except that the mass density is reduced slightly during the storage period as oxygen is drawn off for cabin pressurization. At the end of the storage period, the oxygen is raised to supercritical pressure by an electric heater. The cabin atmosphere requirements are supplied and the portable life support system oxygen bottles reliably charged from this supercritical oxygen source.

The hydrogen tank is filled initially with saturated liquid hydrogen which builds up pressure over the storage period to a predetermined design value. At this pressure, hydrogen is vented to space to maintain a maximum system pressure.

3.4 ELECTRICAL POWER

Initial concept studies were made by NASA to establish a basic power system concept for MOLAB. The selected power sources were: H_2/O_2 fuel cells to provide the relatively high power and high energy requirements of the manned phase; a radioisotope thermoelectric generator (RTG) to supply the relatively low power and high energy requirements of the storage phase; and a secondary battery to supply the relatively high power and low energy requirements for initial activation and checkout. Based on these initial concept studies and preliminary discussions with NASA, the MOLAB power subsystem has been logically divided into three functional blocks: the primary power sources, the auxiliary and secondary power sources, and power system management.

Preliminary design studies included a detailed definition of electric power and energy requirements for the various mission phases, a comparison of various candidate concepts for the elements of the power system, and a selection of a specific configuration as a baseline power system to describe system integration, system interfaces, and specific operational requirements.

3.4.1 Analysis

The requirements have been classified into three major categories: power and energy quantity, power quality, and major power blocks. The power requirements have been divided into convenient categories for the purpose of assisting the general layout and bus configuration of the power distribution system. Figure 3.4-1 is a bar chart which summarizes the power and energy requirements according to various major blocks of power. This data has been obtained from detailed power load profiles plotted as a function of time for the various days and phases of the MOLAB mission.

The approach used in the evaluation of several potential MOLAB fuel cell systems consisted of two parts: digital computer mass optimization of each candidate fuel cell design within the MOLAB system constraints, and comparison of optimized fuel cell candidates on the basis of various quality-type parameters.

The computer optimization determines the minimum mass system for each of the applicable fuel cell designs subject to specific MOLAB system constraints such as: load profile, radiator specific cooling capacity as a function of time, maximum radiator area constraint, and voltage regulator constraint.

MAJOR POWER AND ENERGY BLOCKS

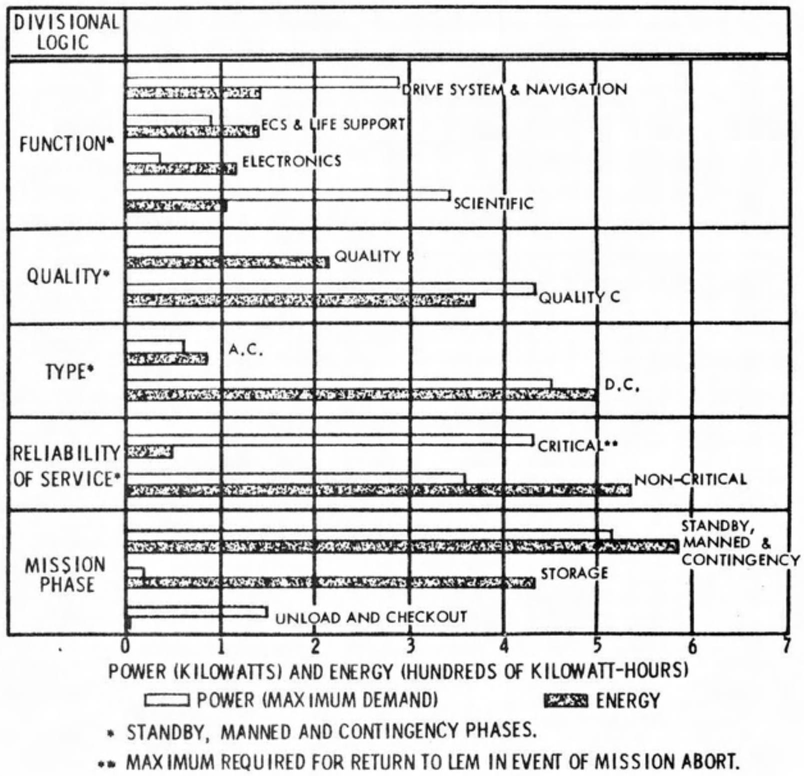


FIGURE 3.4-1

The optimized (minimum mass) systems are then compared on the basis of reliability, life, mass, and development risk. An important result of the comparison is that the Allis-Chalmers design requires less mass than the other designs, particularly when radiator and voltage regulation constraints are applied.

The development risk will be the least for systems evolved from existing hardware such as the Allis-Chalmers and Pratt and Whitney designs. Table 3.4-1 is a summary of mass comparisons of the several candidate systems.

A comparison was made of various RTG concepts for auxiliary power and batteries for secondary power. A plutonium-238 concept rated at 125 watts output was selected as a baseline for auxiliary power. Two silver-zinc batteries, each with a nominal rating of 1350 watt-hours, were selected for secondary power.

3.4.2 System Description

A summary description of the selected power system is shown in Table 3.4-2. The power system consists of three source modules and a power system management module which provides the following functions:

- Distribution of power between power sources and buses.
- Bus-feeder switching and bus-tie switching.
- Load switching.
- Power source start-up and shut-down control.
- Central control logic.
- Monitoring.
- Voltage regulation.
- Battery charging.
- Power conditioning.

FUEL CELL SYSTEM WEIGHT COMPARISONS

FUEL CELL SYSTEM	SYSTEM WEIGHT IN KG (AND LBS). AND VOLTAGE REGULATION CONSTRAINT (VOLTS)			
	OPTIMUM SYSTEM NO REGULATION CONSTRAINT	± 4 V.	± 3 V.	± 2 V.
AC1	585 (1290) 26.5 V - 31.7V	585 (1290)	585 (1290)	591 (1302)
AC2	715 (1576) 26.5V - 31.3V	715 (1576)	715 (1576)	720 (1587)
GE 2	590 (1299) 26.5 V - 33.5 V.	590 (1299)	592 (1306)	695 (1535)
PW1	625 (1379) 26.5 V - 39.4V	639 (1407)	650 (1433)	690 (1525)
PW 2	910 (2006) 26.5 V - 37.1 V.	966 (2134)	1030 (2275)	1180 (2600)
UC	646 (1428) 26.5V - 28.9V	646 (1428)	646 (1428)	646 (1428)

RADIATOR AREA CONSTRAINT • 4.65 m^2 (50 ft^2)

AC1 • ALLIS-CHALMERS, MOLAB DESIGN

AC2 • ALLIS-CHALMERS, HARDWARE UNDER TEST AT NASA HOUSTON

GE2 • GENERAL ELECTRIC, MOLAB DESIGN (INTERMEDIATE TEMPERATURE)

PW1 • PRATT & WHITNEY, MOLAB DESIGN

PW2 • PRATT & WHITNEY, CURRENT APOLLO HARDWARE

UC • UNION CARBIDE, MOLAB DESIGN

TABLE 3.4-1

POWER SYSTEM SPECIFICATION SUMMARY

MODULE	PRINCIPAL COMPONENTS	MAX. PWR DEMAND (KW) ENERGY (KWH)	POWER TYPE	WEIGHT KG.	VOLUME M^3
PRIMARY POWER	•4 FUEL CELL MODULES •FUEL AND TANKS •THERMAL CONTROL •AUXILIARY EQUIPMENT	5 KW ▷1 525 KWH	28/56 VOLT D-C ± 13% VOLTAGE REGULATION	602 (1329 LBS)	2.32 (82 FT^3) RADIATOR 4.65 M^2 (50 FT^2) .17 M^3 (6.25 ft^3)
AUXILIARY POWER	•PU^{238} RTG •VOLTAGE REGULATOR •THERMAL CONTROL	0.11 KW ▷2 2.6 KWH/24 HR CYCLE	28 VOLT D-C ± 7% VOLTAGE REGULATION	22 (48.5 LBS)	.09 (3.2 ft^3)
SECONDARY POWER	•AGZN BATTERY •BATTERY CHARGER	1.4 KW ▷3 1.4 KWH	28 VOLT D-C	30 (67 LBS)	.009 (.314 ft^3)
POWER SYSTEM MANAGEMENT	•CABIN DIST. BOX CONVERTER INVERTERS CENTRAL CONTROLLER CIRCUIT BREAKERS DISTRIBUTION BUSES •AFT DIST. BOX INVERTERS CIRCUIT BREAKERS DISTRIBUTION BUSES	D-C CENTRAL CONVERTER SUPPLY - 1 KW A-C CENTRAL INVERTER SUPPLY - 0.75 KW	D-C (1) 28/56 VOLT ± 14% (2) 28 VOLT ± 7% AUX (3) 28 VOLT ± 7% CONVERTER A-C (1) 115/200 VOLT 3-PHASE 400 CPS INVERTER	74 (163 LBS)	.120 (4.25 FT^3)
				TOTAL WEIGHT 728 (1,607 LBS)	TOTAL VOLUME 2.72 (96 ft^3)

▷1 STANDBY, MANNED AND CONTINGENCY PHASES.

▷2 STORAGE PHASE.

▷3 UNLOAD AND CHECKOUT PHASE

TABLE 3.4-2

A number of possible power system configurations have been analyzed and three-wire 28/56 volt d.c. system with a ± 14% voltage regulation tolerance was selected as the most applicable candidate on the basis of mass savings and growth potential. In addition, equipment is included to provide: 750 watt central three-phase 400 cps a.c., 1,000 watt 28 volt ± 7% regulated d.c. power, and an auxiliary bus with battery/RTG d.c. power source.

In order to avoid excess mass penalties, the development of a new fuel cell is required. A new design does not require an increase in the state-of-the art and can be confidently scheduled.

3.5 ASTRIONIC SYSTEMS

During MOLAB delivery to the Moon, telemetry monitoring data is supplied to the LEM Truck for transmission. Mission analyses of lunar surface activities show that astrionic system functions are required during four operational phases: deployment, storage, closure and manned exploration.

Detailed requirements of seven subsystems were derived from comprehensive functional analyses for each operational phase. A brief summary of the subsystems and their functional requirements are given in Table 3.5-1.

In addition, requirements and guidelines imposed by the Statement of Work and the Apollo Program led to further astrionic system requirements. In satisfying these requirements, Apollo equipment designs were adapted wherever possible. In those instances where developed equipment was not available, current technology was specified.

3.5.1 System Description

The seven subsystems of the astrionic system are shown in block diagram form in Figure 3.5-1.

