LUNAR SURFACE MOBILITY SYSTEMS COMPARISON AND EVOLUTION (MOBEV)

FINAL REPORT

VOLUME II

BOOK 1

MOLEM, MOCOM, MOCAN

PART 1

TECHNICAL REPORT

BSR 1428

NOVEMBER 1966

THE Bendix CORPORATION

Aerospace Systems Division

FINAL REPORT

THE BOOK YOU ARE READING IS INDICATED BY THE ARROW.

LUNAR SURFACE MOBILITY SYSTEMS COMPARISON AND EVOLUTION (MOBEV)

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VOLUME II

BOOK 1

MOLEM, MOCOM, MOCAN

PART 1

TECHNICAL REPORT

BSR 1428

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER,
HUNTSVILLE, ALABAMA
UNDER CONTRACT NO. NAS8 - 20334

Approved by: C. J. Weatherred
C. J. Weatherred, Director
Lunar Vehicle Programs

NOVEMBER 1966

THE Bendix CORPORATION **Aerospace Systems Division**

FOREWORD

This document presents the results of the Lunar Surface Mobility Systems Comparison and Evolution Study (MOBEV) conducted for the National Aeronautics and Space Administration, Marshall Space Flight Center Huntsville, Alabama, under Contract NAS8-20334. The Bendix team responsible for the MOBEV Study includes Bendix Systems Division of The Bendix Corporation, Bell Aerosystems Company, and Lockheed Missiles and Space Company. Bendix, in addition to overall program management and system integration, has been responsible for LRV Systems, Mission Studies, and the MOBEV Methodology. Bell has been responsible for the Flying Vehicle Systems; Lockheed has been responsible for the LRV Human Factors, Environmental Control, Life Support, and Cabin Structures.

The study was performed by personnel of the Lunar Vehicle Program Directorate of Bendix Systems Division, The Bendix Corporation, under the direction of Mr. C. J. Weatherred, Program Director; Mr. R. E. Wong, Engineering Manager; and Mr. C. J. Muscolino, Project Manager, MOBEV. The NASA Technical Supervisor for the contract was Mr. Richard Love, R-P&VE-AA, Marshall Space Flight Center.

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The following nomenclature is used throughout the report and was adopted to facilitate recognition of the large number of vehicles and missions considered.

ROVING VEHICLES

1. First (letter) (R) defines vehicle as Rover.

2. Second (number) (0 through 3) defines vehicle crew size.

3. Third (letter) (A through D) defines specific mission of vehicle.

4. Fourth (letter) (E or B) defines vehicle as being Exploration or Base Support vehicle.

Example: R1BE (rover—one man—vehicle B mission—exploration vehicle)

FLYING VEHICLES

1. First (letter) (F) defines vehicle as Flyer.

2. Second (number) (0 through 3) defines vehicle crew size.

3. Third (letter) (A through E) defines specific mission of vehicle.

Example: F1B (flyer—one man—vehicle B mission)

CSM	-	Apollo Command and Service Module
G&N	-	Guidance and Navigation
AES-MLS	-	AES Manned Lunar Surface
ALSEP	-	Apollo Lunar Surface Experiments Package
LFV	-	Lunar Flying Vehicle
MFS	-	Manned Flying System
MIMOSA	-	Mission Modes and Systems Analysis for Lunar Exploration
SLRV	-	Surveyor Lunar Roving Vehicle
DPV	-	Design Point Vehicles
LLV	-	Lunar Logistics Vehicle
ESS	-	Emplaced Scientific Station

SECTION 1

INTRODUCTION AND SUMMARY

This report is submitted in response to the Phase I requirements under NASA Contract No. NAS8-20334, "Mobility Systems Comparison and Evolution Study."

1.1 OBJECTIVES

The objective of the supplementary study is to prepare vehicle conceptual designs derived from existing Apollo spacecraft. The existing spacecrafts are the Apollo Lunar Module (LM), the Apollo Command Module (CM), and the Boeing CAN. In the program the conceptual design for the MOLEM was examined as a derivative of the Apollo LM. Grumman Aircraft and Engineering Company has performed a conceptual design study of a MOLEM derived from a LM-Shelter. The basic guideline for the conceptual designs is to retain as much of the existing spacecraft systems as possible, provided that the required performance is met and the final weight of the resulting system is within the LM-Truck delivery capability. specified at 8500 lb for this study.

Resources data (costs and development time) for each of the conceptual designs has been prepared. For cost estimating purposes, it is assumed that all basic spacecraft are fully developed. For example, it is assumed that the LM-Shelter subsystems will be fully developed and available prior to the MOLEM development in the case of a MOLEM derived from the LM-Shelter.

1.2 GROUND RULES AND CONCEPTUAL DESIGN APPROACH

The established ground rules require that each conceptual design retain the basic cabin structure (pressure shell) of the primary spacecraft. If the basic structure requires extensive modification, the resulting vehicle is equivalent to a new design, since its cost will be comparable to that for a new vehicle development.

The reaction control systems and landing aids are located on the LM-Truck with the exception of the MOLEM derived from a LM-Shelter where these items are retained on the mobility systems to minimize development costs.

Each of the conceptual designs generated has been evaluated against the performance requirements (Appendix A) to determine its acceptability. Where the total system weight exceeds the 8500-lb LM-Truck weight capability, the system performance has been degraded to meet the weight constraints.

Figure 1-1 shows the study flow diagram for the supplementary study. The study consists of a review of applicable documents, conceptual system design, subsystem design analyses and establishment of system performance, sensitivity data, recommended systems, and development of resources data. The output consists of the resulting conceptual designs of Apollo spacecraft mobility derivatives and their resource requirements. These designs are candidate systems for the initial mobility spectrum.

The conceptual design approach is shown in Figure 1-2. The existing spacecraft data were first reviewed and analyzed and the nonfunctional components for mobility systems were identified. For example, the heat shield and re-entry communications systems on the Command Module, and the ascent engine and the reaction control systems on the LM are not required. Following the identification of nonfunctional components, the remaining subsystems are examined to determine whether or not they meet the required performance in a mobility system. Weight and performance sensitivities are determined. These are analyzed with particular emphasis on delivery system weight constraints. Subsystems are then finalized.

The selected conceptual design resulting from this procedure provides maximum performance within the launch vehicle and design restraints while maintaining maximum use of existing equipment.

1.3 SUMMARY RESULTS

1.3.1 MOLEM

Initially, the basic LM was examined to determine interchangeability of subsystems and components for the MOLEM vehicle conceptual design. From the basic ground rules previously defined and the requirements of maximum use of existing equipment and a LM-Truck delivery vehicle, a conceptual design has been completed, (see Table 1-1), which

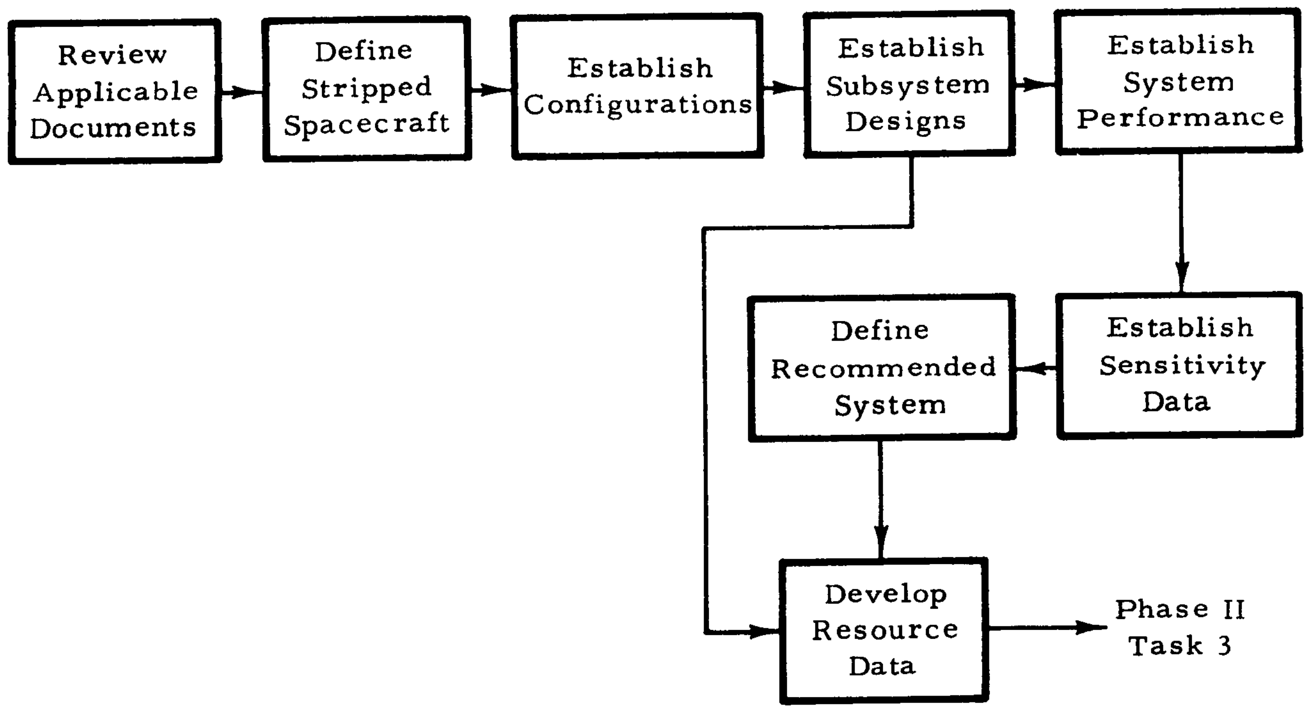

Figure 1-1 Study Approach for MOLEM, MOCAN, and MOCOM

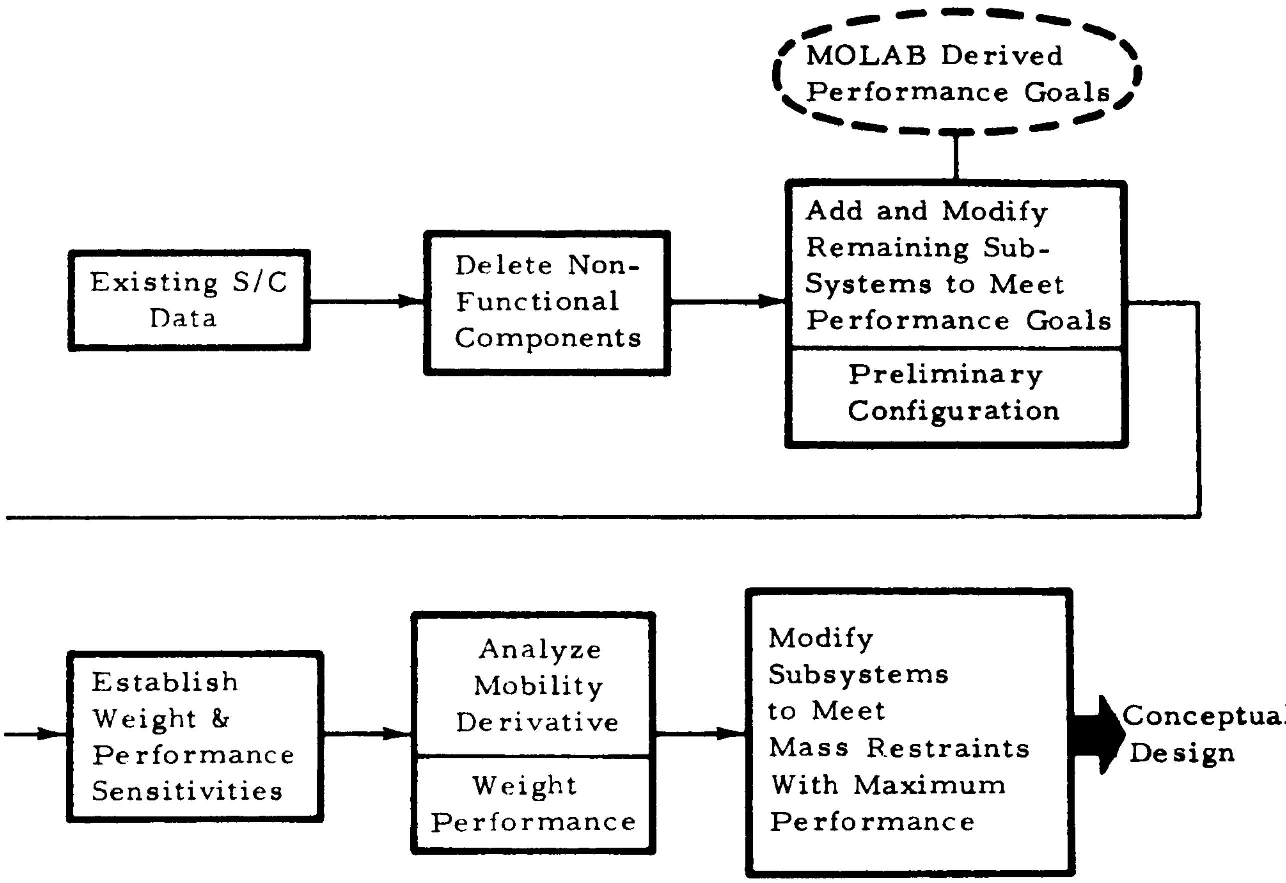

Figure 1-2 Conceptual Design Approach

TABLE 1-1

MOLEM MAJOR MODIFICATIONS AND DEVELOPMENT ITEMS

Subsystem	Modifications	Development Items	Comments
1. Structures-(including cabin pressure shell)	Remove ablation material Remove heat shield substructure Remove insulation	Yes	Internal structu Chassis attachm
2. Stabilization & control	Remove	No	---
3. Navigation & guidance	Retain	Yes	---
4. Instrumentation	Retain	Yes	---
5. Power	Remove	Yes	RTG, radiator, cryogenic tankag fuel cells, batter
6. Life support & crew station	Retain & modify	Yes	Display panels, control panels, environmental control modified
7. Propulsion	Remove	No	
8. Reaction control	Remove	No	---
9. Communications	Retain	Yes	
10. Mobility	None	Yes	Entire system: traction drive mechanism, steering drive mechanism, wheels, suspension system chassis, mobility controller
11. Tiedown & unloading	Remove	Yes	---
12. Landing subsystem	Remove	No	---

defines, in general, the subsystems retained from the basic LM. A summary of the resulting MOLEM design is presented in the following paragraphs. Detailed results are contained in Section 2 herein.

1.3.1.1 MOLEM Configuration

Figure 1-3 is a perspective of the MOLEM concept. The cabin is a modified LM ascent stage and is mounted on an aluminum box-beam frame supported by four metal-elastic wheels. The suspension is folded to provide a minimal storage configuration for unmanned delivery on the LM-Truck. The environmental control system (ECS) radiators, S-band communications antenna, and a radio direction-finder loop antenna are located on top of the cabin. Scientific equipment lockers, radioisotope thermoelectric generator (RTG), batteries, liquid hydrogen tank, fuel cells, primary power accessories, and the mobility control unit are located on the aft platform. Liquid oxygen tanks are located on each side of the cabin.

Figure 1-4 shows the launch envelope installation of the MOLEM system. The antennas and the suspension have been folded. The vehicle is supported during launch by links which tie the vehicle chassis directly to the LM-Truck structure.

1.3.1.2 MOLEM System Description

The MOLEM system characteristics are given in Table 1-2.

1.3.1.3 MOLEM System Performance

The MOLEM system performance is summarized in Table 1-3.

The MOLEM carries a crew of two with sufficient life-support capability to complete a 14-day lunar stay with a 7-day emergency reserve. Accommodations are provided for 320 kg of scientific equipment, and 75 kwh of power is budgeted for this equipment. This vehicle has a total range capability of 400 km with a typical mission radius of operation of 80 km from the LM-Truck landing point. The maximum average speed over the Engineering Lunar Model Surface (ELMS) is 10.0 km/hr. The maximum speed on level compacted soils ($K_\phi = 6$, $n = 1.25$) is 16.7 km/hr, and the maximum speed on soft soils ($K_\phi = 0.5$, $n = 0.5$) is 13.0 km/hr. The specific mobility energy over the ELMS (50% maria and 50% uplands) is 0.44 kwh/km resulting in a driving requirement of 175 kwh, and contributing to the total system energy requirement of 693 kwh used for the power system design.