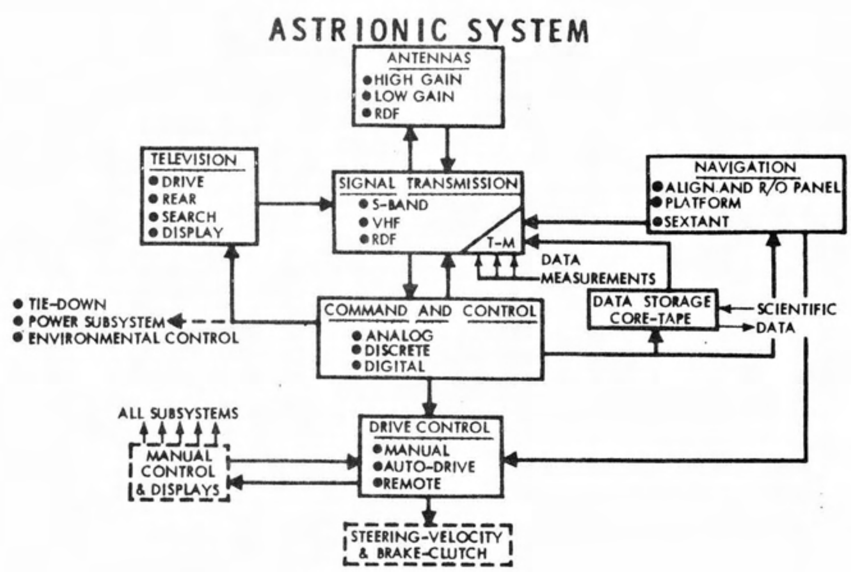


FIGURE 3.5-1

ASTRIONIC SYSTEM REQUIREMENTS - OPERATIONAL PHASES

Subsystem	Mission Phase: Deployment	Storage	Closure	Manned Exploration [1]
Television	.Observe front & rear terrain to detect obstacles to deployment. .Observe MOLAB unloading. .Determine initial azimuth.	.None	.Survey lunar landscape for path selection. .Detect mobility obstacles while driving. .Reference azimuth deviation. .Back-up position determination by lunar surface sightings. .Aid in site certification.	.Watch external operations such as EVA or drilling. .Aid crew in path selection. .Provide rear view capability. .Give Earth originated video displays. .View LEM take-off
Navigation	.None	.None	.Provide continuous data on present position, heading, velocity, distance traveled, attitude and altitude. .Accept initial position data.	.Provide continuous data on present position, heading, velocity, distance traveled, attitude and altitude. .Provide data for position update. .Accept updated position data.
Communication	.Establish a MOLAB to Earth link for transmission of TV, TM and TRC [2] data. .Establish an Earth to MOLAB link for reception of C & C, and RC data.	.Provide MOLAB to Earth link for periodic transmission of scientific and engineering TM data. .Provide Earth to MOLAB link for activation of MOLAB subsystems.	.Maintain a continuous MOLAB to Earth link for transmission of TV, TM and TRC data. .Maintain Earth to MOLAB link for reception of C & C and RC data. .Establish LEM to MOLAB link for reception of stop/go commands and RDF to LEM. .Provide a MOLAB to CM link for relay of TM to Earth.	.Maintain a continuous MOLAB to Earth link for transmission of TV, TM, TRC, Biomed and voice data. .Maintain Earth to MOLAB link for voice, TV and RC data (C & C for backup). .Provide LEM/MOLAB voice link. .Provide EVA/MOLAB voice link. .Provide a CM/MOLAB voice link. .Provide a MOLAB to CM link for relay of TM to Earth. .Provide LEM to MOLAB link for RDF to LEM.
Command and Control	.Accept activation signal from LEM-Truck. .Accept command data from communication subsystem. .Decode commands and supply to affected subsystems.	.Controls periodic check of on-board environment and subsystem functional capabilities.	.Supply sufficient commands to afford complete control of the MOLAB in the absence of the crew. .Inhibit incomming commands and generate a stop command if a condition dangerous to the vehicle is sensed by other subsystems.	.Upon request, relieve astronauts of selected or all control functions.
Telemetry	.Monitor performance of all MOLAB subsystems. .Prepare data for transmission output is to be PCM at 1.6 or 51.2 Kbps. .Provide timing signals to selected subsystems.	.Collect & prepare data for periodic check of on-board environment and subsystem functional capabilities. .Read-out scientific data store periodically.	.Same as deployment	.Monitor performance of all MOLAB subsystems. .Provide for periodic measurement of crew biomedical data. .Provide for selected scientific data preparation. .Provide for period read-out of scientific data stores. .Prepare all data for transmission. .Provide timing signals to selected subsystems.
Data Storage	.None	.Provide data storage for scientific experiments. .Provide for limited timed on-off commands of scientific equipts.	.Same as Storage	.Provide buffer storage of scientific and operations data.
Driving Control	.Straighten Ackermann Wheels. .Control extension of rear unit. .Set steering to straight ahead. .Control drive power to wheels. .Control brakes. .Accept commands from C&C only.	.None	.Control velocity servo loop & drive power to wheels. .Control heading servo loop. .Control brakes. .Control wheel clutches. .Accept commands from C&C only.	.Control Velocity. .Control heading. .Control brakes. .Control wheel clutches. .Provide these control modes to the astronaut: (1) Direct, manual control. (2) Auto Drive Control, (Auto-Pilot). (3) Remote (Earth) Control..

Notes: 1) In addition to requirements listed under Manned Exploration, all of the Astrionic System functions under Closure will be needed for the emergency retrace maneuver.
2) Abbreviations:

C & C	Command & Control System.	Kbps	Kilo-bits per second.	RC	Range Code	TRC	Transponded Range Code
CM	Apollo Command Module.	LEM	Apollo Lunar Excursion Module.	RDF	Radio Direction Finding	TV	Television
EVA	Extravehicular Astronaut.	PCM	Pulse Code Modulation	TM	Telemetry		

TABLE 3.5-1

Television Subsystem

The television subsystem contains five major assemblies.

The stereo driving cameras are spaced 24 inches apart and are located above the radiator at the forward end of the MOLAB cabin. To permit continuous driving during remote operation, the camera assembly is stabilized in pitch and roll.

The search camera is used primarily as a navigational aid. It is mounted on a mast and can be rotated $\pm$ 180° in azimuth and $\pm$ 60° in pitch. A two-lens turret permits selection of wide angle and narrow fields of view.

The rear-view camera is mounted on the aft unit of the vehicle. It is used by an Earth monitor as an aid during unloading from the LEM Truck. Pictures may also be displayed to the MOLAB crew on the cabin kinescope during manned operations.

All cameras are of similar electrical design and have self-contained passive thermal control. The major difference is that the stereo driving cameras have a single low scan rate whereas the search and rear-view cameras are provided with dual scan rates (5 and 60 fields per second). The lower scan rates will be used when video information is transmitted to Earth (i.e., within the 500 kc transmission bandwidth); the higher scan rate will provide the MOLAB astronauts with a flicker-free kinescope display.

The astronaut TV display assembly is located inside the cabin and is used for monitoring the search and rear-view cameras. This assembly will also be used to display Earth-originated television.

The central video sequencer assembly supplies synchronization and scanning signals for each of the camera assemblies.

Navigation Subsystem

The navigation subsystem consists of four major assemblies.

The coordinate heading platform is a three-degrees-of-freedom gimbal assembly which is used to measure vehicle heading and attitude. A heading gyro, a vertical sensing accelerometer assembly, and their amplifiers, are mounted on the inner platform. The platform is erected and stabilized with respect to lunar gravity by the inner and outer gimbals which are positioned by torquers. Resolvers to measure vehicle heading and attitude are located on the gimbals.

The guidance alignment panel contains power switching, alignment control, malfunction detection, and portions of the coordinate display electronics for the stable platform. The panel displays vehicle attitude information from the coordinate heading platform and accepts remote or operator-derived erection signals for the coordinate heading platform. This panel is similar in design to the Apollo inertial measurement unit control panel, and uses common controls, displays and electronics wherever possible.

The navigation control and readout panel accepts vehicle pitch and heading information from the coordinate heading platform and vehicle speed and distance pulses from the drive wheel odometer. These inputs are operated upon by the panel electronics and displayed to show distance traveled, relative altitude, position, and heading. Data displayed can be remotely or manually updated. During driving periods, the display data will be automatically and continuously updated utilizing the odometer output, and the coordinate heading platform pitch and heading angle.

The periscopic sextant is used for position and azimuth update. Employing standard nautical navigation techniques, a position fix with a one sigma error of 276 meters with zero gravity anomaly can be obtained. Known MOLAB position and measurement of bearing angle to a star produces an azimuth update with a one sigma error of 2 arc minutes. The design of the sextant is similar to an aircraft type periscopic sextant.

Communication Subystem

The communication subsystem provides the reception, transmission and signal processing capability necessary to permit two-way communications between MOLAB and MSFN, CM, LEM and EVA. It also derives MOLAB to LEM bearing based on the reception of LEM VHF signals by an Adcock antenna array. The communications subsystem consists of the following units:

Unit	Primary Function	Remarks
S-Band Transponder	Voice, TV, command and range code reception from Earth. Voice, TV, TM and transponded range code transmission to Earth	LEM equipment.
Transceiver A	Simplex voice with CM. Voice, stop and go commands from LEM.	LEM equipment.
Transceiver B	Telemetry transmission to CM, voice transmission to LEM, voice and biomedical reception from EVA.	LEM equipment.
Transmitter C	Voice transmission to EVA.	LEM equipment.
Bearing Receiver	Derive bearing to LEM.	State-of-the-art equipment.
Low Gain S-Band Antenna	Receive/transmit low data rate signals without antenna positioning.	State-of-the-art equipment.
High Gain S-Band Antenna and Position Servo	Receive/transmit high data rate signals and TV. Antenna is positioned continuously by Earth-tracking servo system.	Antenna is state-of-the-art. Servo is LEM design.
VHF Antenna	Receive/transmit CM, LEM and EVA data.	State-of-the-art equipment.
DF Antenna	Determines bearing to LEM by use of a VHF Adcock antenna.	State-of-the-art equipment.
Premodulation Processor	Performs signal selection, subcarrier modulation and demodulation.	LEM equipment.
Audio Centers	One for each astronaut. Amplifies and selects voice signals.	LEM equipment.

Command and Control Subsystem

The design of this subsystem is based on the Gemini command and control system.

The command and control subsystem accepts command signals from the communication subsystem and performs address, parity and verification checks before routing the command to the addressee. The output signals of the command and control subsystem are supplied in a form best suited to the user subsystem and include analog, digital and discrete commands.

The discrete commands are distributed using a 32-wire, three-coincident-pulse matrix. This technique has the advantage of greatly simplifying the wire harness design and subsystem interfaces, yet can easily accommodate growth of the present command list. The interface between the manual control (on-board) and remote control is accomplished by a command converter located within each subsystem.

Telemetry Subsystem

The telemetry subsystem collects and encodes all MOLAB subsystem measurements. The equipment employed is the LEM design with minor modifications. Output is selectable at either 1.6 or 51.2 kbps at a format compatible with the other ALSS telemetry systems. The telemetry subsystem also generates timing signals for all other subsystems. Long term timing accuracy is two parts per million.

The telemetry subsystem, in conjuction with the command and control subsystem, provides the means for accomplishing remote checkout.

Data Storage Subsystem

Two storage devices yield sufficient flexibility for MOLAB data storage. The analog tape recorder with seven parallel input channels provides a general purpose data store for scientific experiments during the manned phase. Output of the recorder is either processed by the telemetry subsystem or directly transmitted by the signal transmission system.

A digital core storage is primarily used during the dormant phases of MOLAB. It provides the time delayed control of scientific equipment and for storage of data of those equipments. Readout is accomplished upon Earth command.

Drive Control Subsystem

The drive control electronics includes the interface between the manual/remote driving commands and the mobility system. Two major functions, heading and velocity control, are performed.

During remote control driving, closed loop heading and velocity controls are utilized and updated by commands received from Earth. A power limit can also be specified and included in the control loop to limit the maximum power used for locomotion.

In the autodrive mode, closed loop heading and velocity controls are utilized to permit "hands off" driving. To change velocity or heading, the subsystem is switched to manual, the new velocity or heading is acquired and the subsystem is switched back to autodrive.

In the manual mode, heading and velocity signals from a manual controller are directly applied to the steering and velocity servos.

The clutches and brakes are either remotely or manually operated by on-off commands. Brake force magnitude is proportional to time duration of the remote brake "on" command.

The preliminary designs of the MOLAB astrionic system has shown that the MOLAB mission-imposed requirements can be satisfied to a large degree with Apollo equipment. The study has also shown that the MOLAB astrionic system design imposes very minor integration requirements on the presently planned Apollo system as shown in Figure 3.5-2

APOLLO/MOLAB ASTRIONICS INTERFACE SUMMARY

CM — NO CHANGES REQUIRED

LEM — TWO MINOR MODIFICATIONS REQUIRED:

(1) TRANSMIT TONE COMMANDS TO MOLAB

(2) RECEIVE REMOTE COMMAND TO ACTIVATE BEACON

LEM/T — TWO INTERFACE REQUIREMENTS:

(1) IN-FLIGHT T/M DATA TRANSMITTED VIA LEM/T S-BAND COMMUNICATIONS

(2) LEM/T PROVIDES INITIAL COMMAND TO ACTIVATE MOLAB S-BAND COMMUNICATION

EVA — NO CHANGES REQUIRED

MSFN — THREE ADDITIONS REQUIRED:

(1) COMMAND GENERATOR (MODIFIED GEMINI)

(2) FM EXCITER FOR UP-LINK TV

(3) MOLAB OPERATING CONSOLES

FIGURE 3.5-2

Development is required of operational displays to be used for Earth control of unmanned mission phases. The displays consist primarily of stereo television and selected telemetry with the capability provided for an operator to generate driving commands.

Further studies are recommended in the areas of:

- Integration of scientific equipment into the MOLAB design.
- Detailed definition of the astrionic system/ground checkout equipment interface.
- Preliminary design of the MOLAB remote control ground support equipment.
- Integration of the MOLAB remote/manned control interface.
- Television simulation testing to determine human tolerance limitations and capabilities for remote driving.

Because of present design uncertainties resulting from the subjective quantities involved in remote driving, it is recommended that an astrionic test vehicle and control station be constructed and system evaluation tests conducted. The vehicle would be a logical extension of the Mobility Test Article Program. The astrionic test vehicle would serve to validate the remote driving and television subsystem simulation, as well as the design of all other astrionic subsystems.

3.6 TIE-DOWN AND DEPLOYMENT

3.6.1 Tie-Down

The tie-down system will provide the structural support between the MOLAB and the ALSS descent stage (LEM Truck) and will react all MOLAB boost, midcourse correction and landing loads to the LEM Truck. Release of all ties from the MOLAB will be accomplished remotely upon receipt of Earth commands. Successful release of all tie-downs are required prior to initiation of the unloading operation.

3.6.1.1 Studies

The design studies for the tie-down configuration primarily involved various arrangements of the tie-down elements in conjunction with the cabin structural arrangement. In order to minimize the induction of secondary loads resulting from LEM Truck deflections, only non-redundant arrangements were considered.

3.6.1.2 Description

The tie-down system consists of 12 compression-tension struts with ball joint connectors at each end. The remote release system incorporates ordnance devices which severs the ball connection on MOLAB allowing the struts to drop to the LEM Truck platform.

3.6.2 Deployment

The MOLAB is required to be capable of being deployed from the LEM Truck deck from more than one azimuth. Deployment will be accomplished by an Earth command. The capability for manual deployment of the MOLAB to the lunar surface is also required. Off-loading will be accomplished on surface conditions that may be as severe as specified in the Engineering Lunar Model Surface (ELMS).

3.6.2.1 Studies

Several approaches considered for MOLAB deployment included a turntable with foldable and extendable type tracks and ramps to allow deployment on any azimuth, and a study of full ramps to the lunar surface. The results of these studies indicated a significant mass penalty for the turntable with a full ramp. These approaches were compared to the finally selected two-azimuth partial-ramp described in Paragraph 3.6.2.2.

3.6.2.2 Description

The MOLAB is deployed from the LEM Truck to the lunar surface in either a forward or aft direction. When assured the tie-down system is released, deployment is accomplished by the use of two step-type ramps and restraining cables for either forward or aft deployment. The cable assemblies include a two-stage honeycomb crush-structure energy-absorber. The cable assemblies are fixed to the LEM Truck deck and include ordnance-release devices at the connection to MOLAB. Manual deployment is accomplished by manually driving MOLAB off the LEM Truck using the controls within the MOLAB.

4.0 GROUND SUPPORT EQUIPMENT AND TEST PROGRAMS

4.1 MOLAB GROUND SUPPORT EQUIPMENT

MOLAB GSE was studied to a depth to permit program costing and provides, in general, a foundation for sound entry to preliminary design. The requirements of MOLAB GSE can be satisfied by knowledge within the present state-of-the-art. No technological research and only limited developments are anticipated.

GSE requirements for the MOLAB originate primarily from: NASA direction; integration, test and logistics planning; and operations and functional analysis. Although all requirement sources are important, it was emphasized during the study that systems integration of MOLAB using existing facilities and equipment was most vital.

The GSE document developed as a result of study of requirements generally covers all out-plant ground equipment operation including training and considers the use of such equipment in-plant when no change of configuration is necessary.

GSE preliminary design effort should be continued to ensure that a compatible design exists throughout the booster, MOLAB vehicle and ground systems, and that MOLAB unique ground equipment requirements are established on a basis compatible with existing equipment in the LCC, MCC and MSFN.

Effort should also be directed toward identification of additional ground equipment as design definition is clarified during follow-on study phases.

4.1.1 GSE Study Objectives

Two primary GSE study objectives were met in the work performed. They are as follows:

- Requirements Reporting - Describing the technical GSE requirements or a plan for their development.
- Resources Planning Support - Providing information to allow cost, manpower, subcontracting and plant facilities estimates to be prepared.

4.1.2 GSE Plan

The GSE plan outlined in the paragraphs below summarizes the GSE centerline developed during the study.

4.1.2.1 Seattle Area Manufacturing and Test

Certain GSE items of transportation and mechanical handling and installation are also utilized during the manufacturing cycle in Seattle. In addition, a series of test benches is provided for and shared by the Production Area, Systems Integration Laboratory and Qualification/Development Laboratories. These benches provide fault isolation and limited component acceptance/performance testing.

MOLAB cryogenic storage, primary power and thermal control subsystems are serviced and tested at Boeing (Tulalip facility) using the Aft Unit Test Van. This van serves the functions of test control simulation, stimulation and data handling. Post-test servicing is also provided by van equipment.

At Boeing (Kent facility), the MOLAB vehicle is checked out system-by-system in an earth ambient condition. A mobility system fixture is provisioned to allow testing of driving, steering and braking operations. A modified version of the Apollo Acceptance Checkout Equipment (ACE) is utilized and ACE associated GSE and carry-on equipment employed.

At completion of earth ambient testing, the MOLAB is placed in the Kent Space Chamber for acceptance tests. The ACE system is required during these tests and also certain elements of the range or MCC equipment (e.g. the Remote Driving Station; the navigational display) may be desirable.

Upon completion of Kent testing, the MOLAB is packaged in its transporter and shipped via the B377PG aircraft to the Kennedy Space Center (KSC).

4.1.2.2 Launch Site Equipment

The MOLAB is processed through essentially the same tests and services at KSC as it has undergone at Seattle, Tulalip and Kent (with the probable exception of space chamber testing). In addition, as testing and servicing progresses from vehicle receipt to launch, it is necessary that virtually the full complement of GSE be available at KSC. Exceptions, in general, consist of certain Mission Control Center (MCC) equipments.

Preparation of the MOLAB at KSC requires routing of the vehicle to several areas. In such activities, handling and transport GSE is employed again. In general terms the routing of the MOLAB is as follows:

- In the Manned Spacecraft Operations Building (MSOB) activities for setup, calibration, equipment checks, subsystems tests and a complete integrated checkout occur. Among GSE utilized are: ACE System, ECS test unit; carry-on units; simulators; equipment service units; driving and steering test unit; a simulated MSFN ground station; and a Navigation and Guidance Test Station.
- In the Cryogenic Test Building, the Aft Unit Test Van is utilized in rechecking the fuel cell cryogenic system and the ECS power equipment.
- The MOLAB is emplaced on the LEM Truck in the Pyrotechnic Installation Building. Handling fixtures, sling sets and miscellaneous special installation tools will chiefly comprise the GSE in this operation.
- Following the MOLAB/LEM Truck marriage, the combined units will be placed in the R-F tower for open-loop tests. Such tests are to demonstrate compatibility of the vehicle transmitter/receiver with MSFN and CM equipment. No special GSE requirements exist in this area.
- If it is deemed necessary, the MOLAB/LEM Truck will be placed in the MSOB altitude chamber to test systems under flight pressure. GSE previously placed in the MSOB should satisfy known requirements in the tests (if any) to be performed here.
- The MOLAB/LEM Truck will be mated with the spacecraft-to-LEM Truck adapter, in the MSOB, then installed in the booster in the Vertical Assembly Building (VAB). No additional GSE items are anticipated in these operations.

- In the VAB, certain umbilicals are connected and equipment start-ups and interface tests made. Spacecraft compatibility, ECS functions and launch-to-landing sequences are verified. The vehicle is placed on the launch pad and environmental enclosures emplaced for final service functions. GSE used throughout these operations consist of such items as the ACE system, handling devices, umbilical lines, and carry-on equipment.

- During countdown, GSE needs are primarily served by cryogen control units, the umbilicals and the Launch Control Center (LCC) ACE.

- Final prelaunch checking is through telecommunications, command and control and telemetry systems. Post launch communciations are planned to be through LEM Truck capabilities until lunar arrival.

The assumption has been made that adequate data interconnection exists between KSC and Houston for Gemini and Apollo to satisfy MOLAB requirements.

Diverse GSE is planned for MOLAB maintenance at KSC. Included are test benches, fluid and electrical systems maintenance equipment, and special component handling and installation devices.

4.1.2.3 Mission Control Center Equipment

Integration of the MOLAB GSE into MCC capabilities for Apollo is of major importance. MOLAB must make optimum use of available Apollo equipment.

MOLAB needs a computer controlled checkout and control system. The present MCC ACE may satisfy MOLAB operations needs.

A real time command system is required for remote driving and steering functions at MCC. The Gemini command system will be modified for use with MOLAB, with the limitation that remote control can be exercised only when the MOLAB is in view of the North America MSFN station.

Certain unique MOLAB GSE is required at the MCC, including the following stations. Remote Driving (allows earth-based operation to control the MOLAB on the Moon); Traverse Plotting (continually records the vehicle's position on lunar maps); Heading and Position (receive sighting data, performs heading and position calculations); Historical Data Recall (provides recall of data based on past MOLAB latitude, longitude and mission time); Video Processing (serves video functions of control, image quality, scan conversion, etc.); MOLAB Operations Director Console (central operations monitor and control point).

Uplink TV will need equipment to supplement existing video transmission capabilities. New requirements include a live studio and the capability to store and recall documentary data (maps; drawings; instructions, etc.).

It is possible that further analysis will reveal additional requirements at MSFN remote sites. Such requirements would be met by GSE and GFE in van-mounted sets.

4.2 MOLAB TEST PROGRAM

The MOLAB Test Program has as its objective the development, qualification and acceptance of a system which, within the necessary program constraints, has the maximum probability of successfully performing its mission.

To meet this objective, a comprehensive test program will be conducted, involving all hardware assembly levels and all phases of testing; from early development and qualification testing through lunar checkouts of the MOLAB by the astronauts in conjunction with their exploratory mission.

The MOLAB test program philosophy and requirements reflect and amplify the intent of NASA's Apollo Test Requirements, M-D MA 1400.

The tests planned in accordance with this philosophy are typical of those for most manned spacecraft; development tests to gather engineering data, qualification tests to prove the adequacy of design, and acceptance tests to verify correct manufacture and maintenance of integrity. Emphasis has been placed on the qualification of the MOLAB system through thorough ground tests in lieu of flight development tests due to the nature of the system design and mission.

While all testing has been considered in the planning effort, stress is given to the identification of potential problem areas and/or more complex test activities with the associated approach and methods for accomplishment. Models, test articles and prototypes have been programmed to satisfy development and qualification requirements at the system or partial system level.

Development Tests

The MOLAB development program includes several areas requiring development testing: mobility, thermal balance, cryogenic storage, fuel cells, meteoroid protection, remote driving, etc.; however, relatively straightforward methods and technology exist for conducting these tests.

The more complex test activities consist of: mobility system tests using a 1/6 scale dynamic model and a full-scale steady-state model; thermal balance tests using a full scale test article; and astrionics integration tests using early developmental subsystems, bench checkout units, and ACE.

Qualification Tests

The qualification program is distinguished by its comprehensiveness. While taking advantage of applicable qualification gained from the Apollo Program, recognition has been made of unique MOLAB system, environmental, and operational requirements. Several of the more complex test activities are associated with the complete MOLAB and consist of: testing a mobility system designed for lunar gravity under Earth gravity; verifying the environmental control capabilities; and demonstrating that the MOLAB is compatible with other elements of the total ALSS, such as the astronauts, remote driving station, spacecraft, etc. Two fully configured MOLAB prototypes are utilized in these qualification tests.

Acceptance Tests

The acceptance test program includes a series of sequential and related functional acceptance tests conducted at all levels of hardware assembly such that degradation of performance will be readily detected at any point in the processing flow. Both ambient and environmental space chamber tests on each completed MOLAB have been programmed providing a performance data baseline against which subsequent pre-mating, prelaunch and lunar checkout data may be compared.

Figure 4.2-1 summarizes the test program phases and shows the major models, test articles and prototypes.