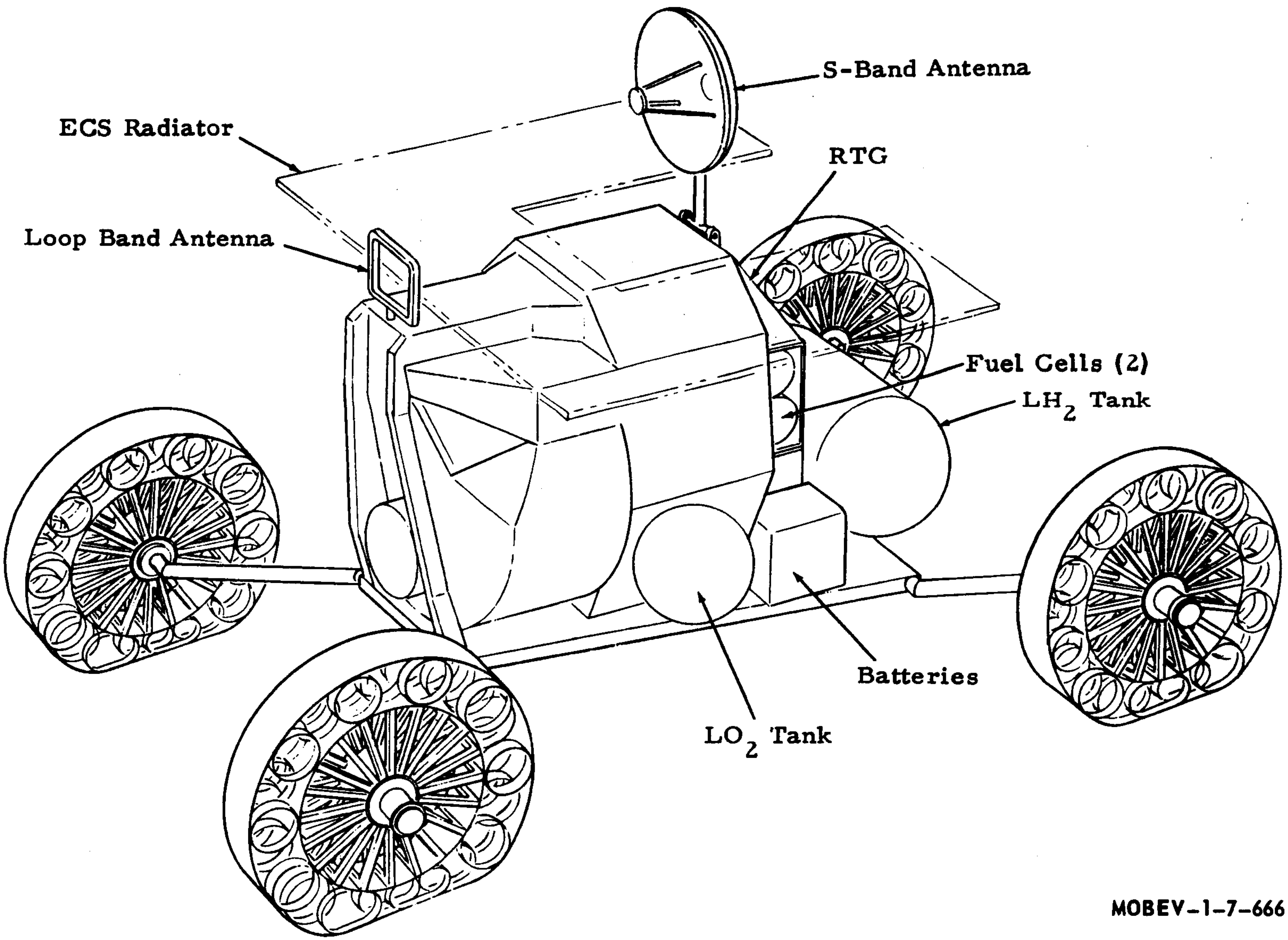

Figure 1-3 MOLEM Configuration

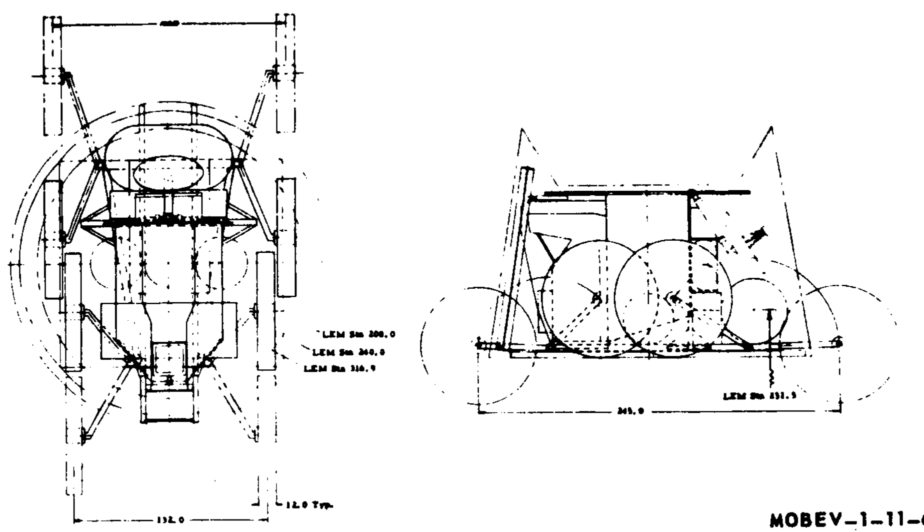

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Figure 1-4   MOLEM Installation

TABLE 1-2

MOLEM SYSTEM CHARACTERISTICS

Cabin	Apollo LM Structure
Environment	Shirtsleeve, $70^{o}F \pm 5^{o}F$
Atmosphere	100% O_2 @ 5 psia
Life support	42 man-days
Prime power	2 advanced P&W fuel cells - 6.97 kw
Secondary power	2 Ag Zn rechargeable batteries (3.6 kwh)
Auxiliary power	56-w RTG
Wheels	Four 2.03 m dia., 0.305 m wide metal elastic
Chassis	Trapezoidal, aluminum box-beam construction
Communications	S-band - voice; PCM telemetry; TV; scientific data; analog data; up-link data VHF-AM—Voice; PCM telemetry Remote control
Navigation	Automatic dead-reckoning

TABLE 1-3

MOLEM PERFORMANCE SUMMARY

Crew	2 astronauts
Cargo capability	320 kg (705 lbm)
Range	400 km
Cabin volume	7.06 cum (250 cu ft)
Usable floor space	2.5 sqm (26 sq ft)
Max. average speed (ELMS)	10.0 km/hr
Speed hard surface	16.7 km/hr
Speed soft soil	13.0 km/hr
Driving time	40 hr
Obstacle negotiability (Zero Speed)	80 cm
Crevice negotiability	173 cm
Turn radius	16.8 m
Specific mobility energy	0.44 kwh/km
Total energy	693 kwh

1.3.1.4 MOLEM Mass Summary

Table 1-4 presents a mass summary of the MOLEM subsystems. This mass summary represents a MOLEM vehicle derived from a stripped LM spacecraft. The total mass is 3516 kg (7745 lb), and, with a 10% weight contingency, is still within the 3859 kg (8500-lb) LM-Truck delivery capability.

1.3.2 MOCOM

The basic Apollo Command Module was examined to determine those subsystems and components required in a mobility system. The propulsion system, the stabilization and control system, and the re-entry systems are not required in the mobile unit. The performance of the remaining systems and components are examined in Section 3.1 to determine whether or not they should be included.

Table 1-5 contains a summary of the retained and deleted CM subsystems.

1.3.2.1 MOCOM Configuration

The MOCOM utilizes a modified Apollo Command Module cabin adapted to mount on a four-wheel, rigid-chassis mobility system. The system is delivered unmanned on the LM-Truck with suspension folded. Six months of dormant storage on the lunar surface are provided along with remote checkout, unloading, and driving features.

Figure 1-5 shows the MOCOM configuration. The cabin is mounted on the chassis with the major axis of the CM cone in a vertical position. This is done to accommodate the design of the docking adaptor, and since the major load paths (structural strength) are in this direction, the astronaut position in the cabin and internal furnishings and operational equipment are revised to compensate for the attitude change between the MOCOM and the CM.

Two liquid hydrogen tanks are mounted under the radiators. Two spherical liquid oxygen tanks are mounted in the right and left rear corners of the vehicle.

TABLE 1-4

MOLEM MASS SUMMARY

	Stripped Spacecraft Mass kg	(lb)	Recommended MOLEM Mass kg	(lb)
Structure	468	(1030)	514	(1130)
ECS	141	(310)	182	(400)
Life support expendables	(*Including ECS Expend)		187.8	(413)
Crew systems	91	(200)	146	(322)
Controls and displays	71	(155)	55	(121)
Communications and navigation	171	(375)	375	(825)
Cabling and instrumentation	100	(220)	100	(220)
Scientific equipment	—	—	320	(709)
Power system	409	(900)	321	(707)
Power system expendables	18	(40)	253	(557)
Mobility	—	—	537	(1180)
Thermal control	(Included in ECS)		45	(99)
Cryogenic tankage	—	—	287	(632)
Tiedown and unloading	—	—	195	(430)
TOTALS	1468	(3230)	3517	(7745)

TABLE 1-5

MOCOM MAJOR MODIFICATIONS AND DEVELOPMENT ITEMS

Subsystem	Modifications	Development Items	Comments
1. Structures (including cabin pressure shell)	Remove ablation material Remove heat shield substructure Remove insulation Add LEM female docking adapter	Yes	Add airlock Internal structure Chassis attachments
2. Stabilization and control	Remove	No	-----
3. Navigation and guidance	Remove	Yes	*Periscopic theodolite, inclinometer directional gyro, vertical gyro, computer, odometer, test panel, displays and controls
4. Instrumentation	Remove	Yes	Cables, sensors
5. Power	Remove power generation Remove power conversion Remove power distribution system	Yes	RTG, radiator, cryogenic tankage, fuel cells
6. Life support and crew station	Remove crew couches Remove side hatch Remove flight control and display equipment Earth survival kit Earth landing restraint system	Yes	Display panels, control panels, seats and restraints, windows
7. Propulsion	Remqve	No	-----
8. Reaction control	Remove	No	-----
9. Communications	Remove	Yes	S-band system, UHF system, data handling system
10. Mobility	None	Yes	Entire system: traction drive mechanism, steering drive mechanism, wheels, suspension system chassis, mobility controller
11. Tiedown and unloading	Remove	Yes	Entire system: vehicle tiedown, multi-azimuth turntable, unloading apparatus
12. Command and control	Remove	No	Remote control system for surface operation: illumination, video sensors, signal conditioners, actuators, command decoder

*Areas where it is possible to use portions of existing CM equipment.

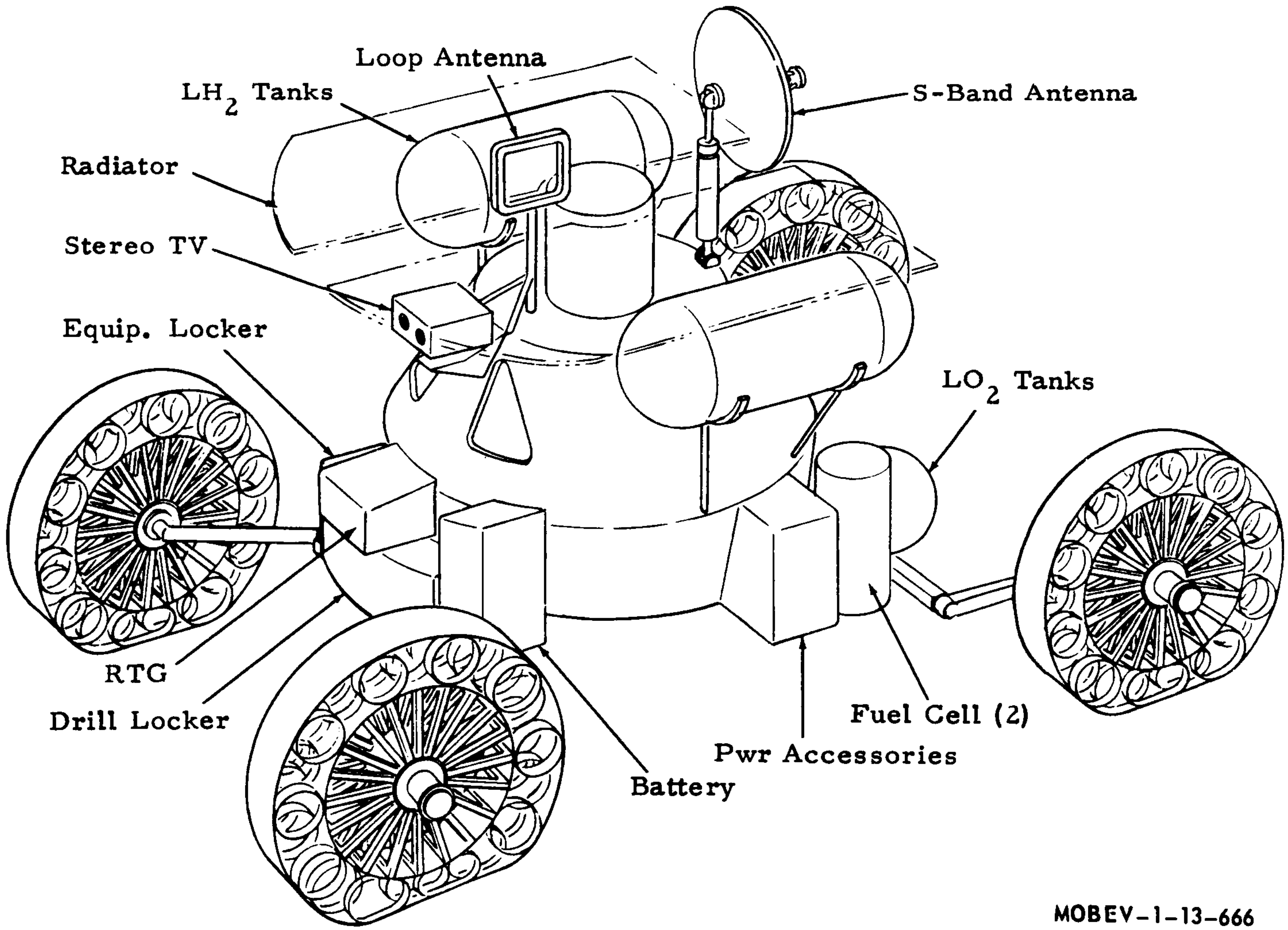

Figure 1-5 MOCOM Configuration

Figure 1-6 shows the installation of the MOCOM under the Spacecraft-to-LM Adapter (SLA) shroud and on top of the LM-Truck. As shown, the vehicle suspension is folded for transportation. The tie-down and unloading rails are mounted on the top of the LM-Truck and fold out for support of the MOCOM as it is lowered to the lunar surface. LM Station 200 is on top of the LM-Truck and LM-station 316.9 is just under the Service Module. The VHF antenna and S-band antennas are folded during the launch and storage mode.

1.3.2.2 MOCOM System Description

The MOCOM system characteristics are summarized in Table 1-6.

1.3.2.3 MOCOM System Performance

MOCOM performance is summarized in Table 1-7.

The MOCOM crew consists of two astronauts who are provided with a 10.3 cubic meters (365 cubic feet) cabin for their 14-day mission. A scientific cargo capacity of 320 kg (705 lb) is available for lunar operations during the mission. Of the total 695 kwh of energy required, 195 kwh are for mobility. The maximum continuous mobility power is 6.55 kw.

1.3.2.4 MOCOM Mass Summary

Table 1-8 contains a mass summary of the MOCOM system derivation.

1.3.3 MOCAN

The basic CAN was examined to determine subsystems and components required in the roving vehicle derivation. Analysis of the performance of the systems and components is contained in Section 3.4.

Table 1-9 provides a description of the spacecraft major modifications and development requirements to derive a mobility unit.

The deletion of items that do not provide the required performance results in the retention of only the basic structure and docking drogue. Since the thermal coating, insulation, and meteroid bumper have been designed for 90-day operations, they can be removed and replaced with lighter

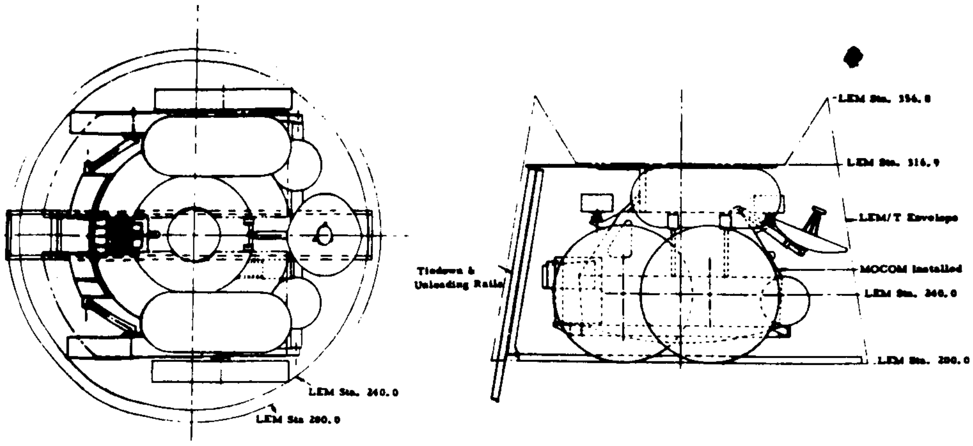

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Figure 1-6 MOCOM Installation

TABLE 1-6

MOCOM SYSTEM CHARACTERISTICS

Cabin	Apollo Command Module
Environment	Shirtsleeve, $70^{\circ}F \pm 5^{\circ}F$
Atmosphere	100% O_2 @ 5 psia
Life support	42 man-days
Prime power	2 advanced P&W fuel cells - 7.55 kw cont.
Secondary power	2 Ag Zn rechargeable batteries (3.6 kwh)
Auxiliary power	55-w RTG
Wheels	Four 2.03 m dia., 0.305 m wide metal elastic
Chassis	Rectangular aluminum box-beam construction
Communications	S-band-voice; PCM telemetry; TV; scientific data; analog data; up-link data VHF-AM—Voice; PCM telemetry
Navigation	Automatic dead-reckoning

TABLE 1-7

MOCOM PERFORMANCE SUMMARY

Crew	2 Astronauts
Cargo capability	320 kg (705 lbm)
Range	400 km
Cabin volume	10.3 cu m (365 cu ft)
Usable floor space	1.8 sq m (19 sq ft)
Max. average speed (ELMS)	10.0 km/hr
Speed hard surface	16.7 km/hr
Speed soft soil	13.0 km/hr
Driving time	40 hr
Obstacle negotiability	70 cm
Crevice negotiability	157 cm
Turn radius	12.8 m
Specific mobility energy	0.487 kwh/km
Total energy	695 kwh

TABLE 1-8

MOCOM MASS SUMMARY

	Initial kg	Initial (lb)	Stripped kg	Stripped (lb)	Selected kg	Selected (lb)	Remarks
1. Structure	2042	(4500)	808	(1780)	757	(1665)	
2. Crew Systems	435	(960)	241	(530)	146	(322)	
3. ECS	161	(355)	160	(353)	201	(442)	
4. Life support expendables	51	(113)	51	(113)	190	(417)	
5. Controls and displays	150	(330)	59	(130)	55	(121)	
6. Navigation and guidance	170	(375)			38	(84)	MOLAB Navigation MOLAB Requirement
7. Communication	128	(283)	88	(193)	160	(353)	
8. Instrumentation	114	(250)	114	(250)	91	(200)	
9. Scientific equipment	0			0	320	(705)	
10. Electric power system	274	(605)	274	(605)	342	(752)	695 kwh (400) km
11. Electric power expendables	(SM)			0	255	(561)	
12. Stabilizer and control system	686	(1510)		0	0		
13. Mobility	N/A		N/A		568	(1250)	
14. Tiedown and unloading	N/A		N/A		211	(465)	
15. Thermal control	---				42	(94)	
16. Cryogenic storage	---				370	(815)	
Total	4211	(9281)	1793	(3950)	3746	(8246)	

TABLE 1-9

MOCAN MAJOR MODIFICATIONS AND DEVELOPMENT ITEMS

Subsystem	Modifications	Development Items	Comments
1. Structures (including cabin pressure shell)	Remove meteroid protection and insulation Remove bottom hatch Remove flight control and display equipment panels	Yes	Airlock, basic structure
2. Stabilization and control	Remove	No	---
3. Navigation and guidance	None	Yes	Periscopic theodolite, inclinometer, directional gyro, vertical gyro, computer, odometer, test panel, display and controls
4. Instrumentation	Remove	Yes	Cable, sensors
5. Power	Remove	Yes	RTG, radiator, cryogenic tankage, distribution system
6. Life support and crew station	No crew provisions in basic CAN Modify ECS Modify Radiator	Yes	Crew seats and restraints, ECS, radiator, fuel cells
7. Propulsion	None	No	
8. Reaction control	Remove	No	
9. Communications	Remove	Yes	S-band system, VHF system, data handling system
10. Mobility	None	Yes	Develop entire system: traction drive mechanism, wheels, suspension system chassis, mobility controller
11. Tiedown and unloading	None	Yes	Develop entire system: vehicle tiedown, multi-azimuth turntable, unloading apparatus
12. Command and control	Remove	Yes	Remote control system for surface operation: illumination, video sensors, signal conditioners, actuators, command decoder

items. The mobility chassis can replace the laboratory support rack. The environmental control system must be replaced by a two-man system. The CAN communications system is dependent on the service module communications system and does not have independent capability. The electric power system, which has only a 1.1 kw capability, is replaced by the larger one required for the mobility system.