TEST PROGRAM PHASING SUMMARY

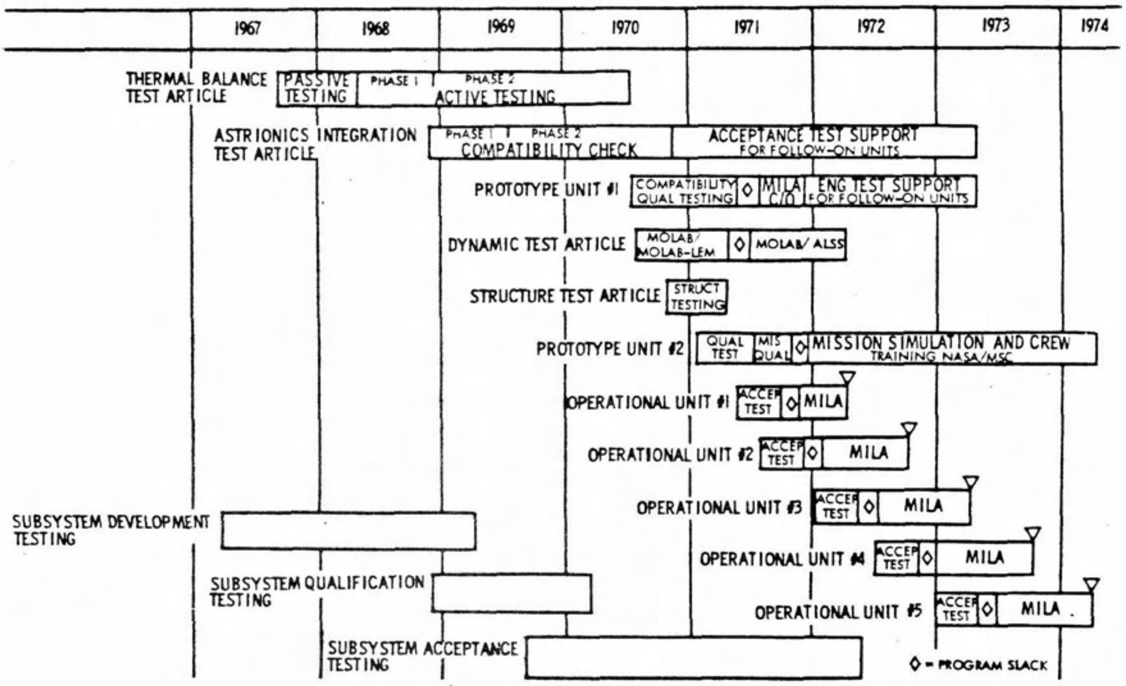


FIGURE 4.2-1

5.0 OPERATIONS ANALYSIS

The operations analysis effort served several purposes during the course of the study, including:

- Provision of a mission model to support the design and analysis efforts.
- Evaluation of MOLAB concept performance flexibility.
- Development of operational sequence logic.
- Operational plan development.
- Evaluation of failure modes and effects.
- Assessment of reliability and crew safety.

The following sections summarize selected areas of the effort.

5.1 OPERATIONAL SEQUENCE ANALYSIS

Analysis was conducted to investigate mission operational requirements and to verify the ability of the baseline MOLAB concept to support their accomplishment. An objective of the effort was to develop the mission operational sequence logic for the baseline MOLAB as a system, rather than for particular subsystems. The effort was directed towards those sequences common to the general MOLAB mission concept, rather than a specific mission plan.

The mission operational logic development provided a tool for the integration of system and subsystem functional requirements into a sequential flow of mission events. This exposes operational interfaces between system elements and establishes a firm basis for mission operational planning.

5.2 BASELINE SCIENTIFIC MISSION DEFINITION AND ANALYSIS

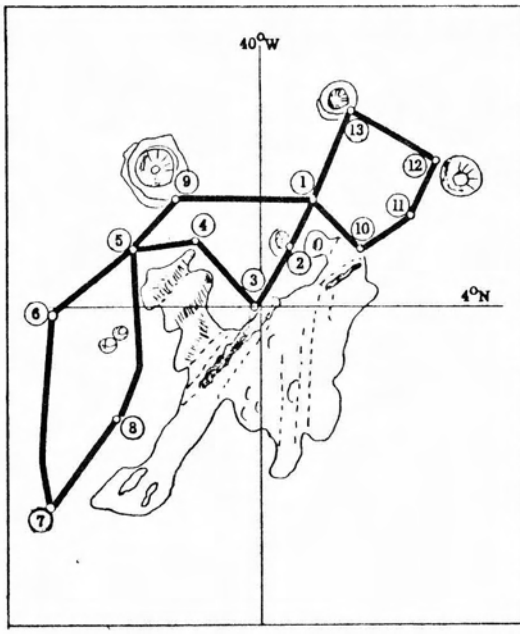
A baseline MOLAB mission was synthesized, based on the guidelines of Annex B to ALSS Statement of Work, and considerations of system constraints and astronaut limitations.

The mission includes the following basic features:

- 14-day stay time. (9 days sunlight, 5 days earthlight)
- A 274 km scientific traverse, composed of a 200 km portion traversed during the lunar day, and a 74 km portion traversed during the earthlight phase.
- The traverse includes 13 sites (stations) of scientific interest at which specific scientific routines are accomplished.

Figure 5.2-1 depicts the traverse, showing the scientific station locations and a distance summary.

BASELINE MISSION TRAVERSE



STA. SEQUENCE	CUM. DIST., KM	RETRACE DIST, KM
1	0	0
2	8	8
3	23	23
4	39	39
5	50	50
6	70	70
7	107	107
8	128	128
5	162	162/50
9	174	62
1	200	88/0
10	214	14
11	226	26
12	238	38
13	256	56
1	274	74/0

FIGURE 5.2-1

A sequence of mission operations was synthesized for the specified 14-day mission, using operations and task analysis and time-line analysis techniques. This provided detail mission operations data to support design and analysis efforts. In addition, the ability of the system to accommodate the postulated workload was verified. The mission time line is summarized in Table 5.2-1.

The synthesis of the baseline mission provided a basis for selecting the items of scientific equipment that are required to satisfy mission requirements. This equipment was evaluated in terms of usage mode and operational requirements to identify requirements imposed on the MOLAB.

CREW TIME SUMMARY

ACTIVITY CATEGORY	CREW DUTY ALLOCATION		%
	MAN A	MAN B	OF MISSION TIME
CREW PERSONAL			
SLEEP	91.0	90.5	27.0
EAT & PERSONAL HYGIENE	22.0	22.0	6.5
DRIVING			
VEHICLE CONTROL	34.0	25.0	8.8
OBSERVATION & NAVIGATION	18.7	24.3	6.4
SCHEDULED VOICE COMM.	7.0	7.0	2.1
OPERATIONAL			
MAINT. & HOUSEKEEPING	14.5	15.5	4.5
MISCELLANEOUS	25.6	25.6	7.6
SCIENTIFIC			
EXTRAVEHICULAR	58.9	57.9	17.4
EXPERIMENT SUPPORT (INSIDE)	37.7	39.8	11.5
DRILLING SUPPORT	5.1	4.4	1.4
CONTINGENCY	21.5	24.0	6.8
TOTALS	336.0	336.0	100.0

TABLE 5.2-1

5.3 MISSION VALUE ASSESSMENT

For the purpose of mission value assessment, scientific activity is divided into four categories:

- Physical experimentation.
- Geological reconnaissance.
- Detailed geological studies.
- Bioengineering and biomedical studies.

Each category contributes significantly to the sum of scientific data extracted during the manned portion of the mission. The value of the data accumulated in each category is related to numerous factors; however, a single major parameter has been selected upon which to base the data value assessment in each category. The unweighted data value for each category is unity for the baseline mission. Other levels of accomplishment are related to this standard through applicable formulas.

Assessment parameters are as follows:

Category	Assessment Parameter
Physical experimentation	Point value rating of experimentation performed
Geological reconnaissance	Distance traversed
Detailed geological studies	Number of sites studied
Bioengineering and biomedical studies	Mission stay time

Since the activity categories represent particular areas of interest which are not necessarily of equal scientific value, importance of weighting factors are applied to activity data values. The scientific value of a particular mission is in the sum of the various activity data value assessments, each having been adjusted by the proper weighting factor.

Figure 5.3-1 shows the accrual of mission scientific value for the 14 day baseline mission. Also indicated are the values of four alternate missions which were synthesized as baseline mission curtailments. This mission family consists of:

Alternate 1 - 7 days of local operation at the LEM Truck landing site; 5 local sites visited; 30 m core hole drilled.

Alternate 2 - 9 days of stay time; completion of the 200 km day loop traverse; no deep core drilling.

Alternate 3 - 10 days of stay time; completion of the 200 km day loop traverse; 30 m core hole drilled.

Alternate 4 - 5 days of stay time; completion of the 74 km night loop traverse; no deep core drilling.

MISSION VALUE SUMMARY

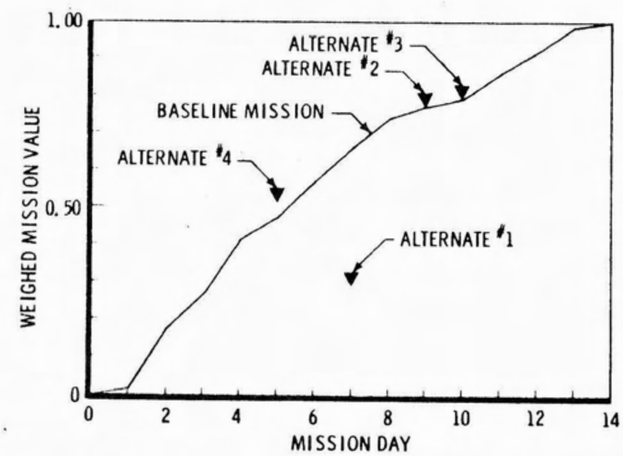


FIGURE 5.3-1

5.4 ALTERNATE MISSION CONSIDERATIONS

The investigation of MOLAB missions deviating from the baseline provided a means for evaluating the flexibility of the baseline MOLAB design. The requirements for alternate missions evolve from the following:

- Revised mission goals.
- Reassessed terrain or vehicle performance.
- System degradation or malfunction effects.

The analysis of alternate mission sequences for a specific MOLAB design must consider the total mission time-energy balance. This balance involves the resources of astronaut man-hours, total available energy for locomotion and science equipment operation, life support oxygen, and cooling water.

In order to evaluate the relative effects of revised mission planning and system malfunctions, the assessment technique outlined in Section 5.3 is applied. Through the assessment of resultant mission scientific value, adverse trends can be identified.

5.5 RELIABILITY AND SAFETY ANALYSIS

Table 5.5-1 summarizes the reliability predictions made versus the goals established. The reliability values for the MOLAB and its major systems represent the probabilities of success considering only hardware failures of the MOLAB systems. Reliabilities for the scientific equipment, tie-down and unloading equipment, and ground support equipment are shown as goals, not results of prediction or assessment.

MISSION SUCCESS SUMMARY

SYSTEM	GOALS	MINIMUM SUCCESS MISSION	BASELINE MISSION
MOLAB	0.90	0.918	0.8507
CABIN	0.964	0.945	0.9493
MOBILITY	0.997	0.9993	0.9693
POWER	0.979	0.9988	0.9778
ASTRIONICS	0.959	0.9771	0.9493
SCIENTIFIC EQUIPMENT	0.999	0.999	0.999
TIE DOWN AND UNLOADING	0.998	0.998	0.998
GROUND SUPPORT EQUIPMENT	0.999	0.999	0.999

TABLE 5.5-1

The reliability predictions for the minimum success mission (Figure 5.3-2, alternate #1), were completed first using the same reliability block diagram model that was used for the initial goal apportionment. More detail was available by the time the baseline mission assessment was begun that allowed construction of a model that accounted for equipment functions and failure effects by mission phases. This more detailed model utilized the results of the subsystem failure mode and effect analyses in developing the baseline mission reliability prediction.

The results from the baseline mission reliability prediction and the failure mode and effect analyses were used for the system safety analyses. These analyses began with the reliability prediction for the manned phase of the baseline mission and examined the alternate means available for the astronauts to return to LEM from an aborted mission. The preferred mode of abort was in the MOLAB as long as it was habitable and manageable. If MOLAB had to be abandoned within 3.2 kilometers of LEM, it was assumed the astronauts would choose to walk back. Beyond that distance, the LFV would be used. These analyses indicated the abort rate to be about 75 expected per thousand missions. Of these, about 72 would result in a successful return to LEM for an overall mission safety prediction of 0.997.