The systems replacing those systems removed from the spacecraft are discussed in detail in Section 4.1.

1.3.3.1 MOCAN Configuration

Figure 1-7 shows a perspective view of the MOCAN configuration. The MOCAN uses the MOLAB wheels and the Boeing CAN basic structure. The Apollo Multipurpose Mission Module (CAN) is mounted on a rectangular aluminum box-beam frame and supported by four 203-cm (80-in.) diameter metal-elastic wheels. The CAN has been designed to utilize fully the volume on top of the LM-Truck and within the SLA.

Figure 1-8 shows the installation of the MOCAN in the required envelope aboard the LM-Truck. At LM Station 316.9 the 178-in.-diameter MOCAN is tangent and clears the SLA by 5-in.

The four wheels are folded and stowed underneath the MOCAN during the in-transit mission phase. The S-band antenna is folded down and stowed against the MOCAN wheel.

1.3.3.2 MOCAN System Description

The MOCAN system characteristics are summarized in Table 1-10.

1.3.3.3 MOCAN System Performance

MOCAN performance is summarized in Table 1-11.

1.3.4.3 MOCAN Mass Summary

Table 1-12 is a mass summary of the MOCAN system.

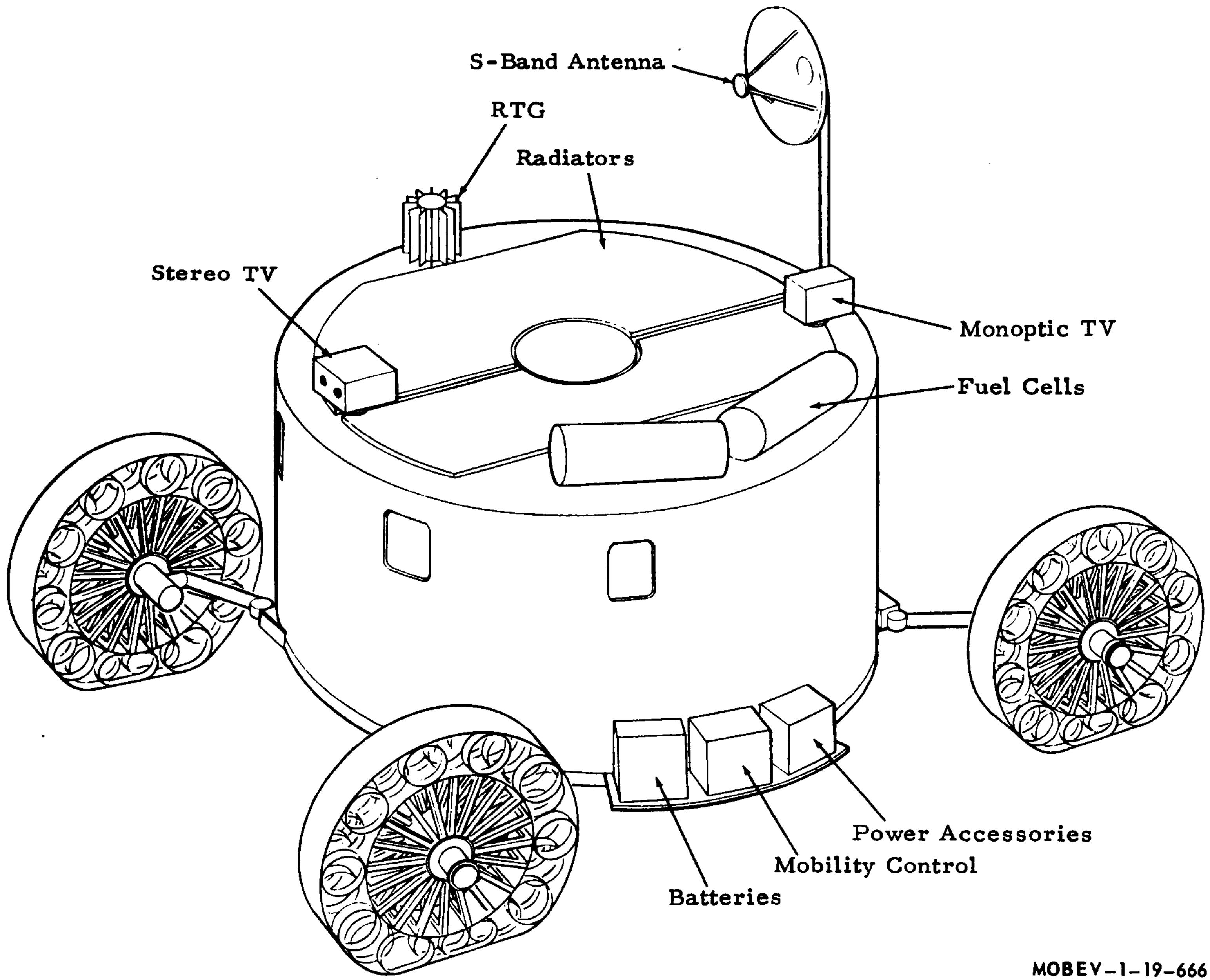

Figure 1-7 MOCAN Configuration

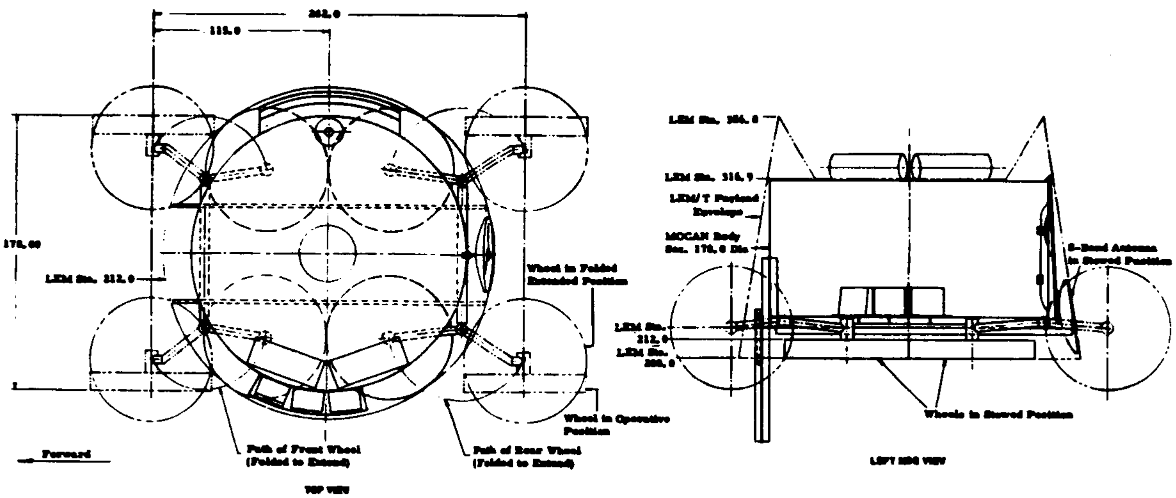

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Figure 1-8 MOCAN Installation

TABLE 1-10

MOCAN SYSTEM CHARACTERISTICS

Cabin	Boeing CAN
Environment	Shirtsleeve, $70^{\circ}F \pm 5^{\circ}F$
Atmosphere	100% O_2 @5 psia
Life support	42 man-days
Prime power	2 advanced P&W fuel cells - 9.56 kw cont.
Secondary power	2 Ag Zn rechargeable batteries (3.6 kwh)
Auxiliary power	56-w RTG
Wheels	Four 2.03 m dia., 0.305 m wide metal-elastic
Chassis	Rectangular aluminum box-beam construction
Communications	S-band-voice; PCM telemetry; TV; scientific data; analog data; up-link data VHF-AM-voice; PCM telemetry
Navigation	Automatic dead-reckoning

TABLE 1-11

MOCAN PERFORMANCE SUMMARY

Crew	2 Astronauts
Cargo capability	320 kg (705 lb)
Range	400 km
Cabin volume	38.2 cu m (1350 cu ft)
Usable floor space	7.9 sq m (85 sq ft)
Max. average speed (ELMS)	10.0 km/hr
Speed hard surface	16.7 km/hr
Speed soft soil	13.0 km/hr
Driving time	40 hr
Obstacle negotiability	60 cm
Crevice negotiability	146 cm
Turn radius	11.7 m
Specific mobility energy	0.585 kwh/km
Total energy	734 hr
Gross mass	4326 kg

TABLE 1-12

MOCAN MASS SUMMARY

	kg	(lb)
Structure	1127	(2480)
Crew systems	146	(322)
Environmental control system	219	(482)
Life support expendables	203	(447)
Controls and displays	55	(121)
Navigation and guidance	38	(84)
Communications	160	(353)
Instrumentation	91	(200)
Scientific equipment	320	(705)
Electrical power system (EPS)	372	(820)
EPS expendables	277	(609)
Mobility	614	(1350)
Tiedown and unloading	250	(550)
Thermal control	72	(157)
Cryogenic storage	382	(840)
Total delivered mass	4326	(9520)

1.4 CONCLUSIONS

Table 1-13 provides a comparison of significant characteristics for MOLAB, MOLEM, MOCOM, and MOCAN. Each of the designs provides for a crew of two, and a scientific payload of 320 kg for a 14-day mission and a 400-km range.

The MOCAN delivered mass exceeds the LM-Truck payload capability (assumed at 3860 kg for this study) by 452 kg. The MOCAN, as discussed in Section 4, can be reduced in weight to nearly the 3860-kg LM-Truck capability by reducing the range requirement to 200 km and mission duration to 8 days. This represents a major degradation to the usefulness of the vehicle. The MOLEM and MOCOM concepts meet the delivered mass restraint, however, they do not provide the weight margin available in MOLAB. This weight margin provides for additional design contingencies and available growth which can include increased payload, range, and/or mission duration. Further, the margin can be used for delivering separate payloads for lunar surface or orbital operations.

Analysis of available cabin free volume results in the conclusion that MOLEM does not meet the NASA stipulated desired free volume for a two-man 14-day mission of 175 cu ft. The limited 150 cu ft free volume necessitates cramped living conditions, stand-up driving, and a minimal size airlock with questionable emergency operation capability. All other concepts exceed the minimum desired free volume, with MOLAB and MOCOM providing margins of 96 and 44 cu ft, respectively. MOCAN with a free volume almost five times greater than desired provides relatively unlimited capability for extensions in mission duration or increases in crew size.

In summary, each of the derivative concepts studied is technically feasible, in the case of MOCAN with degraded performance, and in the case of MOLEM with marginal cabin space. However, they do not offer any measurable advantages over a system which is designed specifically for mobility use.

TABLE 1-13

COMPARISON OF MOBILITY SYSTEMS CHARACTERISTICS

Item	System			
	MOLAB	MOLEM	MOCOM	MOCAN
Crew size	2	2	2	2
Range (km)	400	400	400	400
Cabin free volume (cu ft)	271	150	219	810
Mass (8500 lb or 3860 kg max. for LM-Truck) (kg)	3221	3527	3743	4326

SECTION 2

MOLEM

2.1 MOLEM STRIPPED SPACECRAFT DEFINITION

This section defines the stripped version of the LM spacecraft. The basis for retaining or deleting subsystems or portions of subsystems is whether or not the associated function is required in a mobility system.

2.1.1 Structure

Analysis and evaluation of the existing LM ascent stage structure shows that the basic LM pressure shell, designed for a 5-psia operating pressure, is adequate for the mobility unit and could be used with minor modifications. These consist of mounting attachments for airlock, radiators. RTG, and fuel cells. The aft equipment rack truss structure is removed together with the accompanying flight controls electronic equipment. The existing LM meteoroid protection skin and insulation is removed, as well as the ascent engine cover and all flight control display panels. The resulting stripped spacecraft structure is summarized as follows in Table 2-1.

2.1.2 Stabilization and Control Subsystem (SCS)

The SCS is deleted because the system will be delivered by the LM truck which incorporates its own system.

2.1.3 Crew Provisions

In the recommended MOLEM configuration, an attempt has been made to avoid any structural modifications to the basic LM; and, therefore, the same general crew concepts have been adopted as for the LM, i.e., a two-man side-by-side, standing arrangement for driving with a suitable restraint system. Visibility for the driver must be augmented to the right and a dual-mirror, forward-looking periscope has been added to the basic LM to provide the MOLEM driver with additional visibility through the right-hand window. It is anticipated that supplementary TV coverage will also be available.

TABLE 2-1

LM STRIPPED SPACECRAFT CABIN STRUCTURE DEFINITION

Item	Retained	Removed	Comments
Pressure shell and bulkheads	X		
Ascent engine cover		X	
Meteoroid protection and insulation		X	
Descent stage attachment (6)	X		Used as chassis attachments
Aft equipment rack		X	
Docking adaptor	X		
Crew station			
Windows	X		
Flight control panels		X	

No distinct scientific work station has been added to the LM configuration for MOLEM. However, during scientific operations in MOLEM the right-hand station is considered the scientific work station and most of the associated controls and displays are oriented to this location.

Normal ingress and egress is through the same forward hatch as provided in LM and a collapsible airlock which has been fitted externally to it. Emergency egress and ingress is provided through the same upper hatch as used in LM. A remote handling box for working on lunar samples has been considered but no suitable location can be identified. Therefore, all work on lunar material must be performed outside the vehicle, or inside with the cabin depressurized.

Information on LM sleeping arrangement is lacking, but on MOLEM two bunks are provided and these are oriented fore and aft and off-center so that the driver can drive with an incapacitated astronaut on one bunk.

The bunks also serve as stowage for the four pressure suits when they are not being worn. (They must be removed from the bunks for sleeping.)

Solar flares require additional shielding for the crew, beyond that afforded by the LM structure itself, during the one to three day flare periods which MOLEM may encounter. The present concept calls for the astronauts to sit on the step which is formed at the juncture of the fore and aft cabin section. They will then erect the shielding material around themselves and remain in the enclosure except for the brief periods which are permissible outside the shelter during the flare activity.

No special eating facilities are provided for MOLEM, other than the additional food stowage necessary for the mission beyond LM requirements. Eating will be time-shared with other duties, and a variety of locations are available for this function, such as the navigator's work table, the step referred to above, and the lower bunk.

For MOLEM waste management, two Apollo-type fecal canisters and relief tubes have been added to the LM. These can be suspended on brackets over the edge of the step mentioned above.

The LM design makes no provisions for personal hygiene because of the very short mission duration. The addition of components for personnel hygiene and the storage space for them are provided in MOLEM.

Additional space in the cabin is provided for storage of the additional pressure suits and portable life support systems (PLSS) required for the longer mission. Storage for additional PLSS expendables associated with extravehicular activity is also provided.

2.1.4 Environmental Control System (ECS)

In general, the processes used for environmental control of LM apply to the MOLEM with two exceptions. The use of an evaporative water cooling system is not practical for a mission of two weeks because of the excessive water requirements. A space radiator cooling system will be used. Water available from the fuel cell will be used in place of stored water to meet drinking water requirements as well as to provide water for PLSS use and abort cooling. Some excesses of water will be available for use as cooling to reduce radiator size under peak load conditions. The environmental control system package must be removed from the spacecraft to make room for the new unit that provides the required radiator system components and a larger lithium hydroxide canister. Most of the existing components can be used in the new package. Table 2-2 summarizes the stripped spacecraft ECS definition.