6.0 RESOURCE ANALYSIS

6.1 GENERAL

A portion of the MOLAB study was devoted to a resource analysis, which defines in terms of dollars and manpower needed, the effort to develop, design, construct, test and deliver five operational MOLAB payloads and associated GSE to appropriate government agencies. In addition, the facilities and time that would be required to support this effort were identified. This section summarizes this resource analysis and describes the approach taken, Team Member responsibilities, and results obtained.

6.2 GENERAL APPROACH

The approach in performing the resource analysis is outlined in Figure 6.2-1.

RESOURCE ANALYSIS APPROACH

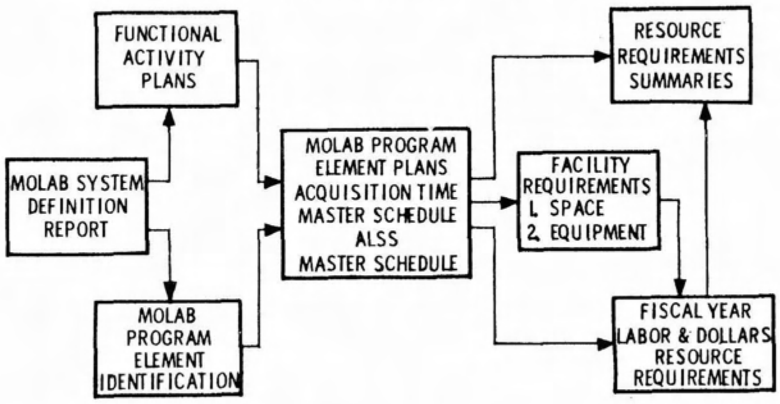


FIGURE 6.2-1

The objective was to provide an overall perspective of the approach for performing the required functions to: (1) develop, design, produce, test and deliver the MOLAB system defined by the Work Breakdown Structure, system and subsystem specifications and the system description; (2) establish the resources required to perform the functions.

The tasks involved were as follows:

- Develop and obtain NASA approval of a Work Breakdown Structure defining program hardware and software requirements to Level 5
- Prepare functional activity plans which define the ground rules and procedures for performing the functional tasks and activities required
- Clarify the work to be done by developing the system and subsystem specifications and descriptions for each hardware program element
- Develop program element plans to identify the decisions, tasks, activities, and activity sequences selected for doing the work and identifying the resources required

- Integrate the element plans to provide acquisition capability for the program elements and for the MOLAB system

- Time phase the MOLAB acquisition capability with other restraining activities leading to hardware go-ahead, and develop delivery dates for operational hardware, and dates for launching MOLAB payloads

- Allocate the total resource requirements to support the schedule and establish fiscal requirements, and summarize these in appropriate plans

6.3 TEAM MEMBER WORK RESPONSIBILITIES

The resource analysis was conducted on the premise the work required for the acquisition of MOLAB will be assigned to the Boeing team as noted below:

- Boeing, as the prime contractor, will be responsible for the overall management and direction of the team effort and be the focal point for coordination with NASA and other ALSS Associate Contractors. In addition, Boeing will be responsible for the integration, testing and delivery of the MOLAB vehicle and its associated ground support equipment as well as for the design development, manufacturing and testing of all other MOLAB subsystems and related ground support equipment not supplied by the balance of the team. Team member responsibilities are stated below according to the MOLAB Work Structure Breakdown.

- General Motors will be responsible, as a major subcontractor, to The Boeing Company, to design, develop, manufacture, and test the following subsystems and related ground support equipment as well as providing support to The Boeing Company for the overall MOLAB system integration and testing tasks.

Drive Mechanism	Steering Mechanism
Wheel Assembly	Drive Power Distribution
Suspension Assembly	Navigation and Guidance

- Radio Corporation of America will be responsible, as a major subcontractor, to The Boeing Company, to design, develop, manufacture, and test the command and control subsystem and, with the exception of telemetry and antennas, all of the communication subsystem. Associated ground support equipment for these systems and components is also provided as well as support to The Boeing Company for the overall MOLAB system integration and testing tasks.

- The Garrett Corporation will be responsible, as a major subcontractor, to The Boeing Company, to design, develop, manufacture and test components of the environmental control subsystem and associated ground support equipment as well as providing support to The Boeing Company for the overall MOLAB ECS system integration and testing tasks.

The general approach planned by each team member for performing the management task at the project level, the project organization that is planned, and the approach that will be used to perform specific management tasks are noted in Sections 2, 3, and 4 of the MOLAB Management Plan - General, D2-83301-1.

6.4 RESOURCE ANALYSIS RESULTS

The resource analysis results are summarized below in terms of schedules, costs, and facility requirements.

6.4.1 Schedules

The schedule results summarized in Figure 6.4-1 provides a period of 20 months between completion of this study in April of 1965 to the start of hardware acquisition in January 1967, which will be used for conducting a program evaluation, updating a work statement and negotiating a contract.

ALSS MASTER PROGRAM SCHEDULE

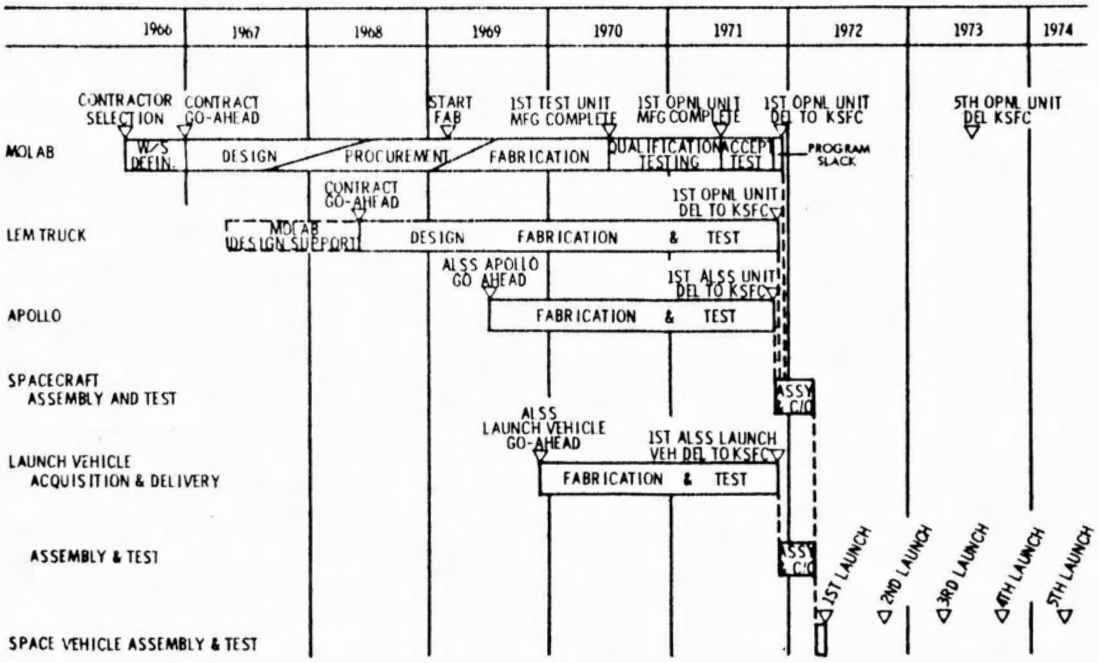


FIGURE 6.4-1

6.4.2 Costs

The cost results are shown in Table 6.4-1 and Figure 6.4-2 and provide the cost data for each hardware and software program element, the accumulative cost curve, and the fiscal requirements. These charts depict only contractor costs and do not provide for commitment liability or profit. The costs also reflects delivery f.o.b. Seattle of all items furnished, and include no allowances for post delivery contractor support. The procurement work package cost breakdown is shown in Table 6.4-2 and indicates the total cost of the work to be performed by the other Team Members as well as the procurement costs associated with the Boeing effort.

6.4.3 Facilities Requirements

No program dollars are required for industry facilities needed to produce and deliver the program end items.

Government facilities funds requirements in the amount of $1,080,000 have been identified to provide for industry needs on government operated facilities during post delivery support operations.

MOLAB COST BREAKDOWN

MOLAB COST BREAKDOWN OF PROGRAM ELEMENTS BY WORK PACKAGES — FUNCTIONAL WORK PACKAGES IN THOUSANDS

*THESE FUNCTIONS ARE NOT DIRECTLY ORIENTED WITH HARDWARE INTEGRATION BUT ARE SHOWN HERE TO SIMPLIFY THE MATRIX

PROGRAM HARDWARE ELEMENTS LEVEL 4	DESIGN	TEST	MANUFACTURING	PROCUREMENT	CREW FUNCTIONS	OPERATIONS & LOGISTICS SUPPORT	MANAGEMENT	FACILITIES PROVISIONING	TECHNICAL INTEGRATION	TOTALS
1.10.3 (HDWE INTEGR) MOLAB VEHICLE SYSTEM	16412	24926	2674	62	* 540	* 2989	34218	—	* 7560	89381
1.1 CABIN SYSTEM	12289	3755	5632	30418	-0-	-0-	-0-	—	-0-	52094
1.2 MOBILITY SYSTEM	10244	2852	3694	57400	-0-	-0-	-0-	—	-0-	74190
1.3 POWER SYSTEM	4586	1038	341	33303	-0-	-0-	-0-	—	-0-	39268
1.4 ASTRIONICS SYSTEM	8373	3195	1114	91913	-0-	-0-	-0-	—	-0-	104595
1.5 SCIENTIFIC EQUIPMENT	—	—	—	—	—	—	—	—	—	—
1.6 TIE DOWN AND UNLOADING SYSTEM	1675	555	934	378	-0-	-0-	-0-	—	-0-	3542
1.7 GROUND SUPPORT EQUIPMENT	26074	3262	8128	73906	-0-	-0-	-0-	—	-0-	111370
1.12 FACILITIES (HARDWARE)	—	—	—	—	—	—	—	—	—	—
GRAND TOTALS	79653	39583	22517	287380	540	2989	34218	—	7560	474440

TABLE 6.4-1

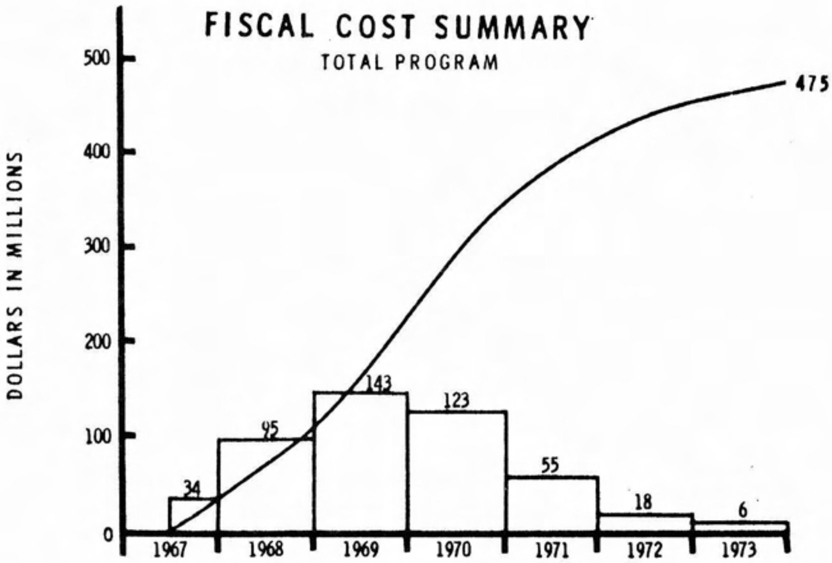


FIGURE 6.4-2

PROCUREMENT WORK PACKAGE

PROCUREMENT COST BREAKDOWN / HARDWARE ELEMENTS	ELEMENTS OF PROCUREMENT COST									
			MAJOR SUBCONTRACTORS							
	RAW MATERIAL AND STANDARDS	MINOR PROCUREMENT	GENERAL MOTORS DRL	RCA	GARRETT	GENERAL MOTORS ACSP	OTHER			TOTALS
1.10.3 (HDWE. INTEG.) MOLAB VEHICLE SYSTEM	62	-0-	-0-	-0-	-0-	-0-	-0-			62
1.1 CABIN SYSTEM	1113	2158	-0-	-0-	27147	-0-	-0-			30418
1.2 MOBILITY SYSTEM	264	1808	55328	-0-	-0-	-0-	-0-			57400
1.3 POWER SYSTEM	374	1925	-0-	-0-	-0-	-0-	31004			33303
1.4 ASTRIONICS SYSTEM	419	3498	-0-	68250	-0-	19746	-0-			91913
1.5 SCIENTIFIC EQUIPMENT PROVISIONS	—	—	—	—	—	—	—			—
1.6 TIE DOWN AND UNLOADING SYSTEM	190	188	-0-	-0-	-0-	-0-	-0-			378
1.7 GROUND SUPPORT EQUIPMENT	2882	19500	5145	30319	6290	9770	-0-			73906
1.12 FACILITIES	—	—	—	—	—	—	—			—
TOTALS	5304	29077	60473	98569	33437	29516	31004			287380