TABLE 2-2

LM STRIPPED SPACECRAFT ECS DEFINITION

Item	Retained	Removed	Added	Modified	Comments
Basic system	X				
Water boiler		X			
Radiator-water boiler RTG hybrid			X		RTG is heat source during storage
Expandable airlock system			X		
Water supply system				X	To store fuel cell water
Stored water				X	Reduced to 8 kg from 136 kg
LiOH, oxygen			X		For longer mission
Suits, PLSSs			X		Extras
Waste management				X	Apollo canisters added
Personal hygiene			X		

2.1.5 Instrumentation

The basic LM operational instrumentation will be retained and modified as required.

2.1.6 Electrical Power Subsystem

The LM ascent stage power system uses batteries as the only source of energy. This type of system is not applicable to a 14-day mission and will have to be replaced by an entirely different design.

2.1.7 Reaction Control Subsystem

Since the mobility system is delivered by the LM-Truck, no reaction control system is required. The deleted equipment consists of tankage, plumbing, fuel, and thrusters.

2.1.8 Communications

Table 2-3 presents a summary of the deleted and retained communications equipment.

2.1.9 Controls and Displays

MOLEM utilizes the same control and display panel structure as the LM. However, the actual controls and displays mounted on the panel structure have been changed to suit the purposes of the MOLEM mission and crew operating requirements. Those LM controls and displays related to flight management have been removed for the MOLEM configuration and additional controls and displays have been provided for the MOLEM mobility and scientific functions.

The primary displays provided on the driver's side include the mobility system panel and the TV panel. The latter can be used as a driving aid to help compensate for the driver's limited view. The mobility panel is split so that the navigation displays portion can be located directly in front of the driver just below his window. The primary display provided on the navigator's side include the basic navigation displays and the warning annunicator panel.

TABLE 2-3

LM STRIPPED SPACECRAFT COMMUNICATIONS DEFINITION

Item	Retained	Removed	Comments
<u>Antennas</u>			
S-band			
Directional, RF unit (steerable)	x		
Servo amplifier and drive mechanism			
Supporting structure and yoke	x		
Switch assembly	x		
In-flight unit (2 ea)	x		
Rendezvous radar antenna	x	x	Mobility system will not require a rendezvous radar system.
VHF			
In-flight unit (2 ea)	x		
<u>RF and Modulation Equipment</u>			
S-band			
Diplexer and power amplifier	x		
Unified equipment	x		
Processor, premodulation	x		
VHF	x		
Transceiver VHF/AM (2 ea)	x		
Switch assembly	x		
Diplexer unit	x		
<u>Television System</u>			
Camera (hand-held camera)	x		
<u>Electrical Provisions</u>			
Electrical wiring	x		
Coax	x		
Connectors	x		

Additional panels are the communications panel, power system panels, ECS panels, life support and contaminant panels, and the scientific data panel. The communications panel is centrally located on the forward panel to permit sharing of the communications function by the crew. The remaining panels, with the exception of the life support, contaminant, and scientific panels, are on the navigator's side to permit him to monitor the related systems during driving. The life support, contaminant, and scientific panels are used infrequently during driving, and are therefore located on the driver's side consoles, rather than the navigator's, because of the limited panel space available in the MOLEM configuration.

The principal driving control is a joystick at the driver's station. This permits steering by means of a right or left motion, acceleration by a forward motion and braking by a rearward motion. A secondary driving capability will also be providdd at the navigator's station.

2.1.10 Propulsion Subsystem

Since no ascent capability is necessary in a mobility system, the entire ascent propulsion can be removed. This includes propellant, tanks, engine, and pressurization system.

2.1.11 Navigation and Guidance

The LEM Navigation and Guidance System components are shown in Table 2-4. The system contains four sensors:

1. Inertial Measurement Unit (IMU)
2. Alignment Optical Telescope (AOT)
3. Rendezvous Radar (RR)
4. Landing Radar (LR)

The IMU is retained tentatively as a sensor of vehicle motion. Since the AOT is used to align the IMU, it is also retained. Both radars should be dropped because no requirement exists for them.

TABLE 2-4

LM NAVIGATION/GUIDANCE SYSTEM APPLICATIONS TO SURFACE NAVIGATION

Item	Retained	Removed	Comments
1. Inertial Measurement Unit (IMU)	x		Possible sensor of vehicle motion
2. Alignment Optical Telescope (AOT)	x		Used to align IMU
3. Rendezvous Radar (RR)		x	No requirement
4. Landing Radar (LR)		x	No requirement
5. LM Guidance Computer (LGC)	x		Will require new program along with possible increased capability
6. Coupling Display Units (CDU)	x		Required for data transfer among LGC, IMU, AOT
7. Power Servo Assy (PSA)	x		Required for IMU, AOT and LGC
8. Display and Control (D&C)	x		Map and data viewer

2.1.12 Stripped Spacecraft Summary

Table 2-5 contains a weight summary of the stripped LM subsystems The ECS is shown as being retained because the mobility system requires this function. However this subsystem is not adequate for the MOLEM vehicle mission and will be replaced with another design.

TABLE 2-5

LM STRIPPED SPACECRAFT WEIGHT SUMMARY
(RETAINED ELEMENTS)

Subsystem	Estimated stripped weights Kg	(lb)	Comments
1. Structure	468	(1030)	Additional shielding required
2. Stability and control	-	-	Not required for LM-Truck delivery
3. Crew provisions	91	(200)	Not adequate for MOLEM mission requirements
4. Environmental control	141	(310)	Not adequate for MOLEM mission requirements
5. Cabling and harness	100	(220)	
6. Electrical power supply	409	(900)	Not adequate for MOLEM mission requirements
7. Reaction control	-	-	Not required for LM-Truck delivery
8. Communications	73	(160)	Not adequate for MOLEM mission requirements
9. Controls and displays	70	(155)	
10. Propulsion	-	-	Not required for LM-Truck delivery
11. Power system expendables	18	(40)	
12. Navigation	99	(215)	
TOTAL	1468	(3230)	

2.2 MOLEM CONFIGURATION

Figure 2-1 presents a perspective of the MOLEM. The cabin is a modified LM ascent stage and is mounted on an aluminum box-beam frame supported by two pairs of metal-elastic wheels. The suspension is folded for unmanned delivery on the LM-Truck. The ECS radiators, S-band communications antenna, and a direction-finding loop antenna are located on top of the cabin. Scientific equipment lockers are located at the rear platform. The RTG, batteries, liquid hydrogen tank, fuel cells, primary power accessories, and the mobility control unit are located on the aft platform. Liquid oxygen tanks are located on each side of the cabin.

Figure 2-2 shows the internal layout of the MOLEM system. The antennas and the suspension have been folded and the vehicle is supported during launch by links which tie the vehicle chassis directly to the LM-Truck structure.

The MOLEM carries a crew of two with sufficient life support capability to complete a 14-day lunar stay with a 7-day emergency reserve. Accommodations are provided for 320 kg of scientific equipment, and 75 kwh of power is budgeted for this equipment. This vehicle has a total range capability of 400 km with a typical mission radius of operation of 80 km from the LM-Truck landing point. The total cabin volume is 7.06 cu m, and the usable floor space is 25 sq m. The maximum average speed over ELMS is 10 km/hr. The maximum speed on level compacted soils ($K_\phi = 6$, $n = 1.25$) is 16.7 km/hr, and the maximum speed on soft soils ($K_\phi = 0.5$, $n = 0.5$) is 13.0 km/hr. A total driving time (0.9 maximum average velocity over ELMS) of 44.5 hr is required for a 400-km traverse. The maximum obstacle and crevice negotiabilities are 80 cm and 173 cm, respectively, and the maximum static turn radius is 16.8 m. The specific mobility energy over the ELMS (50% maria and 50% uplands) is 0.44 kwh/km, resulting in a driving requirement of 175 kwh, and contributing to the total system energy requirement of 693 kwh used for the power system design.

Table 2-6 presents an initial mass estimate of the MOLEM subsystems. This mass summary represents a MOLEM vehicle derived from a stripped LM spacecraft making maximum use of existing LM hardware. The total mass is 3516 kg (7745 lb) and, with a 10% weight contingency, is still within the 3859 kg (8500-lb) LM-Truck delivery capability.

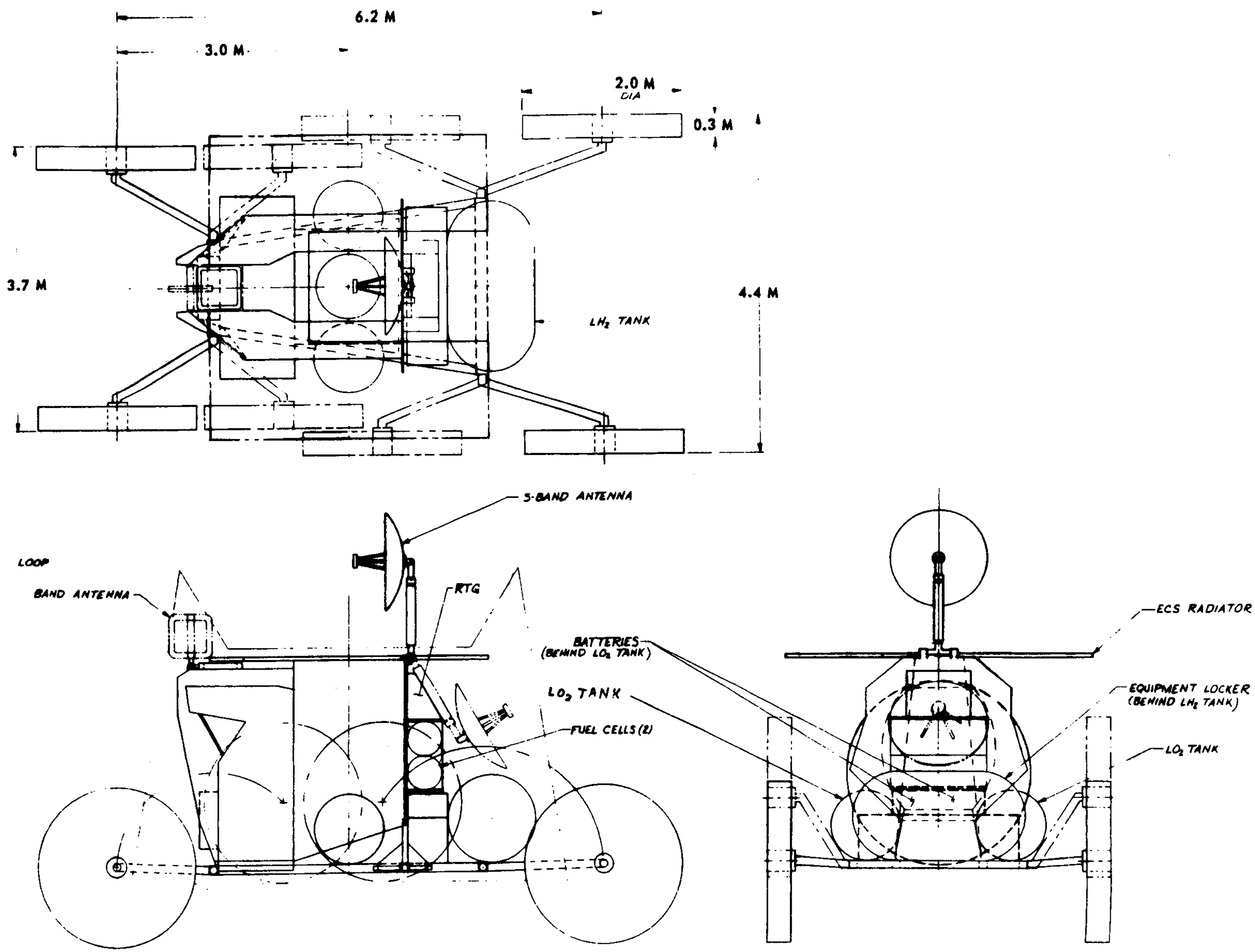


Figure 2-1 MOLEM Configuration

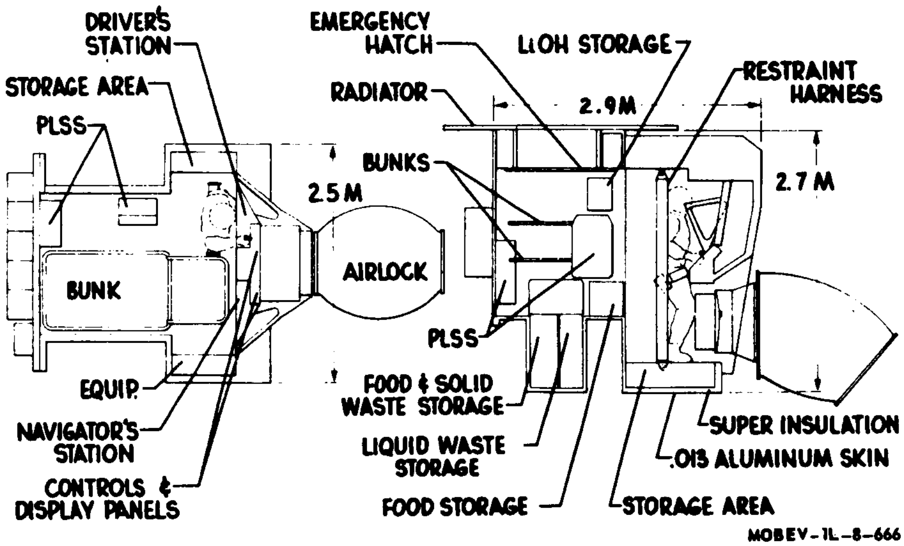


Figure 2-2 MOLEM Internal Arrangement

TABLE 2-6

MOLEM DERIVED FROM LM STRIPPED SPACECRAFT

	Stripped Spacecraft Mass		Recommended MOLEM	
	kg	(lb)	kg	(lb)
Structure	468	(1030)	524	(1152)
ECS	141	(310)	182	(400)
Life support expendables	(Including ECS Expend)		187.8	(413)
Crew systems	91	(200)	146	(322)
Controls and displays	71	(155)	55	(121)
Communications and navigation	169	(375)	375	(825)
Cabling and instrumentation	100	(220)	100	(220)
Scientific equipment	–	–	320	(709)
Power system	410	(900)	321	(707)
Power system expendables	18	(40)	253	(557)
Mobility	–	–	537	(1180)
Thermal control	(Included in ECS)		45	(99)
Tiedown and unloading	–	–	195	(430)
Cryogenic package			287	(632)
TOTALS	1468	(3230)	3527	(7767)

2.3 MOLEM SYSTEM DESIGN

This section defines the designs for all the major MOLEM subsystems. Each subsystem has been analyzed to identify the modifications to LM hardware and any new development items required.

2.3.1 Cabin Structure

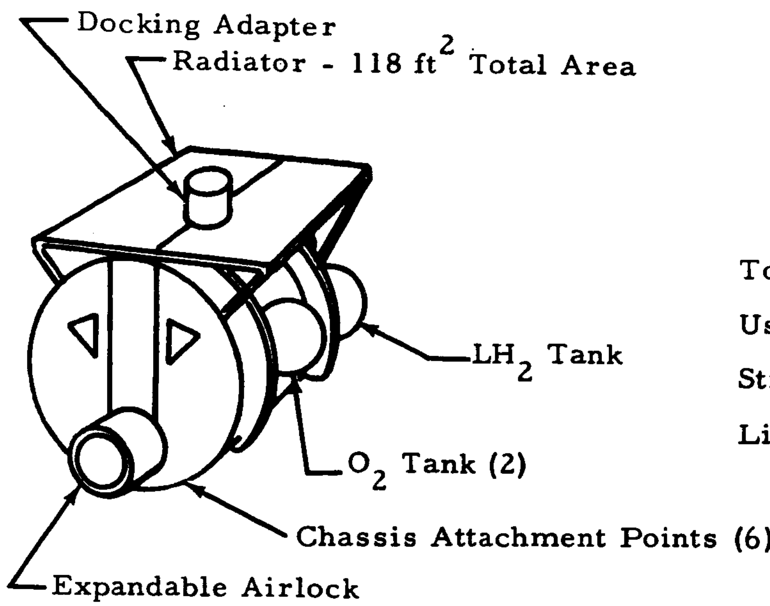
The modifications required to the LM ascent stage are summarized in Figure 2-3.

The cabin structure is required to withstand all loads and environments from launch, translunar flight, docking, descent, and lunar landing, storage, unloading, and operational deployment on the lunar surface. The structural design criteria for the existing LM/Apollo mission is more severe than the criteria for the cabin mobility system during lunar surface operation. This can be seen from Table 2-7 where the mobility loads of 4 lunar g are well within the existing Apollo spectrum. Hence, it can be concluded that, from a structural standpoint, the basic LM ascent stage can be used as a mobility vehicle derivative without major structural changes.

Using minimum structural modification as a guideline, different concepts were considered for (1) improving visibility, (2) a scientific glove-box installation, and (3) seats for driver and navigator. An additional window centrally located between the two existing LM windows was considered, but it was concluded that the improvement in visibility obtained was not sufficient to justify the structural requalification required for its installation. Again, the installation of a glove-box was considered but the structural requalification requirements were not considered justifiable.

The present LM windows are designed for use with the astronauts in a standup position. Seats were considered for both driver and navigator but the seat height required for eye level viewing through the windows would result in knee interference with the control panels.

The internal arrangement of the MOLEM cabin provides for a 2-man side-by-side driving arrangement encompassing a left-hand driver's station and a right-hand combined navigator's and scientific work station. Special restraint harnesses are provided while the driver is in the normal standing position. A mirror driving system has been added to improve visibility.