TABLE 6.4-2

6.5 RESOURCE ANALYSIS LIMITATIONS

The utilization of the MOLAB payload will require the implementation of several work items for which a resource analysis has not been performed in this study. These work items are identified on Figure 6.5-1

WORK ITEMS NOT INCLUDED IN THE BOEING MOLAB COST PACKAGE

1. SUPPORT FOR PREMATING CHECKOUT, PRELAUNCH AND MISSION OPERATIONS OF MOLAB AND ASSOCIATED G.S.E.
2. THE FOLLOWING TASKS ASSOCIATED WITH GOVERNMENT FURNISHED EQUIPMENT:
   - A. COMPATIBILITY TESTING OF SCIENTIFIC EQUIPMENT WITH MOLAB AND ITS ASSOCIATED G.S.E.
   - B. MAINTENANCE, REPAIR OR MODIFICATION OF G.F.E.
3. SUPPORT FOR PRE DELIVERY MOLAB TESTING AT GOVERNMENT FACILITIES (QUALIFICATION TESTING) OTHER THAN TEST ENGINEERS.
4. TRAINING OF CREW/ASTRONAUT, LAUNCH SITE PERSONNEL, AND OTHER GOVERNMENT PERSONNEL.
5. LUNAR BASED G.S.E.
6. SUPPORT ASSOCIATED WITH THE FOLLOWING TASKS AS DEFINED IN THE MANAGEMENT PLAN D2-83301-1, FIGURE 3.1-1.
   - A. ALSS SPACE VEHICLE INTEGRATION
   - B. ALSS SPACE CRAFT INTEGRATION
   - C. ALSS SYSTEM INTEGRATION
   - D. ALSS MISSION OPERATIONS
   - E. ALSS LAUNCH SITE PROVISIONS
7. WORK ASSOCIATED WITH:
   - A. MAINTENANCE OF MOLAB PAYLOAD AND ASSOCIATED G.S.E. SUBSEQUENT TO DELIVERY
   - B. ON SITE INCORPORATION OF CHANGES RESULTING FROM POST DELIVERY TESTING
   - C. PROVIDING FOR RETROFIT CHANGE KITS SUBSEQUENT TO DELIVERY
8. LEM TRUCK AND APOLLO SIMULATORS AS MAY BE REQUIRED FOR ACCEPTANCE AND QUALIFICATION TESTS FOR MOLAB AND ASSOCIATED GROUND EQUIPMENT.

FIGURE 6.5-1

7.0 MOBILITY TEST ARTICLE (BLOCK I)

7.1 INTRODUCTION

The Block I Mobility Test Article (MTA) is used to test the lunar surface vehicle concept selected for the MOLAB and the LSSM. The design utilizes the 6 x 6 semi-articulated mobility subsystem with the minimum required structure to support: the operator; operator's seat; a roll bar; instrument display; controls; and power, attitude sensing, and communication equipment.

The scope of work performed under this contract was the initiation of a design and preparation of procurement specification for a full scale Block I MTA.

The preliminary design is based on the mobility configuration concept developed for the MOLAB and used as an example for the LSSM; however, the MOLAB basic vehicle dimensions were used and an attempt was made to confine its estimated mass to 1/6 of MOLAB mass.

The purpose of the Block I MTA is to perform lunar simulation steady-state mobility tests on Earth, including soft soil and obstacle negotiation tests.

Provisions would be included in the design of the Block I MTA so that it can be modified for anticipated subsequent dynamic tests (Block II MTA).

7.2 DESCRIPTION

Figure 7.2-1 shows the general configuration. In order to simulate lunar gravity on Earth by obtaining equivalent steady-state response, it was a design goal to have the MTA mass equal to 1/6 of the MOLAB mass. In order for the mobility elements to be full size and have the required strength, it is necessary that these elements on the MTA be approximately the same mass as on the MOLAB. Since they represent approximately 1/6 of the MOLAB mass and the MTA must include the additional elements noted in 7.1 above, the 1/6 MOLAB mass could not be met. The estimated MTA mass approaches 1/4 of the MOLAB mass. The desired steady state test results are, however, not significantly affected by this mass difference.

MTA GENERAL CONFIGURATION

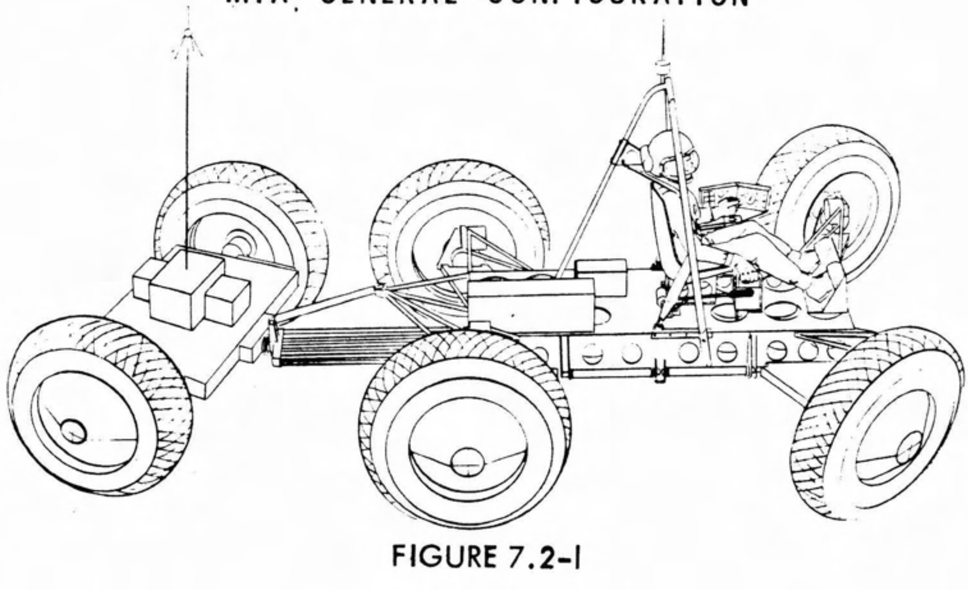


FIGURE 7.2-1

The structure is typical airframe type construction. The vehicle is supported by a torsion bar suspension system. The torsion bars are designed for adjustment to facilitate leveling the vehicle and for easy replacement with bars having a different spring rate as would be required for the Block II MTA. The front wheels utilize Ackermann type steering and the aft unit uses articulated steering which is coordinated with front wheel steering. Steering will be accomplished through hydraulic actuation. The wheel dampers are adjustable to accommodate various MTA gross weights. The wheels are of the MOLAB wire mesh design, except that for Block I, to accommodate the increased weight, the inner frame within the wheel is replaced with an inner tube which can be inflated to duplicate the MOLAB tire deflection. Each wheel is driven by an electric motor through a gear reduction and a harmonic drive unit. A 28/56 volt battery is installed on the aft unit.

The MTA has electrically controlled hydraulic service brakes and spring actuated band type parking brakes. The parking brakes can be de-activated electrically.

The MTA instrumentation provides for 61 data channels. The system is designed to telemeter, to a ground station, all the data necessary for measuring vehicle performance. Among the many functions included are vehicle speed and distance, local accelerations, attitudes, voltages, currents, temperatures, and wheel torques.

7.3 SUMMARY

The MTA test program will evaluate the mobility characteristics of the six-wheeled semiarticulated concept of lunar surface vehicles. It will permit evaluation of the flexible-frame, pitch-limiter, suspension and wheel characteristics as they relate to mobility and will augment existing scale model test data. It should be noted that both the MOLAB and the LSSM vehicles use this same vehicle concept and differ principally only in relative dimensions. Therefore, MTA test results are applicable to both vehicles.

The test program will also afford an opportunity to evaluate man/machine relationships, particularly in regard to vision and controller versus control characteristics.

8.0 LUNAR SHELTER/LABORATORY AND SMALL LUNAR SURFACE VEHICLE

The approximately 10 percent portion of the ALSS Payloads Preliminary Design Study devoted to the Lunar Shelter Laboratory/Small Lunar Surface Vehicle concept was directed at the elements of an Apollo Extension System (AES) lunar surface exploration payload, as directed by MOLAB Note 031.

The primary objective of the study was the analysis of mission operations and system performance to determine the parameters of an optimum surface mobility aid (Local Scientific Survey Module) that would be included in the AES payload. A conceptual design was prepared for an example LSSM to further guide future preliminary design studies of this type of exploration vehicle.

8.1 ELEMENTS OF THE AES PAYLOAD

Preliminary physical and performance definitions were established for the three principal constituents (in addition to LEM-Shelter of the AES Payload; surface mobility aids (LSSM), flying mobility aids (LFV), and scientific equipment.

8.1.1 LSSM

A principal constraint in AES payload element definition is the stowage volume available within the modified LEM envelope. This constraint, as defined by Appendix 1 of Note 031, was studied with the aid of a 1/20 scale mockup to establish limiting dimensions and overall proportions for LSSM's in two size ranges. These are approximately 60% to 80% of MOLAB size, respectively. The smaller vehicle is basically unsuited for 2-man operation due to center-of-mass, height and resulting degraded stability characteristics. It could, however, carry a second astronaut in lieu of cargo for special situations. The larger vehicle can accommodate a 2-man crew as a normal operating mode. Both six- and four-wheeled examples of these basic 1-man and 2-man vehicles were considered.

Mobility system mass estimates were based on the LSSM proportions established from volume constraints, and on MOLAB mobility system design studies.

Power system mass estimates were guided by preliminary formulations of mission profiles and preliminary estimates of LSSM locomotion, astrionics and scientific equipment power loads. The calculations indicate a mission energy requirement of 24 kw-hr, with peak power load of approximately 3 kw in the case of scientific drill operations. Mass estimates were made for H_2-O_2 fuel cell (with supercritical reactant storage), rechargeable Ag-Zn battery, and a family of RPU-battery power generation systems. A power system mass of the order of 100 kg. is indicated.

Three astrionics subsystem mechanizations were formulated to meet three levels of possible performance ranging from minimal to elaborate. Although final LSSM design may be expected to provide a hybrid of these three levels, this approach permitted the parametric definition of a spectrum of possible astrionics subsystem mechanizations. For purposes of LSSM preliminary definitions, mass and power allotments on the order of 60 kg and 100 watts appear reasonable.

LSSM definition in terms of approximate vehicle mass is completed by relating desired maximum payload mass to vehicle unladen mass, Figure 8.1-1. Preliminary mass estimates of 300 kg and 500 kg are derived for the 1-man and 2-man LSSM's respectively, corresponding to payload allowances of 280 and 440 kg.

Preliminary performance analysis of the 1-man and 2-man LSSM vehicles revealed only small locomotion energy and mobility differences between vehicle sizes and configurations. The obstacle capability studies indicate advantages of six-wheeled configurations in step climbing and crevice crossing. For a given mobility system configuration, the difference in capability of the two vehicle sizes is relatively small.