Total Vol	- 250 ft^3
Usable Vol	- 150 ft^3
Structure Weight	- 1150 lb
Life Support Weight	- 1326 lb

ITEM	LM/MOLEM COMPARISON		
	ADDED	MODIFIED	COMMENTS
Pressure Shell & Bulkheads		X	Minor mods - airlock and radiator attachments.
Meteoroid Protection and Insulation	X		Existing shield removed and replaced by 0.013 skin.
Chassis Attachment		X	Use LM existing attachments.
Crew Station		X	LM flight panels and controls removed. Mobility panels and controls added.
Bunks	X		
Airlock	X		
Driving Mirror System	X		Expandable airlock and pump
Canister Storage for Waste and Food	X		

Figure 2-3 MOLEM Cabin External Arrangement

TABLE 2-7

CABIN STRUCTURAL DESIGN CRITERIA

Condition	LM, Apollo Command Module and CAN Limit Load Factors and Pressures	MOLEM MOCOM MOCAN
Boost	5.65 g vertical +0.70 g horizontal	Same
Docking	0.08 g vertical 0.11 g horizontal	Same
Lunar landing (LM only)	Initial impact 8 g vertical 0 g horizontal Rockback 0 g vertical +8 g horizontal	Same
Mobility		4 lunar g (any direction)
Cabin Pressure	5 psia	
Meteoroid protection criteria		99% probability of no penetrations 75% confidence level
<u>Safety Factors</u>		
Cabin pressure	1.5 (yield) 2.0 (ultimate)	Same
Unpressurized	1.10 (yield) 1.40 (ultimate)	

All flight control panels for the LM ascent stage have been removed and replaced by mobility control and display panels. The lower center part of the front bulkhead contains the egress/ingress hatch which is connected to an expandable airlock.

The aft compartment contains the bunks, arranged fore and aft above each other, the ECS heat exchanger, the PLSS recharge station, and the emergency exit. A food and waste storage container is provided in place of the LM ascent stage engine. Equipment and storage are located along the sides of the cabin. The footrest parts of the bunks extend into the forward compartment and must be folded back under the bunks when not in use.

Table 2-8 summarizes the structural weight breakdown for the preferred MOLEM configuration. Figure 2-4 shows the preferred MOLEM cabin arrangement. Figure 2-5 summarizes the cabin system weights and cg.

2.3.2 Power System

The following criteria were used for selecting the power system concepts:

1. The vehicle shall make maximum use of existing subsystems developed previously for space applications, e.g. Apollo CSM fuel cells.

2. Consider design improvements (weight, performance) if the existing subsystems with no modification cannot satisfy the system constraints.

3. Consider new power systems if the existing systems with projected improvements still cannot satisfy the mission constraints or require excessive weight or performance penalties.

The major mission and system restraints and power requirements are as follows:

1. The power system shall be capable of being stored on the lunar surface in a standby mode for at least 6 months.

2. The power system shall be designed for a 1-day operating capability plus a 7-day emergency survival requirements.

TABLE 2-8

MOLEM STRUCTURE MASS

Cabin Structure	(lb)		kg	
Front Face				
Skin	(80.0)		37.2	
Shielding (meteoroid protection insulation listed with thermo)	(15.0)		6.8	
Beams	(34.9)		15.8	
Frames	(12.6)		5.7	
Trusses and supports	(8.0)		3.6	
Windows	(20.0)		9.1	
Hatches	(25.0)		11.4	
Joints, splices, fasteners	(9.7)		4.4	
		(207.2)		94.1
Air Lock (expandable)		(121.5)		55.2
Cabin (forward compartment)				
Skin	(57.0)		25.9	
Shielding (meteoroid skin)	(14.0)		6.4	
Beams	(11.0)		5.0	
Longerons	(18.2)		8.3	
Stiffeners	(22.5)		10.2	
Frames	(17.6)		8.0	
Trusses and supports	(39.4)		17.9	
Decks	(8.0)		3.6	
Windows	(3.6)		1.6	
Joints, splices, fasteners	(19.3)		8.8	
		(210.6)		95.6
Aft Compartment				
Skin	(73.0)		33.1	
Shielding (meteoroid skin)	(31.0)		14.1	
Bulkheads	(94.1)		42.7	
Beams	(31.8)		14.4	
Longerons	(7.6)		3.5	
Stiffeners	(27.1)		12.3	
Frames	(31.6)		14.3	
Trusses and supports	(85.8)		39.0	
Decks	(67.8)		30.8	
Hatches	(25.0)		11.4	
Joints, splices, fasteners	(17.9)		8.1	
		(492.7)		223.7
Controls & Displays (including instruments)		(120.0)		54.5
		(1152.0)		523.1

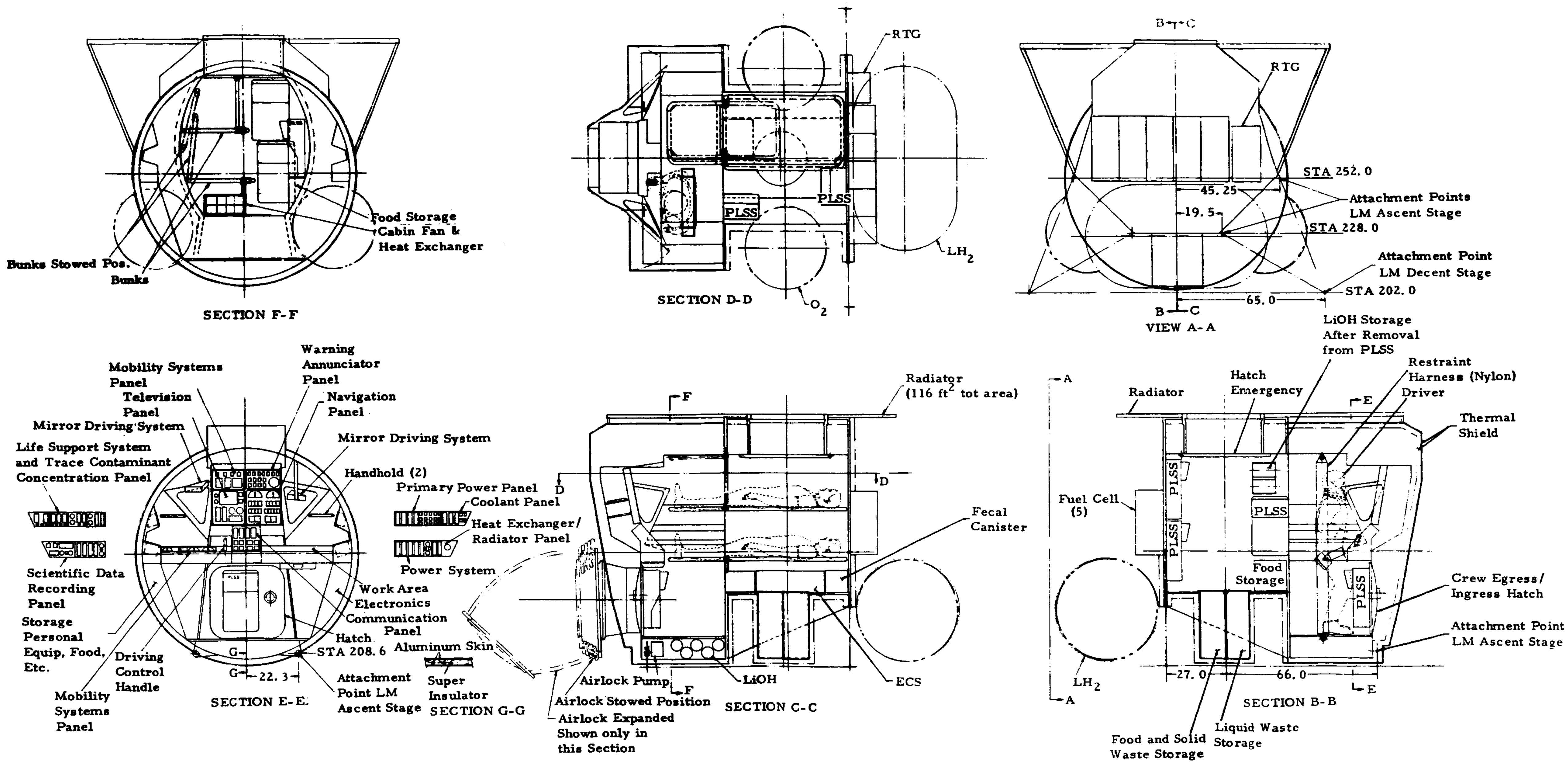


Figure 2-4 MOLEM Cabin Phase I Study

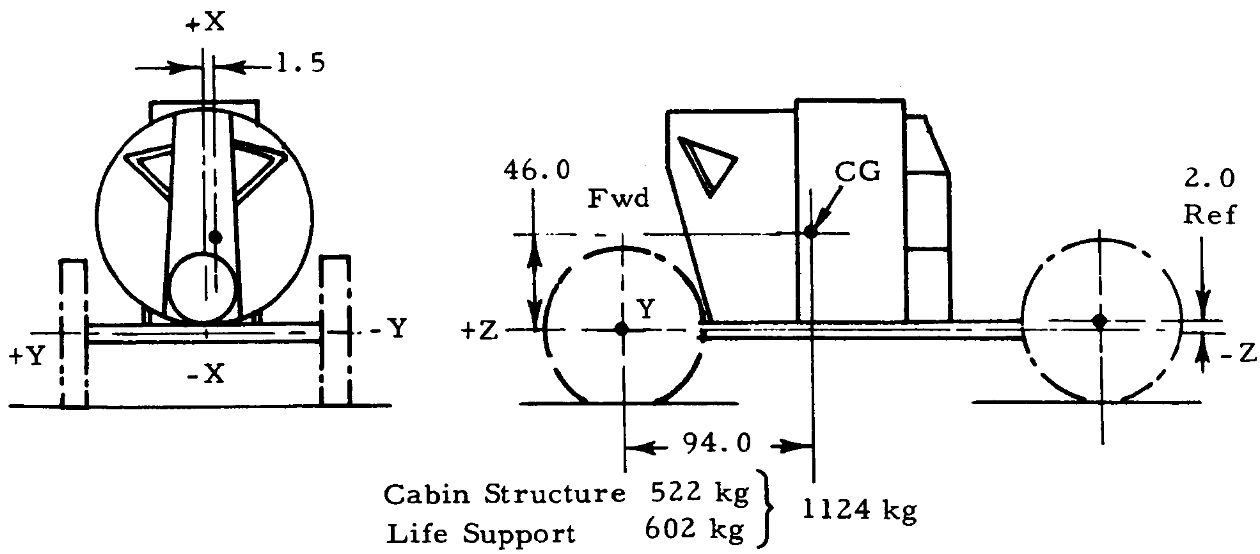


Figure 2-5 Weight and CG for MOLEM Cabin System

3. The power system shall provide the necessary tankage and controls for the life support oxygen. The life support oxygen requirement is 200 lb for the 14-day operation and the 7-day survival.

4. The power and energy requirements are summarized in Table 2-9.

TABLE 2-9

MOLEM POWER AND ENERGY SUMMARY

	14-day mission	7-day emergency extension
1. Mobility		
a. Maximum continuous power	5.97 kw	0
b. Peak power	10 kw	0
c. Ave. power & duty cycle	4.38 kw x 40 hr	0
d. Energy	125 kwh	0
2. Experiments		
a. Ave. power & duty cycle	0.5 kw x 126 hr	0
	x 0.25 kw x 40 hr	
b. Energy	73 kwh	0
3. Astrionics		
a. Comm. Ave. Power and Duty Cycle	0.412 kw x 336 hr	0.15 kw x 100 hr
b. Navigation Ave. Power and Duty Cycle	0.425 kw x 63 hr	0
c. Energy	166 kwh	15 kwh
4. Cabin & Thermal		
a. Energy (100% duty cycle)	175 kwh	90 kwh
5. Total Load Energy	588 kwh	105 kwh

The alternate concepts considered for the MOLEM power system include two different fuel cell designs for the primary power subsystem:

1. The existing Apollo C/SM fuel cell power supply. This system is based on 1960 technology.

2. The improved fuel cell power supply. This system is similar to the C/SM fuel cell but has higher efficiency and power density (kw/lb). Performance estimates are based on improved electrode designs and are projected for 1968-1970 periods.

Table 2-10 summarizes the power system weight comparisons for the two fuel cell designs. The improved fuel cell design was selected because of the weight advantages.

A study was conducted to determine potential weight savings for reduced mission requirements. The following reduced requirements were considered:

1. Delete the 7-day survival requirement

2. Reduce the mission duration from 14 to 8 days and delete the 7-day survival requirement.

Table 2-11 presents the results of this study.

The power system provides electrical power during the inflight, debarking, lunar storage, and scientific mission phases. The electrical power requirements vary from 50 w during the lunar storage phase nighttime to a maximum continuous demand of 6.97 kw during the scientific mission phase. The short-duration (<1-min) peak power demand is approximately 10 kw. The power system also furnishes thermal power for the lunar storage phase thermal control, and provides storage for 200 lb of life support oxygen.

Figure 2-6 shows the power system block diagram. This system consists of five major subsystems: primary power utilizing H_2-O_2 fuel cells; secondary power consisting of rechargeable batteries; auxiliary power utilizing a radioisotope thermoelectric generator; cryogenic storage and supply consisting of hydrogen and oxygen fluids and tanks; and power conditioning and distribution.

TABLE 2-10

MOLEM POWER SYSTEM MASS

	Item	Mass (kg)	
		3 existing P&W Apollo C/SM fuel cell assemblies	2 improved P&W fuel cell assemblies
I	Primary power	381	200
II	Secondary power, auxilary power, and power conditioning and distribution	70	93
III	Fuel cell radiators	(included in item I)	28
IV	Cryogenic excluding usable fluids	338	277
	Total—Excludes Usable Fluids	790	598
V	Usable fluid for fuel cells		
	H_2	45	29
	O_2	353	224
	Total—Includes Usable Fluids	1189	851

TABLE 2-11

MOLEM POWER SYSTEM MASS—REDUCED REQUIREMENTS

Item	Mass (kg)			
	14-day mission, delete 7-day survival requirements (400-km range)		8-day mission, delete 7-day survival requirement (400-km range)	
	3 existing P&W Apollo fuel cell assemblies	2 improved P&W fuel cell assemblies	3 existing P&W Apollo fuel cell assemblies	Improved P&W fuel cell assemblies
I. Primary power	381	200	381	200
II. Secondary power, auxilary power, power conditioning, distribution equipment	70	93	704	93
III. Radiator	(included in item I)	28	(included in item I)	28
IV. Cryogenic excluding usable fluids	310	227	255	197
Total excludes usable fluids	761	548	706	518
V. Usable fluid for fuel cells				
H_2	39	25	25	14
O_2	300	190	191	150
Total includes usable fluids	1100	763	923	682

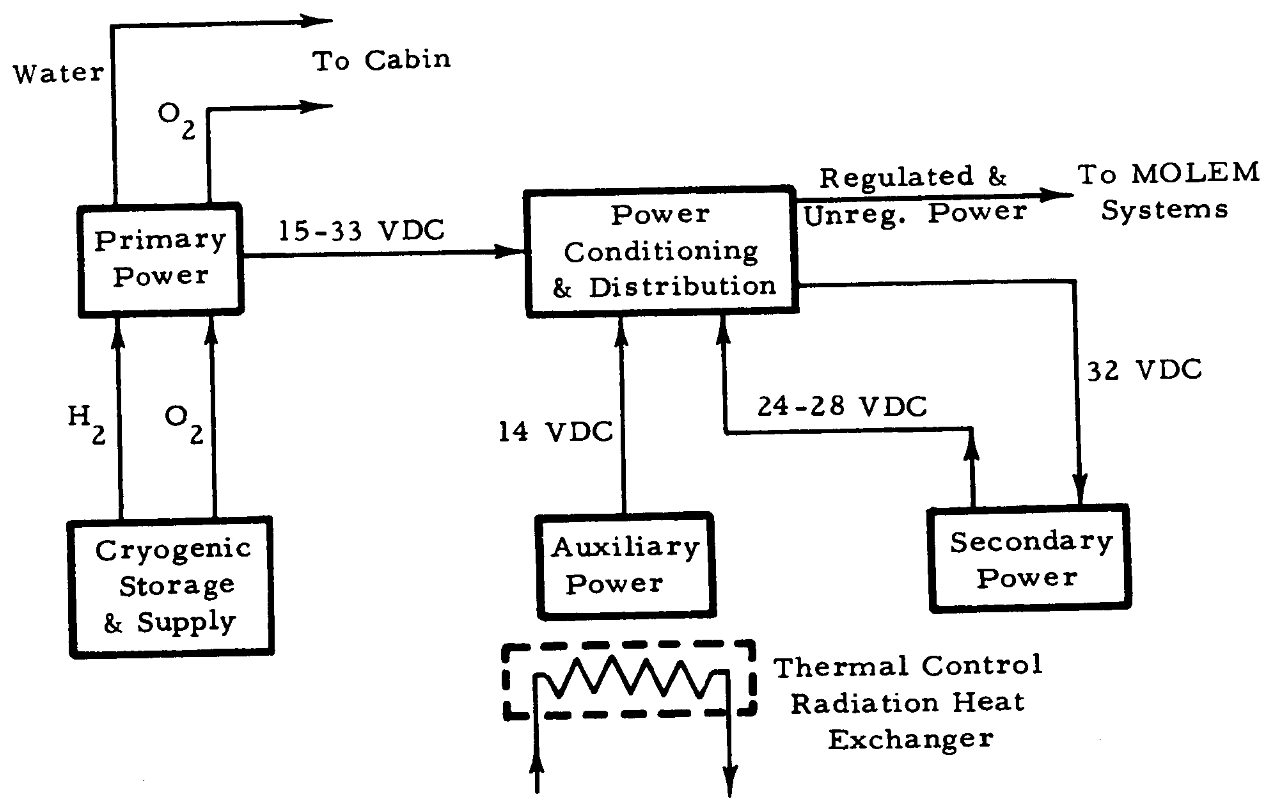


Figure 2-6 MOLEM Power System Block Diagram

During the lunar transit and storage phases, the auxiliary power furnishes a low level continuous power for thermal controls and trickle charging the batteries. During peak load demands (e. g. , checkouts), the secondary power provides the additional power required if the demand is in excess of the RTG output. During the scientific mission phase, the fuel cells will be activated and will be used as the primary source of power.

The total power system mass is 851 kg, excluding the fuel cell reactants. The hydrogen system weight includes boil-off and residual fluid. The oxygen tanks are sized to store the fuel cell oxygen and 91 kg of O_2 for life support. The oxygen system weight includes the residual fluids and the tanks.

2.3.2.1 Primary Power

The primary power subsystem consists of two Pratt and Whitney (P&W) Aircraft fuel cell assemblies, a primary power accessories package, and a fuel cell radiator. The proposed fuel cells are optimized for the MOLEM requirements and are based on modifying the present Apollo C/SM fuel cells including projected improvements. The P&W fuel cell is a moderate temperature hydrogen-oxygen system using nickel electrodes and approximately 80% potassium hydroxide electrolyte.

Figure 2-7 shows the primary power fluid schematic. The fuel cell assemblies are rated 3.5 kw (maximum continuous power) per fuel cell assembly. Each fuel cell assembly consists of a primary loop (recirculating hydrogen and water vapor fluids), a part of a secondary coolant loop (FC-75 fluid), a storage phase thermal control loop (FC-75 fluid), and reactant lines. The storage phase thermal control loop is deleted from Figure 2-7 for clarity. The primary power accessory package consists of the coolant pumps, cryogenic heat exchangers, and gaseous H_2 and O_2 for lunar checkout. Parts of this package are common to the secondary loops from the two fuel cell assemblies.

The primary loops transfer waste heat from the fuel cell stacks to the secondary loops, condense water vapor from the fuel cell stacks, and supply product water to the cabin system. The primary regenerators maintain the fuel cells in thermal equilibrium over the power spectrum. At high power level operation, these regenerators are bypassed. At reduced power level operation, the heat leaving the fuel cell stacks is conserved by circulating the fluids through the regenerators, and the bypass flow rates are controlled by the fuel cell stack temperatures.

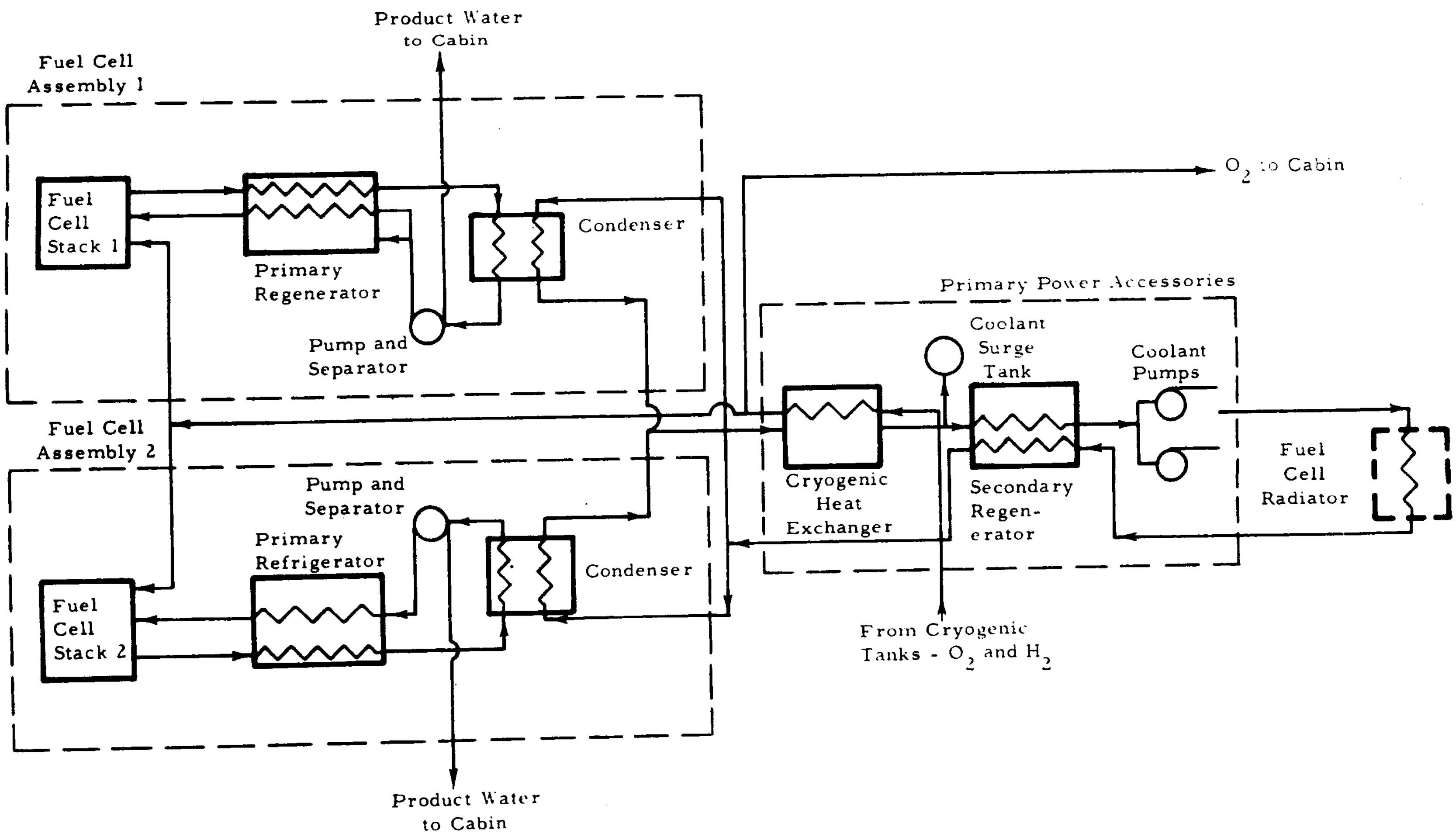


Figure 2-7 Primary Power Fluid Schematic

The secondary loops transfer the fuel cell waste heat from the condensers to the fuel cell radiator. The functions of the secondary regenerators are similar to the primary regenerators, and the bypass flow rates are controlled by the condenser hydrogen exit temperature.

A cryogenic heat exchanger is provided to contain the cryogenic reactants to 50°F during maximum continuous power operation. Lower conditioning temperatures will exist during low-power operation, since the coolant temperature from the fuel cell radiator is lower. Oxygen is also conditioned for crew use in this heat exchanger and transferred to the cabin system.

2.3.2.2 Secondary Power

The secondary power subsystem consists of two sealed, rechargeable, silver-zinc batteries. Each battery is made up of 16 series-connected cells and rated at 1800 w-hr at a 24-v discharge level. The storage phase cycle life requirement is about five deep discharge cycles with the energy required in the range of 350 to 1000 w-hr. The batteries are connected in parallel and the total capacity is 3600 w-hr. The depths of discharge to meet the storage requirements range from 9.7% to 28%.

2.3.2.3 Auxiliary Power

The auxiliary power subsystem consists of a small radiosotope thermoelectric generator (RTG) of the SNAP-27 type. The RTG gross output is 56 w at 14 VDC. The RTG also provides the thermal energy for the storage phase thermal controls. Heat is transferred from the RTG to the thermal control heat exchanger by radiation.

2.3.2.4 Cryogenic Storage and Supply

The cryogenic storage and supply subsystem consists of one cylindrical hydrogen tank (internal length-to-diameter ratio equals 2), two spherical oxygen tanks, the cryogens, and controls. This system is designed for 180 days of storage on the lunar surface.

Oxygen is stored in two identical nonvented spherical tanks at subcritical pressure of approximately 300 psia. Under subcritical conditions the fluid exists in liquid and gas phases which are easily distinguishable and separable. Hydrogen is stored in one cylindrical tank designed and initially filled to obtain a supercritical pressure of approximately 660 psia prior to venting and prior to completion of 180-day standby.

The hydrogen and oxygen tanks are double-walled vessels with superinsulation in between. The space between the inner vessel and the outer vacuum jacket is evacuated to 10^{-8} torr. Within the inner vessel are mounted thermal conductors to reduce thermal stratification; a quantity sensor; a temperature sensor; and a heater used to maintain tank pressure during use. The inner vessel is supported by low-conductivity bumpers. The external equipments include valves, disconnects, and signal conditioners.

2.3.3 Mobility System

The major elements of the MOLEM mobility system are: (1) two pairs of metal elastic wheels constructed of titanium, aluminum, and non-metallic treads and side walls (the front pair being slightly stiffer than the rear), (2) two pairs of suspension and deployment mechanisms consisting of axis cranks, torsion bars, deployment drives, and dampers (the front pair being slightly stiffer and shorter than the rear), (3) two traction and steering drive assemblies located inside the front wheel hubs featuring a hermetically sealed DC series traction motor, nutator transmission, two-stage brake systems, and a dynamically sealed steering actuator, (4) two traction drive assemblies similar to those in item 3 without steering actuators located inside the rear wheel hubs, (5) a trapezoidal chassis frame constructed of welded aluminum beams with box-type cross sections sized to distribute concentrated loads to the tiedown points and the wheel supports, (6) a cryogenic storage and supply system consisting of two subcritical oxygen spherical tanks mounted on the chassis aft section and two supercritical hydrogen cylindrical tanks mounted to the cabin, and (7) a mobility control unit mounted outside the cabin which distributes controlled power to the drive and steering motors.

2.3.3.1 Wheel Assembly

Each wheel has an overall diameter of 2.03 m and a width of 0.305 m. The inner 1.35 m-diameter core is constructed of aluminum struts connecting the aluminum hub to the inner aluminum rim. This rigid inner core is made of a single material to minimize thermal stresses arising from the wide lunar temperature range. Flexible rings connect the inner aluminum rim to the outer titanium rim. These rings are fabricated from titanium, because of its high strength-to-weight ratio, high maximum elastic strain, and long fatigue life. Each pair of flexible rings is protected from over elongation by an overload band. These bands are operative primarily during the transmission of torque.

2.3.3.2 Traction Drive Mechanism

The traction drive mechanism (TDM) for each of the four MOLEM wheels consists of wheel support bearings, hub support structure, radiator, TDM direct current motor, brake, gear shaft clutch, planetary transmission, and nutator transmission.

The TDM motor drives the nutator transmission and wheel through a first-stage planetary transmission. The planetary transmission provides a 5:1 speed shift actuated by electrical command for high wheel torque and low-speed vehicle mobility. The nutator transmission design allows hermetic sealing of the TDM motor, brake, planetary transmission, and associated bearings. Only the nutator gear mesh and wheel support bearings are exposed to the dynamically sealed environment provided by the fixed-clearance grease-packed seals of the wheel support bearings.

The TDM may be decoupled from the wheel manually by unbolting the nutator external bevel gear from the wheel. Remote decoupling may be actuated by igniting an explosive charge to shear the torque section between the wheel and nutator transmission.

Vehicle braking at high speed is effected by driving the TDM motor as a generator. Low-speed (0 to 5 kpm) vehicle braking and no-power parking brake are accomplished by the mechanical brake on the TDM motor shaft.

2.3.3.3 Steering Drive Mechanism

The steering drive mechanism (SDM) for each of the two front wheels consists of a direct current motor and nutator transmission, steering linkage, kingpin, and kingpin support structure. The motor is hermetically sealed by a nutator transmission. The SDM motor and transmission are coupled to the hub support structure by a two-bar steering linkage which pivots the wheel about the kingpin axis.

The SDM may be manually decoupled from the hub support structure by unbolting the two-bar linkage from the nutator transmission. Remote decoupling may be actuated by igniting an explosive charge to shear the two-bar linkage.

2.3.3 4 Chassis

An independent trapezoidal chassis is employed on MOLEM. The equipment supported directly by the chassis is as follows:

1. Scientific equipment lockers at the rear platform

2. RTG, battery, fuel cells, primary power accessories, and mobility control unit located on the aft platform

3. Cabin

4. Liquid oxygen tanks on each side of the cabin.

The chassis is primarily a structural aluminum frame which resists normal and coplanar loads and moments. The structural members resist both torsion and bending stresses. Members are closed rectangular sections of built-up aluminum webs and chord angles. The closed forms provide the necessary torsional rigidity; the rectangular shapes provide good flexural efficiency and simplify equipment mountings. Special fittings are provided at juncture points and at primary load points. A rear platform is provided to facilitate ingress and egress through the airlock. The platform also serves as a base for manual unloading (if necessary), and can be used for a work surface when the astronaut is outside the vehicle.

Based on a 3514 kg vehicle the MOLEM mobility mass is summarized in Table 2-12.

TABLE 2-12

MOLEM MOBILITY SUBSYSTEM MASS

Item	Weight kg	(lb)
TDM Assy (4)	134	(295)
Traction Assy (4)	168	(370)
SDM Assy (2)	18.1	(40)
Suspension Assy	79.5	(175)
Controls	34	(75)
Chassis	102	(225)
TOTAL	535.6	(1180)

2.3.4 Life Support Environmental Control

To define the life support system for MOLEM, parametric system trade-offs were performed. The first of these was the egress/ingress trade-off which considered cabin dump without airlock pump

It is anticipated that there would be two egress/ingress cycles per day for the 14 days on the nominal mission. With a simple cabin all the atmosphere in the spacecraft is lost each time the hatch must be opened to space. This also necessitates the nonegressing astronauts to be in a suit during exit and re-entrance of the primary astronaut. It also makes possible the inability to repressurize the cabin due to a failure of the hatch to seal. This would be a prohibitive method of egress/ingress, in terms of weight. One way to minimize this loss and minimize the danger of inability to repressurize the cabin is to provide a lock. The egressing astronaut would enter the lock, close the door between the lock and the main cabin, check the suit, seal his suit and dump the lock atmosphere to space. When there was no longer significant atmosphere therein, the door between the lock and the lunar surface would be opened and the astronaut would egress for a normal EVA. Upon return he would enter the lock, close that hatch, repressurize the lock using make-up from oxygen stores, and when pressure equaled that in the main cabin, open the hatch connecting the two compartments. Thus, with each cycle, only the atmosphere in the lock is lost. However, even much of this loss can be minimized by providing a pump connecting the lock and the main cabin. A typical cycle would consist of the following.

The main cabin would be at 5 psia and the lock would have essentially no atmosphere. Cabin gas, not stored oxygen, would be permitted to bleed into the lock until the pressure in the cabin and airlock was equal, when the pressure would approach 3.5 psia. An egressing astonaut would enter the airlock after opening the connecting hatch between the main cabin and airlock, close that hatch and after closing his suit system, wait 5 min while an evacuation pump transferred atmosphere from the airlock back to the main cabin raising the pressure in the main cabin back to 5.0 psia for the duration of the 8 hr of EVA. The egressing astronaut would then open the hatch between the airlock and the lunar surface and egress. Upon return he would close that hatch and again allow atmosphere to bleed from the main cabin to the airlock, raising the airlock pressure from essentially 0 to 3.5 psia. When pressure was equalized between the main cabin and the airlock, the connecting hatch could be opened, the returning EVA astronaut would proceed into the main cabin, close the hatch and again the lock pump would re-evacuate the gas from the airlock to the main cabin again raising the pressure to 5 psia. Thus, only for the short periods when the airlock is being used would the pressure in the main cabin be as low as 3.5 psia. This is entirely acceptable for a short period of time. The disadvantage of this system is that there is an energy requirement and a power requirement associated with the pump. It is inherently less reliable than less complex systems. However, even if the pump were to fail, the system could be used as a simple lock operation.

Figure 2-8 presents the weight penalties associated with the three ingress/egress methods plotted against the number of cycles of operation. For the design value of 28 cycles the airlock plus pump shows a significant weight savings.

A cabin thermal control system study was conducted to define this major ECS subsystem. The first step in the study was to establish the requirements and loads for the system. A review of previously conducted trade-offs was then accomplished to establish the concept to be used for thermal control (i.e., water evaporation, radiator, mechanical refrigeration, or hybrid). The use of a space radiator covered with a surface providing a very low α_S/ϵ has proved to be the best concept for active thermal control on the lunar surface for a mission in this time range.

The next step in the study was to establish the cabin insulation design. Trade-off studies showed that insulation thicknesses in the range of 1 in. resulted in cabin heat leaks that were small compared with other cabin loads. Variation in thickness has little effect on system weight because the changes in insulation weight are offset by corresponding changes in the cooling and heating system. Based on an insulation thickness of 1 in. and the established heat loads, a cooling system was configured. Night operation was then analyzed and the need for a cabin and radiator heating system established. A system that combines the cooling and heating of equipment, cabin atmosphere, and RTG was then established and weight estimates were made.