LSSM MASS INCREMENTS

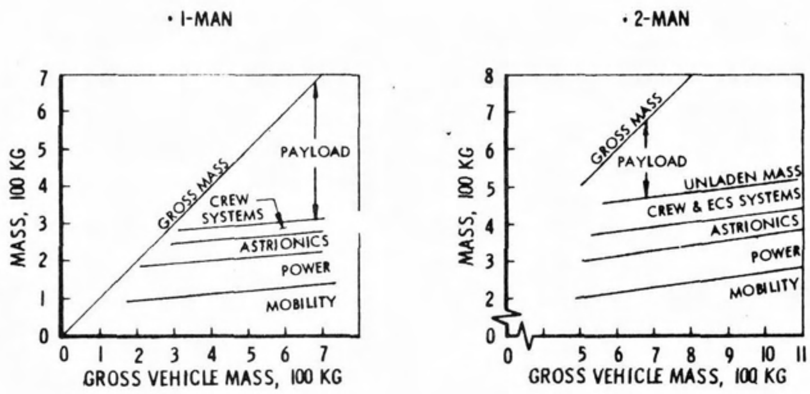


FIGURE 8.1-1

8.1.2 Lunar Flying Vehicle (LFV)

Performance estimates were made for point-to-point round trip missions via LFV at optimum velocity to define the relationships between propellant mass requirements, payload mass (including crew), and mission radius capabilities. These data are approximate only, since they reflect such simplifying assumptions as fixed dry mass regardless of propellant and payload mass, and fixed thrust-to-weight ratio regardless of vehicle mass.

8.1.3 Scientific Equipment

The equipment for the AES scientific payload was selected and placed into categories according to Appendix 2 of MOLAB Note 031. The value ratings for scientific equipment established by Bendix in their Scientific Mission Support Studies were normalized on the basis of the total equipment candidate list. Plotting these value increments vs the associated mass increments, with priority order as established by the Bendix ratings, results in the value rating chart shown in Figure 8.1-2.

SCIENTIFIC EQUIPMENT VALUE

• BASED ON BENDIX SMSS - BSR 1074

• NORMALIZED TO 507 KG = 100

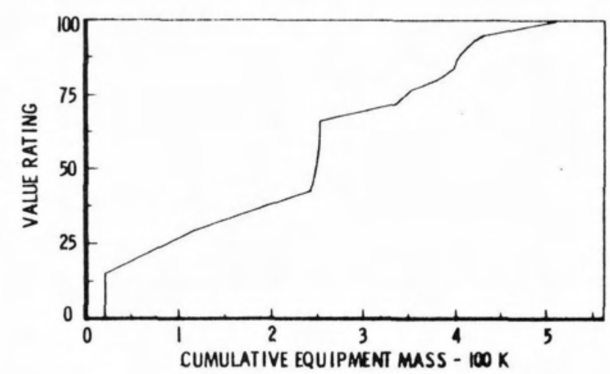


FIGURE 8.1-2

8.2 AES MISSION ANALYSIS

Geological reconnaissance is considered of highest priority for early lunar surface missions, and about two-thirds of the sorties should be of this type. Two-man operation enhances mission efficiency by allowing the geologist to concentrate on his primary discipline during and between stops while the driver performs the secondary tasks of driving, surveying, sampling, and photography.

Approximately 50 percent of the sortie duration will be utilized in travel, and the extent of reconnaissance traverses will be dependent upon the vehicle speed. A cruising speed of 8 km/hr is required to complete a 24 km traverse to the outer limit of the available area during a six-hour sortie.

Geophysical experimentation is considered of second priority and about one-third of the planned sorties should be of this type. One-man operation is adequate since observation of the terrain for other than driving purposes will not be necessary. Stations may be selected and located during geological reconnaissance. Sorties to pre-selected and located stations without the necessity for observational duties during travel will yield maximum time for actual experimentation.

Because of PLSS limitations on astronaut activity time outside of the LEM-Shelter, a relatively large block of mission time is available for scientific activities conducted within the LEM-Shelter. A correspondingly large amount of scientific equipment can be effectively employed in these activities.

8.3 AES PAYLOAD ELEMENT EVALUATIONS

The mobility and scientific elements of the AES payload were evaluated in terms of their contributions to the three mission categories of geological reconnaissance, geophysical experimentation, and LEM-Shelter experimentation.

8.3.1 Geological Reconnaissance

The relative capabilities of 1-man and 2-man LSSM vehicles for geological reconnaissance within the framework of the AES lunar surface exploration concept were evaluated on the basis of their ratings in four mission success factors. The LFV is excluded from this evaluation since its performance characteristics are basically unsuited to geological reconnaissance operations.

Of the four rating factors, crew carrying ability is rated highest in importance (40%) on the basis of operations considerations that emphasize the importance of providing for a specially trained scientist, with maximum freedom to concentrate on his observations. Vehicle speed and mobility characteristics are rated next in importance (25% each). Cargo carrying capacity is rated lowest (10%) since the mission requires a minimum of scientific payload.

On these bases, the 2-man LSSM exhibits a 50% mission success advantage over the 1-man vehicle.

8.3.2 Geophysical Experimentation

Both 1-man and 2-man LSSM vehicles and the LFV were evaluated against the mission success factors of geophysical experimentation missions. In this case, the time available for remote site experimentation is considered of chief importance (50%). The LFV rating in this category is based on additional analyses that indicated only one sortie could be conducted without excessive penalty to the total mass allowance for scientific equipment. Mobility and cargo capacity are judged next in importance (20% each). Crew capacity is ranked lowest (10%) since 1-man operation is considered adequate for remote experimentation operations.

The 30% advantage of the 2-man LSSM over the other candidate mobility aids is less pronounced than in the case of geological reconnaissance and would be even less so with more pessimistic vehicle speed assumptions.

8.3.3 LEM-Shelter Experimentation

The rating for LEM-Shelter experimentation is obtained by considering the scientific equipment mass allowance and the accumulative equipment mass scoring curve shown in Figure 8.1-2. No additional value is allowed for equipment inventories in excess of 507 kg., since requirements for only that amount have been identified at this time.

8.4 AES PAYLOAD CONFIGURATION COMPARISON

A representative set of AES lunar surface exploration payload configurations (Table 8.4-1) was formulated by establishing six feasible combinations of the three candidate mobility aid payload elements (1-man and 2-man LSSM's and the LFV) to accommodate three types of surface missions (geological reconnaissance, geophysical experimentation, and rescue). Estimated mass allowances for system integration were then added to the vehicle combination masses, and the difference of this total from 1136 kg defined the final element of scientific equipment mass.

AES PAYLOAD CONFIGURATION

<table>
<tr><th rowspan="2">ELEMENT</th><th colspan="6">CONFIGURATION</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td>GEOLOGICAL RECONNAISSANCE VEHICLE</td><td>1-MAN LSSM</td><td rowspan="2">2-MAN LSSM</td><td rowspan="2">2-MAN LSSM</td><td rowspan="2">1-MAN LSSM</td><td rowspan="2">1-MAN LSSM</td><td rowspan="2">2-MAN LSSM</td></tr>
<tr><td>GEOPHYSICAL EXPERIMENTATION VEHICLE</td><td rowspan="2">LFV 400</td></tr>
<tr><td>RESCUE VEHICLE</td><td>NONE</td><td>LFV 260</td><td>NONE</td><td>1-MAN LSSM</td><td>1-MAN LSSM</td></tr>
<tr><td>SCIENTIFIC EQUIPMENT MASS, KG</td><td>361</td><td>536</td><td>251</td><td>786</td><td>461</td><td>211</td></tr>
<tr><td>SYSTEM INTEGRATION ALLOWANCE, KG</td><td>75</td><td>100</td><td>125</td><td>50</td><td>75</td><td>125</td></tr>
</table>

TABLE 8.4-1

The LFV mass of 400 kg in Configuration 1 provides sufficient propellant for a single 8 km distant geophysical reconnaissance sortie, plus reserves for a rescue mission. The LFV mass of 260 kg in Configuration 3 provides for a single rescue mission only

8.4.1 Crew Safety

Preliminary safety analyses were conducted based on typical 14-day missions and payload configurations incorporating various combinations of the vehicles discussed previously.

In general, all of the LSSM vehicles appear to be quite safe in this analysis. The analysis, however, shows that the LFV is apparently less safe in its use as an operational vehicle.

8.4.2 Mission Success

The six AES lunar surface exploration payload configurations were evaluated for mission success potential by weighting and combining their capability ratings in each of the three facets of the scientific mission. The weighting factors used reflect mission analysis estimates that emphasize the importance of geological reconnaissance activity, especially for early lunar exploration missions.

Configuration 2, incorporating a single 2-man LSSM and 536 kg. of scientific equipment, scores distinctly higher than the other five in mission success potential.

Although it is recognized that more refined analyses of crew safety and mission success may result in different conclusions, this evaluation is considered sufficiently clear cut to warrant the selection of Configuration 2 as the basis for initial conceptual design studies.

8.5 EXAMPLE LSSM CONCEPTUAL DESIGN

As a result of the preliminary operations and performance analyses, general system requirements were established and used as the basis for an example LSSM conceptual design (XLSSM):

- The mobility subsystem will be based on a 6 x 6 semi-flexible frame configuration similar to that incorporated on MOLAB.
- The LSSM will provide capability for carrying a two-man crew plus 170 kg of scientific equipment.
- The target unladen mass (fully fueled but without crew or cargo) is 500 kg.
- A 300 watt radioisotope thermionic generator will be used in conjunction with a 4 kw-hr battery.

Table 8.5-1 and Figure 8.5-1 summarize the dimensional characteristics and general arrangement of the XLSSM.

Table 8.5-2 summarizes estimated mobility performance characteristics of the XLSSM. Table 8.5-3 summarizes the XLSSM mass estimates.

XLSSM GENERAL CHARACTERISTICS

GROSS VEHICLE WEIGHT WITH 2 MAN CREW	1005 KG (2212LBM)
AXLE LOADS	
AXLE 1	35.9%
AXLE 2	31.7%
AXLE 3	32.4%
LENGTH (OVERALL)	4.88 M (192 IN)
WIDTH (TO OUTSIDE OF WHEELS)	2.34 M (92 IN)
WHEEL BASE (OVERALL)	3.66 M (144 IN)
TREAD	2.03 M (80 IN)
WHEEL DIAMETER	1.22 M (48 IN)
WHEEL WIDTH	0.30 M (12 IN)
WHEEL DEFLECTION AT NOMINAL LOAD	6.10 CM (2.4 IN)
GROUND CLEARANCE	0.51 M (20 IN)
ANGLE OF APPROACH	90° +
ANGLE OF DEPARTURE	90°

TABLE 8.5-1

XLSSM GENERAL ARRANGEMENT

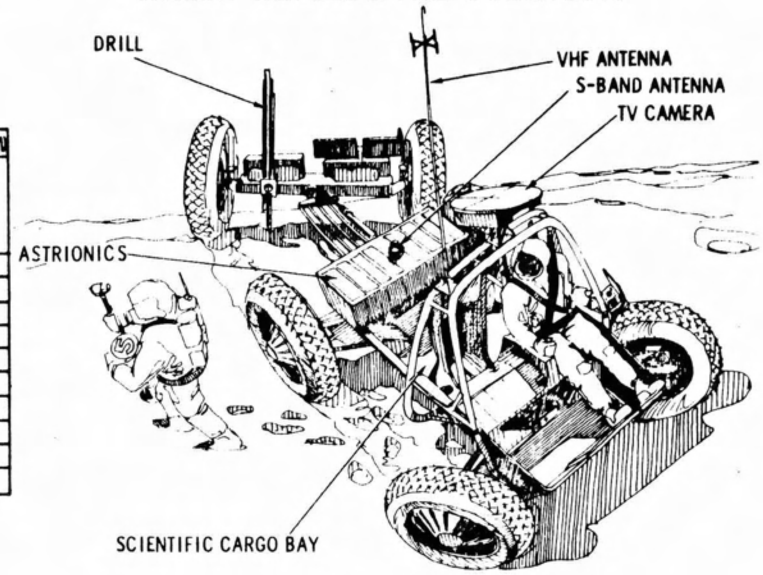


FIGURE 8.5-1

XLSSM PERFORMANCE CHARACTERISTICS

DP/W @ k_ϕ = 0.083, n = 1.0, ϕ = 20°	0.23
STEP OBSTACLE CAPABILITY	1.55 M (61 IN)
CREVICE CROSSING CAPABILITY	1.55 M (61 IN)
TURNING RADIUS (MINIMUM)	5.43 M (214 IN)
OFF-TRACKING	0.29 M (11.5IN)
STATIC SIDE SLOPE STABILITY	48°
STATIC LONGITUDINAL SLOPE STABILITY	62°
LOCOMOTION ENERGY OVER ELMS UPLANDS MODEL	90 W-hr/km
VELOCITY CAPABILITY OVER ELMS MARIA MODEL	6.9 km/hr

TABLE 8.5-2

XLSSM MASS SUMMARY

DESCRIPTION	MASS	
	LBM	KG
POWER SYSTEM	259	118
ASTRIONICS SYSTEM	120	55
MOBILITY SYSTEM	695	316
CREW SYSTEM	65	29
TOTAL UNLADEN MASS	1139	518
ASTRONAUTS	402	182
PLSS	290	132
SCIENTIFIC EQUIPMENT	381	173
GROSS VEHICLE MASS	2212	1005

TABLE 8.5-3

8.6 STUDY CONCLUSIONS

It is important to keep in focus the particular judgments and assumptions that influenced the course of this analysis. The emphasis placed on the suitability and effectiveness of manned geological reconnaissance for early lunar exploration missions, with the associated high-value mobility aid parameters of speed and 2-man crew capacity, was chiefly responsible for the indicated advantage of the largest size LSSM that can be provided.