Table 2-13 presents the heat loads and thermal control characteristics used in the thermal analysis. The radiator operating temperatures given in Table 2-13 reflect the requirements of the electronic equipment and cabin and suit cooling systems. The quantity of water available for cooling was established by comparing water available from the fuel cells

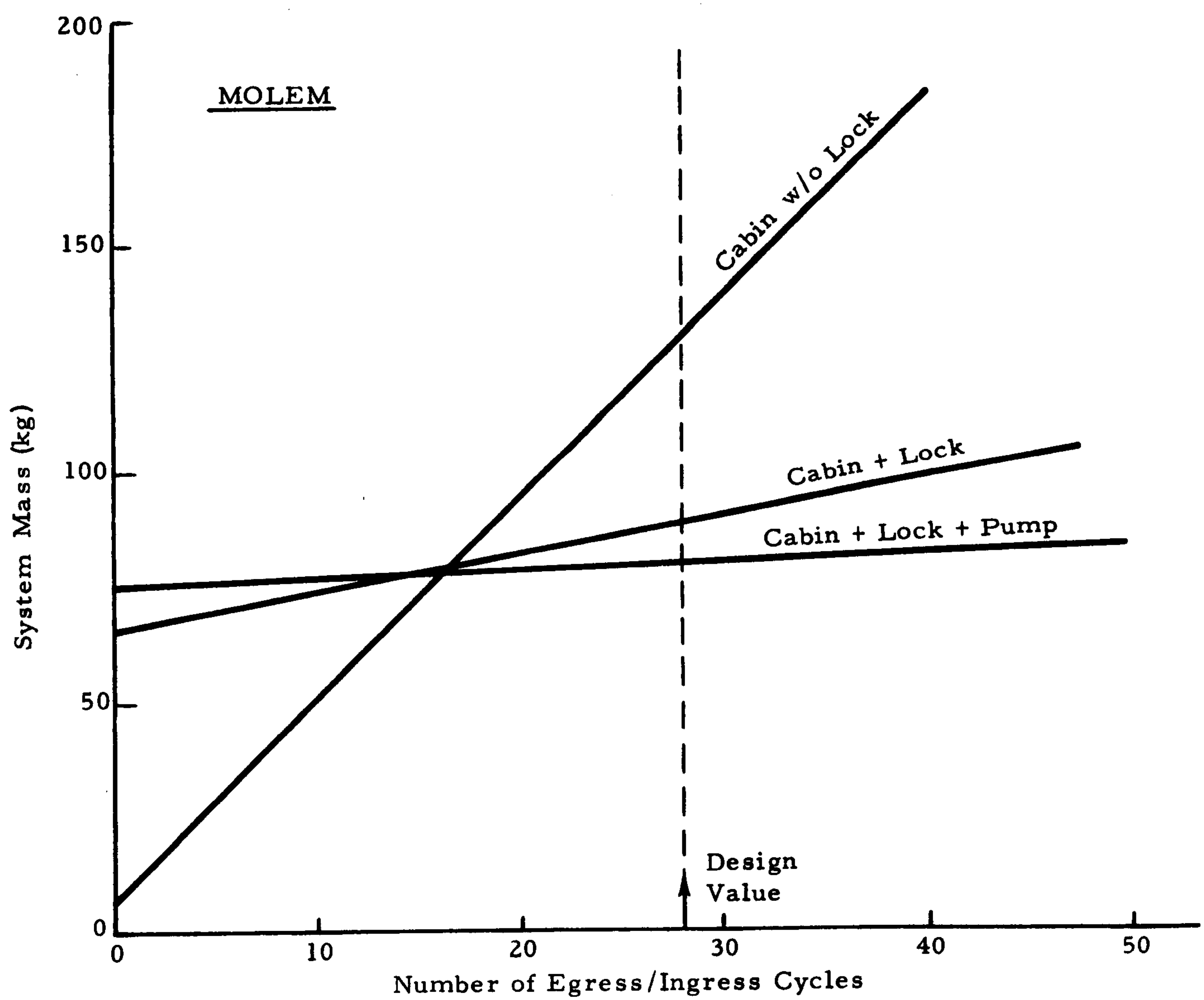


Figure 2-8 MOLEM Ingress/Egress Trade-off

TABLE 2-13

MOLEM THERMAL CONTROL SYSTEM CHARACTERISTICS

Cooling System		
Properties		
Equipment Radiator Full Load Temperature		100^{o}F
ECS Radiator Full Load Temperature		35^{o}
Water Available for ECS Evaporative Cooling		8 lb/day
Radiator Surface Characteristics		$\alpha S/\epsilon = 0.043/0.80$
Loads		
Equipment Loop		1210 watts
ECS Loop Equipment		265 watts
Metabolic	1 man	275 watts
	2 men	550 watts
	3 men	825 watts
Heating System		
Properties		
RTG as heat source		
Loads		
2 Men Metabolic and Machinery		815 watts
Heat Leak out		60 watts

with the water needs of drinking, PLSS use, and emergency thermal control. Excess water was then used to reduce radiator size by using this water for heat rejection during peak load conditions. The radiator surface used is the optical solar reflector, which results in an equilibrium surface temperature of approximately $-100^{\circ}F$ at the subsolar point.

Based on the procedure outlined previously and the loads presented above, the thermal control system schematically represented by Figure 2-9 was synthesized. Two parallel loops are envisioned. One to provide cold plating for electrical and other equipment and the other to provide heat transport from the suit and cabin heat exchangers. These heat exchangers are, of course, accepting thermal loads that appear in the cabin. Each loop has its own radiator. The equipment radiator can operate at a higher, and therefore, more efficient, temperature than the ECS radiator. A pair of diverter valves in each loop are the key to control. During normal operation, when refrigeration is required, the first diverter diverts all flow from the RTG directly to the ECS radiator. This control uses as its information source cabin or suit temperature. When heat leak rate out exceeds heat production sources in the cabin, the diverter valve would begin to supply fluid through the RTG, using it as a heat source. A second diverter valve guarantees that the ECS radiator would not be exposed to such low temperatures during standby that refrigerant FC 75 would freeze or become extremely viscous. Cross coupling of pumps of the two loops is possible in the event of failure of one. A redundant water boiler is also provided so that in the event of loss of radiator performance, the water boiler would provide emergency thermal rejection capability and also makes minimum radiator area possible by providing "topping" during peak heat dissipation periods. Even in the event of complete loss of this thermal control system, the suit loop would have emergency heat retention capacity in the form of another emergency water boiler located in the suit loop.

The various elements of the life support system were combined into a total system. Figure 2-10 presents a schematic of the ECS for the MOLEM vehicle. The thermal control system shown by Figure 2-9 is shown as a box in the upper right-hand corner of Figure 2-10. In the MOLEM ECS, two suits are supplied conditioned oxygen in parallel. As the gas leaves the suits laden with water vapor, carbon dioxide, and other contaminants, it is processed through a lithium hydroxide and charcoal bed in which CO_2 and other trace contaminants are removed and particles filtered. From there it goes to a fan where it experiences the pressure rise necessary to induce the flow around the loop. The gas then goes to the suit loop heat

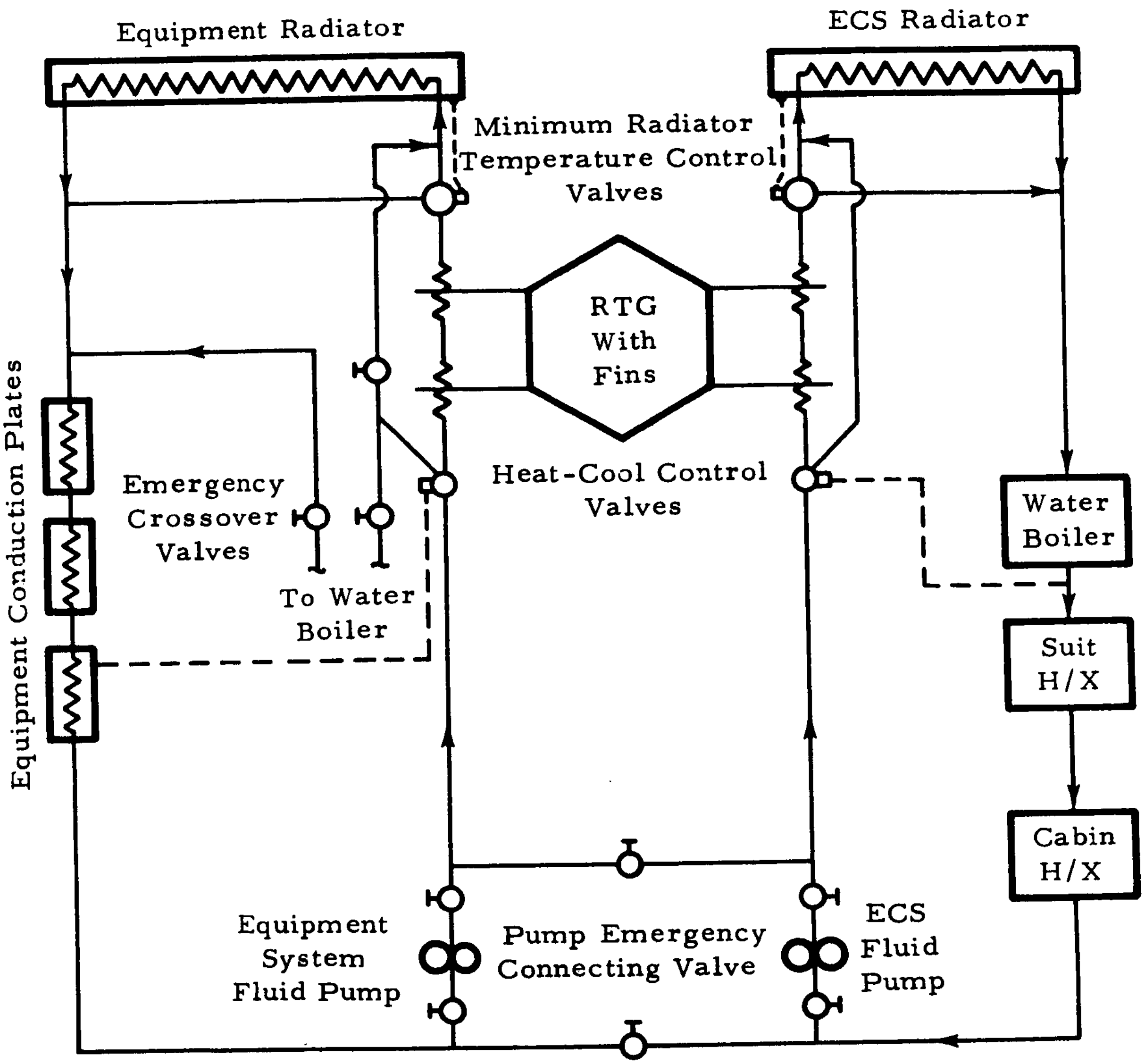


Figure 2-9 Thermal Control System Schematic

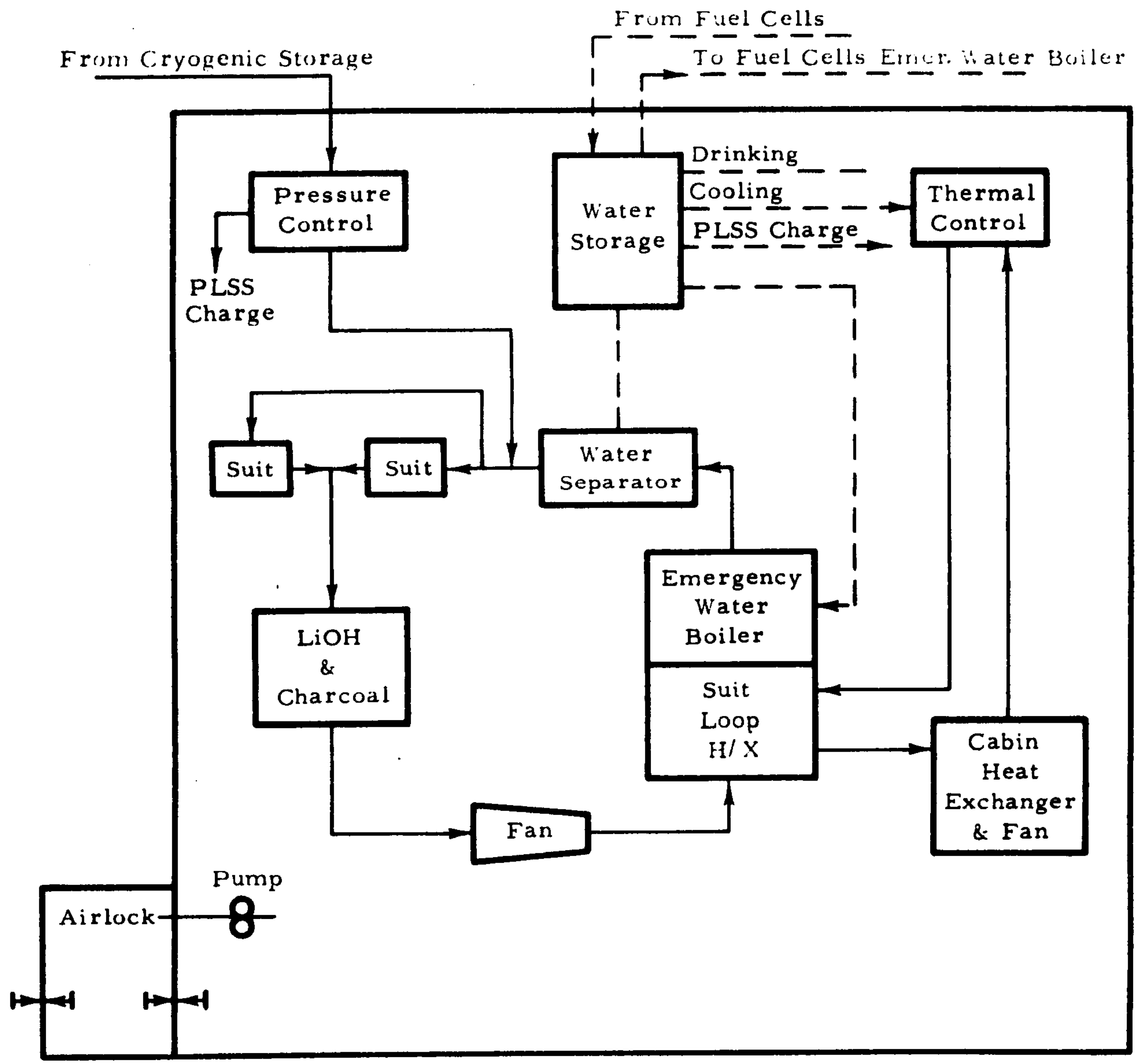


Figure 2-10 Environmental Control System Schematic

exchanger where it is cooled and water condensed, then to a water separator where the entrained condensed water is separated and recovered in the water management system. The flow is then ducted back to the suits. Liquid oxygen makeup for either suit leakage in the decompressed cabin mode or cabin leakage in the normal mode, and metabolic consumption is made up from cryogenic storage through a pressure regulator. The regulator system also provides PLSS recharge. The water system consists of storing condensed water coming from the fuel cells and from the suit loop water separator and providing water for drinking, for PLSS recharge, for emergency water boilers in the fuel cells, and thermal control and the suit loop emergency water boiler. The cabin heat exchanger and fan provides thermal control elsewhere in the cabin environment. A lock pump and airlock control the loss of atmosphere from the cabin during egress/ingress.

The MOLEM life support system mass estimates are presented in Table 2-14.

2.3.5 Communications

Figure 2-11 depicts the block diagram of the MOLEM communications subsystem. The cross-hatched blocks are original LM equipment items. The remaining blocks are new items of equipment that have been added to provide the following services:

Voice communications between earth and MOLEM via S-band and via VHF-AM relay through the CM; between MOLEM and the CM via VHF-AMJ; and between MOLEM and the astronaut via VHF-AM
PCM telemetry from MOLEM to earth via S-band and emergency PCM telemetry relay via VHF-AM to the CM
TV, Scientific Data, and Analog Data from MOLEM to earth via S-band
Command Data from earth to MOLAB via S-band.

Table 2-15 contains an equipment list and performance summary of the communications subsystem equipments and subassemblies, and Table 2-16 contains a mass summary.

2.3.6 Navigation

This section describes the MOLEM navigation subsystem, including component mass, power, and volume.

The navigation units listed in Section 2.1 as "retrained" were used as a starting point for concept selection. Other units were added as needed to provide a complete subsystem. It is emphasized that this concept does not represent the best concept available, but rather one which makes maximum use of Apollo hardware.

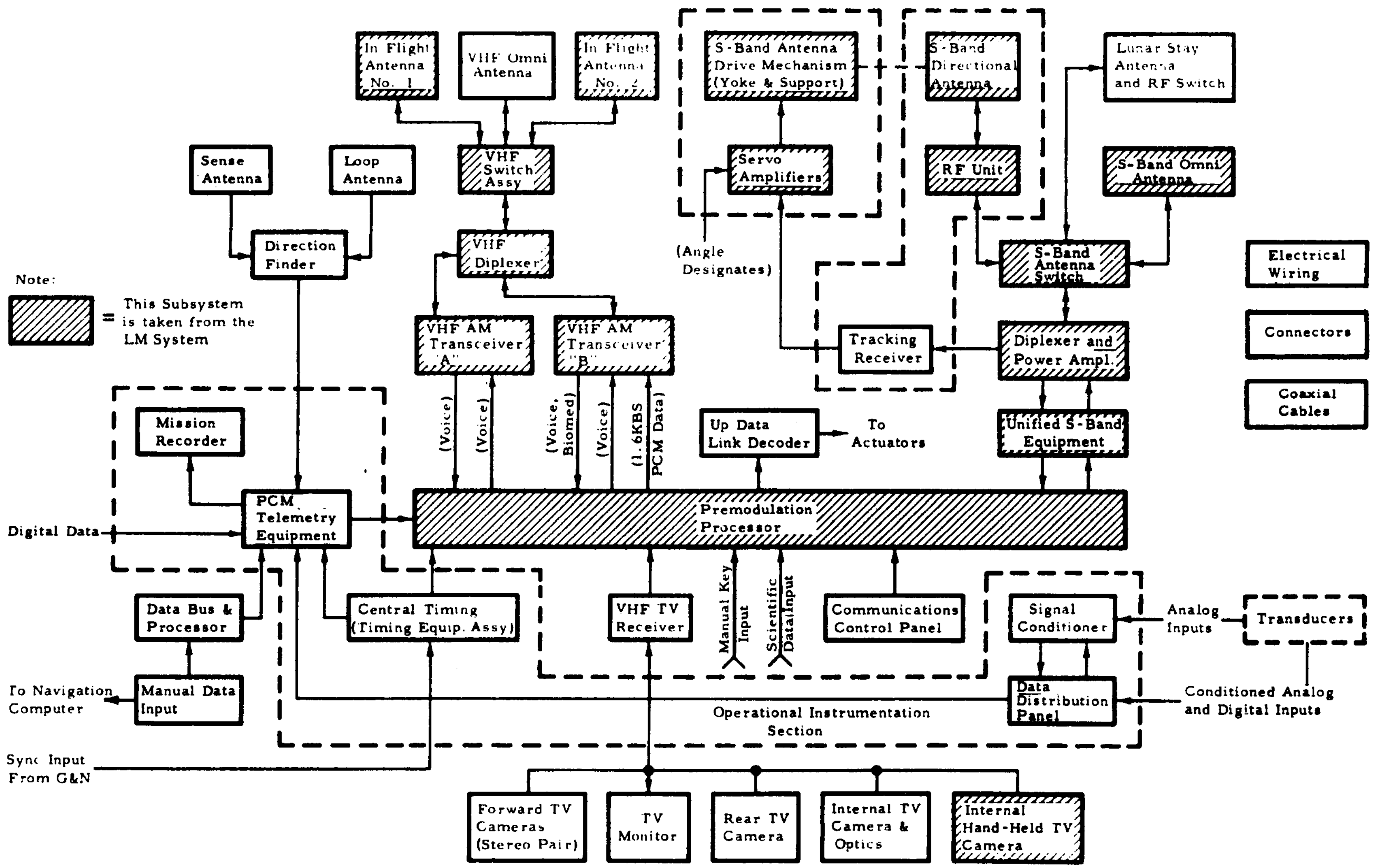


Figure 2-11 MOLEM Communications Subsystem Block Diagram

TABLE 2-14

MOLEM LIFE SUPPORT SYSTEM DATA

Item	Weight kg		Weight (lb)	
Environmental Control System				
Suit and cabin atmospheric conditioning	45		(100)	
Radiator cooling system	82		(180)	
Oxygen supply and pressure control	20		(45)	
Water management	16		(35)	
Controls, wiring, supports	18		(40)	
		182		(400)
Crew Provisions				
Suits and suit accessories	59		(130)	
Portable life support system	42		(92)	
Waste management	9		(20)	
Food preparation and personal hygiene	9		(20)	
Emergency equipment and accessories	27		60	
		146		(322)
Misc. Thermal Control				
Cabin insulation weights	18		(39)	
Storage phase heating system	27		(60)	
		45		99
Expendables				
Lithium hydroxide and charcoal	89		(195)	
Oxygen	91		(200)	
Water	8		(18)	
		188		(413)
Total		560		(1234)