The indecisive nature of the safety analysis, which was not interpreted as indicating a material advantage for a system incorporating a redundant rescue vehicle, further supported the advantage of a single large vehicle over two smaller vehicles.

The XLSSM preliminary mass and performance estimates are considered reasonably valid, since from a mobility system viewpoint the vehicle is essentially an 80% scale MOLAB. However, the subsystem design concepts that affect the vehicle's operational usefulness are in many cases distinct from those suitable for MOLAB, and further work will be necessary to define an optimum design.

A more objective analysis of lunar scientific missions is necessary to establish the requirements placed upon the exploration system by the scientific endeavor. This analysis should detail mission profiles to accomplish specific scientific tasks and to reflect realistic estimates of man's capabilities under the extremes of stress that will characterize lunar surface exploration.

Additionally, more detailed LSSM preliminary design and program definition studies should be conducted. These could utilize the current XLSSM conceptual design as a point of departure, and initially examine in more depth the impact of alternate subsystem design concepts on vehicle performance and mission safety.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 RESEARCH AND ADVANCED TECHNOLOGY

A complete and well-validated scheduling and costing of the entire MOLAB program has been made, including necessary research and development work, assuming the start of the acquisition phase in January, 1967. Listed below are those areas of research and advanced technology development in which earlier work would be most beneficial to the MOLAB and other lunar exploration programs. It is recommended that these items be implemented before 1967 to enhance the early delivery of a successful lunar exploration system in a cost effective manner.

9.1.1 Biotechnology and Human Research

Space Suit Development - Man's scientific effectiveness on the Moon will be bounded to a large degree by mobility and dexterity afforded by the pressurized space suit. Capability beyond that of current space suits or their foreseeable derivatives should be a development objective. Development should proceed on a non-specular reflective space suit coating compatible with thermal requirements.

Astronaut Vision - A comprehensive simulation should be made of the astronaut navigating and driving task under lunar lighting and reflectance conditions, with object recognition against non-contrasting backgrounds.

Lunar Gravity Effects on Man - Research required involves further definition of man's work capability, the physiological effects of near weightlessness, and man's reaction to multiple stresses (noise, heat, vibration, work load) while under reduced gravity.

9.1.2 Electronics and Control

Remote Driving - Detail design of the television subsystem requires that a laboratory simulation program be conducted to define:stereo baseline; frame rate and resolution versus speed and task; and vehicle motion effects on operator efficiency. Analog simulation of the MOLAB on-board control loop has verified the chosen design concept, but a total system simulation with a remote human operator is required. An astrionics equipped MTA would be appropriate.

VHF Propagation - Theoretical and experimental research should proceed to establish feasibility of a beyond line-of-sight VHF communications and radio direction finding capability on the Moon.

9.1.3 Materials and Structures

Cryogenic Tanks - Insulation development should focus on the practical means of achieving reproducible, near-theoretical conductivities for insulation applied to MOLAB-type tanks. Special emphasis must be placed on the design and development of an integrated cryogenic storage system meeting MOLAB requirements.

Lubrication and Bearings - Bearings and lubricants will probably present the most severe materials problems in the entire vehicle. MOLAB and other lunar vehicle usage is unique because of the relatively high load and shock requirements in combination with low temperature, high vacuum, and dust environment. Current knowledge must be supplemented by a comprehensive test program.

Thermal Coatings - Added weight in water boiling would be required if expected surface coatings were not achieved. Current experimental coatings approach the requirements, but development work is required to obtain production quality coating to survive the long term lunar exposure.

Hatch Seals - MOLAB has a stringent compartment leakage design goal. An analysis and test program is recommended to develop and demonstrate sealing adequacy.

9.1.4 Power Systems

Radioisotope Power Unit - A development program should be started leading to the availability of a low-mass 100-watt radioisotope thermoelectric generator for MOLAB. This requirement stems from power demands of the MOLAB during storage. A conclusion was reached, during the failure mode and cost effectiveness analysis, that added safety would be provided the crew (in the case of complete fuel cell/power cryogenic failure) if the RPU was sized at approximately 300-500 watts. Also, studies of the LSSM power requirements indicate that 250-300 watts is optimum for postulated missions. Therefore, additional system analyses and design feasibility work should be centered on a 300 to 500 watt thermionic generator for both MOLAB and the LSSM.

Fuel Cell - A fuel cell development program is required to meet the MOLAB performance and mass allocations. New fuel cell designs indicate savings of 450 kg over use of the Apollo design. Since the time to qualified hardware is estimated to be 40 months, this item is one of the significant pacing items for the MOLAB Program.

9.2 LUNAR ENVIRONMENT

9.2.1 Meteoroids

Primary sporadic meteoroids, meteoroid showers, and secondary lunar ejecta caused by the primary particles constitute the hazard for which MOLAB must be designed. Current MOLAB design criteria are in line with available data; however, no rational account is taken of meteoroid showers or ejecta. These latter effects may impose severe restraints on the MOLAB design. The lunar surface meteoroid hazard could best be studied by a stationary lunar-based penetration-type sensor with omni-directional sensing areas.

9.2.2 Surface Temperature

Further attention should be placed on defining minimum lunar surface temperatures. Minimum temperature can affect environment control, materials selection and component test environments.

9.2.3 Surface Composition and Terrain

An early, encouraging indication is the relative agreement of surface roughness content between Ranger 7 derived data and the assumed surface for MOLAB design. Surface sampling by Surveyor may yield data that could permit further optimization of mobility design.

9.2.4 Particulate Radiation

Additional data is required on solar particle events, solar wind and electromagnetic radiation to determine their potential hazard to MOLAB. Solar Cycle 20 research plans appear adequate in obtaining this data.

9.3 SUGGESTED ADDITIONAL EFFORT

9.3.1 Beneficial Early Development

Very little new basic research is required for MOLAB. It is recommended that the engineering development and study tasks which have been identified be implemented. A first step should be the detailed description and time phasing of the various recommendations.

9.3.2 LEM Truck Capability

The LEM Truck descent mass capability is very important in defining the MOLAB vehicle and its lunar surface operation. It is appropriate that this capability be defined as well as possible now and that future MOLAB work be constrained to produce a mission/design consistent with this capability.

9.3.3 Ground Support Equipment

Further study is required in the area of Ground Support Equipment. An early identification and integration of all GSE Requirements to support the MOLAB System Concept is necessary to make maximum utilization of existing Apollo ground equipment at KSC, MSC, MSFN remote site stations, and identify any additional lower level equipment not covered by this study.

9.3.4 MOLAB/Scientific Experiments Integration

More detailed examination is required of the packaging, operability and interface requirements of the MOLAB scientific experiment packages. As an example, the drill, as currently configured, does not lend to effective integration with the MOLAB vehicle.

9.3.5 MOLAB Adaptation to Mission Criteria Variations

It is recommended that the proposed MOLAB vehicle and its operation be reviewed for conformance with missions in which some of the basic criteria are different. Suggested studies include: reduction of six months storage to three months, in which the launch pad operations are part of the study; and a study of landing MOLAB outside of the currently considered lunar latitude-longitude limits, even on the back side of the Moon.

MOLAB is designed to accommodate a wide spectrum of possible lunar surface conditions. A study should be made of the potential system advantages should the Surveyor and Lunar Orbiter data show the surface conditions to be defined within narrower limits.

9.3.6 MOLAB Reuse

Added thought should be given to the extended utilization of a MOLAB vehicle beyond its initial two-week mission. Study should be made of the possibility of expendables replenishment and subsequent additional surface missions. Work should also proceed along the lines of how MOLAB may be left, unmanned, to provide the most benefit as a testing laboratory, meteoroid sensor, landing beacon, etc.

9.3.7 Cost Effectiveness Comparison of LEM-Shelter/LSSM and MOLAB

Work should be started on making realistic comparisons of the several applicable lunar surface exploration systems. The first task is the evolution of a rating technique for accomplishments on the Moon. Total cost effectiveness will have to include booster costs, commonality with other programs and other factors to keep the "Moon hardware" costs in perspective.

9.3.8 LEM-Shelter/LSSM

Recommended study areas include mission and operations analysis to establish, more objectively, requirements placed on the exploration system by the scientific endeavors. Also, detailed LSSM preliminary design and program definition studies should be conducted.

9.3.9 MTA

The Mobility Test Article will be an extremely useful vehicle for study of manned lunar mobility. It is recommended that added work be done on defining "small" dynamically scaled models (say 1/6 size) to produce verification of analytical vehicle design data.

9.4 SUMMARY

The Boeing Company and its Team Members have evolved the conceptual design of a Mobile Lunar Laboratory which will meet or exceed the requirements identified by the NASA. The design proposed has versatility in accomplishing its mission over a wide range of lunar environmental and terrain conditions. Extensive use of Apollo components, equipment and facilities is made in the MOLAB system.

Although the vehicle proposed does not meet the target mass of 6500 lbm (2948 kg), it can be successfully landed on the lunar surface by a LEM truck with the currently indicated capability. Additional MOLAB mass reductions would involve reduced mission capability or a higher risk design.

Very little new basic research is required for MOLAB. It is recommended that the engineering development and study tasks which have been identified be implemented. A first step should be the detailed description and time phasing of the various recommendations.

Confidence can be placed in the MOLAB resources planning. Both costs and schedules information have been validated by comparisons with other programs down to a relatively detailed level.

The MOLAB Program is an effective extension of the current Apollo Program. And, when considering the current investment in the Apollo Program, and the high costs of delivery of payloads and men to the lunar surface compared to the estimated costs of the MOLAB Program, it may well be the most cost effective means for lunar exploration.

10.0 GLOSSARY

ACE	Apollo Acceptance Checkout Equipment
AES	Apollo Extension System
ALSS	Apollo Logistics Support System
C&C	Command and Control
CM	Command Module
CSM	Apollo Command and Service Modules
DP/W	Draw-bar-pull to Weight Ratio
DSIF	Deep Space Instrumentation Facility
ECS	Environmental Control System
ELMS	Engineering Lunar Surface Model
EVA	Extravehicular Astronaut
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
K_ϕ	Soil Modulus of Deformation
KB/SEC	Kilobits per Second
KSC	Kennedy Space Center
LCC	Launch Control Center
LEM	Lunar Excursion Module
LFV	Lunar Flying Vehicle
LH_2	Liquid Hydrogen
LO_2	Liquid Oxygen
LSS	Life Support System
LSSM	Local Scientific Survey Module
MCC	Mission Control Center (Houston)
MOLAB	Mobile Lunar Laboratory
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MSOB	Manned Spacecraft Operations Building
MTA	Mobility Test Article
n	Soil Deformation Exponent (Dimensionless)
RDF	Radio Direction Finding
RPU	Radioisotope Power Unit
RTG	Radioisotope Thermoelectric Generator
VAB	Vertical Assembly Building
VHF	Very High Frequency