TABLE 2-15

PERFORMANCE SUMMARY - ASTRIONICS EQUIPMENT, COMMUNICATIONS

DESCRIPTION OF ASTRIONICS, COMMUNICATIONS MOLEM	
1. ANTENNA SUBASSEMBLIES	
1.1 S-band Directional Antenna	Gimballed Steerable Dish Freq 2090-2300 Mc, Gain (db)/Beam Width—28.6 db/4.8°, 22.9 db/11.1°, 14.9 db/25.2°, Provides Communications Link to Earth (Recommend 4 ft Dish)
1.2 Antenna Drive Mechanism	T.B.D.
1.3 Servo Amplifier Unit	Tentative - (Ant. Accel. Max $64^{\circ}/Sec^2$, Ant. Velocity, Max $8.4^{\circ}/Sec$)
1.4 Tracking Receiver Unit	T.B.D.
1.5 S-band Omni Antenna	Crossed Dipoles, Freq 2000-2300 Mc VSWR 2.0:1, Polarization Circular, Gain 5 db
1.6 S-band Inflight Antenna (2 Ea)	Circularly Polarized Spiral Conical Antenna Backup to 1.1 One on X&Y Axis of Vehicle Gain Shall be >-3 db in respect to a Right Hand Circularly Polarized Isotrope Over 85% of Sphere
1.7 S-band Antenna Switch	T.B.D.
1.8 VHF Omni Antenna	Crossed Dipoles Freq 250-300 Mc, Gain 5 db VSWR 2.0:1
1.9 VHF Inflight Antenna (RCA)	Type Similar to (1.6) Gain > -6 db in Respect to Linear Isotrope Over 85% of Sphere, VHF Link to EVA
1.10 Lunar Stay Antenna ( )	Erectable Antenna, TV Support
1.11 VHF Antenna Switch	T.B.D.
1.12 Sense Antenna, Direction Finding	Whip Type Antenna, Z = 50 ohms, Gain 4.8 db
1.13 Loop Antenna, Direction Finding	Loop Type Antenna
2. RF AND MODULATION EQUIPMENT (S-BAND)	
2.1 Diplexer and Power Amplifier Unit	Po Per Channel 25w Cascade 50w Transmitter Freq Band 2270-2300 Mc, Input Drive Power 250 mw, Conduction Cooled Amplitrons
2.2 Unified S-band Equipment (T)	PM ft = 2282.5 Mc, FM ft = 2277.5 Mc, PWR Out 250 Mw, 5w or 20w, RFBW 3.0 Mc PM, 4.0 Mc (Max) FM
(R)	Phase Lock Type, fr = 2101.8 Mc, Dynamic Range -52.5 to -132.5 dbm If Bw 6.0 Mc
3. RF AND MODULATION EQUIPMENT (VHF)	
3.1 Diplexer Assembly	Isolation 30 db Peak PWR Input 5w
3.2 Transceiver AM (No. 1) Voice & Biomed	Transmits PCM Data at 1.6 KBS (Shall RCV EMU Data From EVA or Voice From CM fo = 259.7 Mc
3.3 Transceiver (No. 2) Voice	Ft = 296.8 Mc, Freq Response 300-3000 CPS Modulation Level 100°, Speech Clipping-Infinite, PWR Out 5.0w, fr = 259.7 Mc, If Bw 70 Kc (6 db)

TABLE 2-15 (CONT.)

4. ADDITIONAL MODULATION SUPPORT EQUIPMENT	
4.1 Pre-Modulation Processor (PMP)	Bi-Phase Modulate 1.6 Kbs Serial Bit Train (NRE) on 1024 Kc Carrier - Mc, FM Telemetry Bw 300-3K Cps, Bw 9 Kc, Bw 55 Kc
4.2 Audio Center	Audio Bw 300-3000 Cps
4.3 Communications Control Panel	28 VDC Control Signals
5. DATA HANDLING EQUIPMENT	
5.1 PCM TM Encoder	Freq Subcarrier 1024 Kc Modulation Psk $\pm 90^{\circ}$, Data Rate 51.2 (Normal) or 1.6 Kbs (Reduced) Word Length Variable to 40 Bits in 8 Bit Subwords
5.2 Central Timing Equipment	Master Timing Source, Timing Clock 1.024 Mc
5.3 Data Bus and Processor	T.B.D.
5.4 Manual Data Input Unit	T.B.D.
5.5 Signal Conditioner Unit	J-Box for All Analog Signals, Conditions Signals to Proper Voltage & Impedance Levels, Temp Eo = 0-5 VDC, Operating Range -150° 0-$+250^{\circ}$C, Zo = 500 Ohms, Pressure 0-20Psi, 0-5V Eo, ± 0.5 Psi
5.6 Data Distribution Panel	T.B.D.
5.7 Data Modulators	5 IRIG Channels, Type VCO, Input Z = 500 K Ohms, Eo Level (Mixed Signal) 0-1 V P-P, Fr = 22.0 Kc, 30.0 Kc, 40.0 Kc 52.5 Kc and 70.0 Kc
5.8 Mission Recorder	T.B.D.
5.9 Emergency Key Unit	Freq 512 Kc, Modulation 512 Kc Keyed on and Off
5.10 Teleprinter Unit	T.B.D. (For Future Use Only)
6. TELEVISION EQUIPMENT	
6.1 Forward TV Camera Assembly	Freq Response Dc to 500 Kc, Modulation FM Directly on Carrier Frame Rate 10 Frames/Sec, 320 Lines/Frame Non Interface, Resolution Prior to Scan Conversion 210 Sq Elements/Line
6.2 Rear TV Camera Assembly	(As Above 6.1)
6.3 Internal TV Camera Units (Units)	(As Above 6.1)
6.4 VHF Television Receiver	Type: AM Supernet, Freq 270 Mc Fixed, If Bw 1.25 Mc (1 db) Signal Output 10 Mw
6.5 Television Monitor Unit	T.B.D.
7. REMOTE CONTROL SUPPORT EQUIPMENT	
7.1 Up Data Link Decoder	T.B.D.
7.2 Direction Finder Unit	T.B.D.

TABLE 2-16

MOLEM COMMUNICATION SUBSYSTEM MASS SUMMARY

Item		Estimated Weight Kg	(lb)
1. Antennas (S-band, VHF)		45	(100)
2. RF & modulation equipment (S-band, VHF)		41	(90)
3. Data handling		68	(150)
4. TV		34	(75)
5. Remote control equipment		5	(10)
6. Electrical provisions		16	(35)
	TOTALS	209	(460)

Table 2-17 lists the components of the MOLEM navigation subsystem. Figure 2-12 shows the block diagram. The retained items are the same as those shown in Section 2.1.2.11 with one exception—the Alignment Optical Telescope (AOT) has been deleted. The AOT can evidently be set in only three distinct positions. For surface navigation it should have no such limitations. It should be able to view the majority of the available stars as well as the surface, without turning the vehicle. Therefore, it has been replaced by a sextant which will incorporate these features.

The IMU will be used as a vertical reference for the sextant in position fixing, as well as an attitude reference for the odometer dead-reckoning system. Ephemeris data are in printed form rather than computer-stored for reliability.

Homing on the LM is accomplished through the Direction Finder which is shown in Figure 2-12, but is carried under Communications in equipment tabulations. It is assumed that a beacon will be installed on the LM.

TABLE 2-17

PRELIMINARY MOLEM NAVIGATION
COMPONENT CHARACTERISTICS

Item	Retained	New	Mass (kg)	Power (w)	Volume (in.^{3})
			Estimated Values		
1. Inertial measurement unit (IMU)	x		25	210	1000
2. Sextant (SXT)		x	5	-	500
3. LM guidance computer (LGC)	x		32	100	2000
4. Coupling display unit (CDU)	x		11	30	1000
5. Power servo assembly (PSA)	x		16	35	1000
6. Display and control (D&C)	x		14	40	800
7. Odometer		x	4	10	1000
	Old equip. Mass	New equip. Mass	Total System Mass		
Totals	98 kg	8 kg	106 kg	425 w	7300 in.^{3}

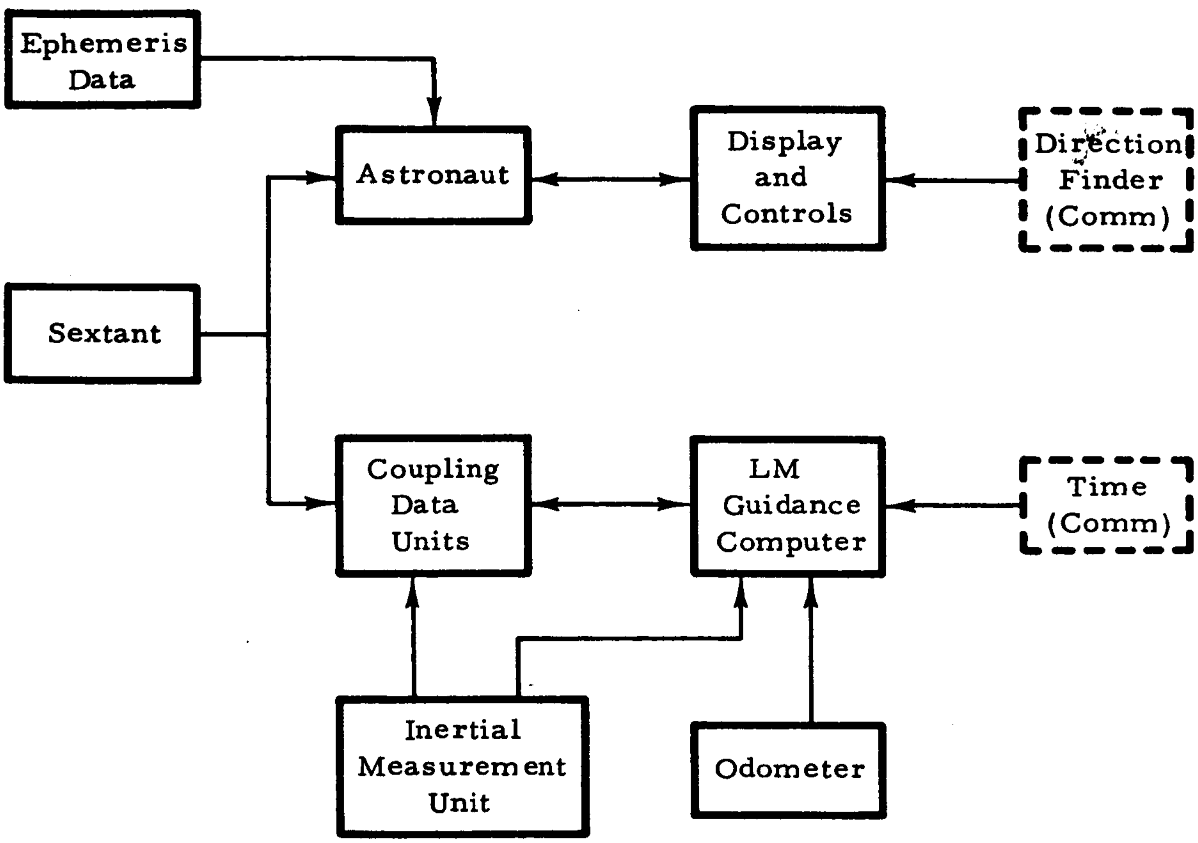


Figure 2-12 MOLEM Navigation Subsystem Block Diagram

The retained units will not likely be usable as is. In particular, the IMU will require modification since in MOLEM it is being used in a different manner from its use in LM. Also, the computer will require some amount of modification to handle the surface navigation problem.

2.3.7 Tiedown and Unloading

The tiedown and unloading system consists of all hardware required to secure the MOLAB to the LM/Truck during the transit to the moon, and to transfer the vehicle to the lunar surface upon arrival.

Unloading can be accomplished automatically or manually by means of flanged wheels attached to the MOLEM main axles and rolling down a 21-ft (from forward hinge point) pair of rails 54-in. apart. The MOLEM can be rotated 360° on a turntable and unloaded in any direction. The 21-ft rails fold into two sections in front of the MOLEM for storage within the payload envelope. The wheels are extended straight up at the time of unloading.

Tiedown is accomplished by means of four pairs of apexed links that transmit the critical landing loads in truss fashion from the vehicle chassis directly to the main structural members of the LM/Truck. Pneumatic release pins sever all tiedown connections.

The total mass of the MOLEM tiedown and unloading equipment is 195 kg.

2.4 MOBILITY AND PERFORMANCE CAPABILITY

2.4.1 Mobility Performance

The MOLEM performance characteristics are itemized in Table 2-18. The calculations of the performance figures are based on the following assumptions:

Gross vehicle mass: 3517 Kg

Soil: ELMS 50/50

Wheel diameter: 2.03 m

Wheel width: 0.30 5 m

Ground pressure: 703 kg/sq m

I_{opt}: 0.1

Hysteresis loss: 0.06

A/L: 0.5

Motor torque: 230 m-kg

Table 2-12, above, contains a summary of the MOLEM vehicle mobility subsystem masses.

TABLE 2-18

MOLEM PERFORMANCE DATA

Parameter	MOLEM Performance
Mass, kg	3517
Obstacle negotiability, cm	80
Crevice negotiability, cm	173
Slope negotiability, degrees	17.5
Draw bar pull, lb	726
Maximum speed (soft soil), km/hr	13.0
Maximum speed (hard), km/hr	16.7
Average speed, km/hr	10.0
Static stability, degrees	50.00
Maximum continuous power, kw	5.97
Specific energy, kwh/km	.44
Static turn radius, m	16.8

2.4.2 Scientific Mission Performance

The MOLEM scientific equipment provisions include:

Location -	Rear platform outside cabin
Equipment mass -	320 kg
Energy -	75 kwh
Range -	400 km
Radius of operation -	80 km

2.4.3 Degraded Mode Analysis Summary

Table 2-19 summarizes the major degraded modes which are capable of enhancing MOLEM mission success and/or crew safety.

In the Mission Success column, "x" delinates those equipment items which have effective backup to allow mission continuation in the event of a single item failure. The "x" identifies those equipment items which have backup of a very limited nature—to allow mission continuation with significant limiations on operating range, radius, or total time on the lunar surface.

In the Emergency Return column, "x" delinates degraded mode capabilities for safe vehicle return from up to 80 km radius. A given function having more than one degree of crew safety backup is indicated by "xx."

The lack of backup tankage in the hydrogen supply is the most outstanding shortcoming shown in Table 2-19. The failure of the hydrogen supply would not only immobilize the vehicle, it would also prevent emergency return and severely limit stay-time extension.

2.4.3.1 Performance Summaries and Degraded Mode Analysis, Communications Equipment

Table 2-20 presents a tabular degraded mode analysis of the communications subsystem shown in Figure 2-13.

TABLE 2-19
MOLEM MAJOR DEGRADED MODE CAPABILITIES FOR MISSION CONTINUATION AND EMERGENCY RETURN DURING THE 14-DAY MANNED MISSION PHASE

Component and Equipment	Backup Modes	
	Mission Success	Emergency Return
Cabin compartment	0	x
Heat rejection (radiators and w/boilers)	(x)	x
Oxygen supplies	(x)	x
Hydrogen supplies	0	0
Traction drive mechanisms	x	xx
Steering drive mechanisms	x	x(x)
Brakes (elect. and elect. /mech.)	x	xx
Suspension (wheel and arm assys)	(x)	x
Fuel cells (primary power)	(x)	x
Power conditioning and distribution	(x)	x
TV cameras (external)	x	xx
VHF (EVA)	x	xx
S-band earth links	x	xx
Navigation	(x)**	xx
Unloading	x*	NA

*Manual vs. automatic, and TV camera redundancy
**Highly dependent on IMU

x - Effective backup mode exists
(x)- Degraded backup mode exists—mission may be continued with serious limitations
xx - Multiple backup for emergency return
0 - No backup

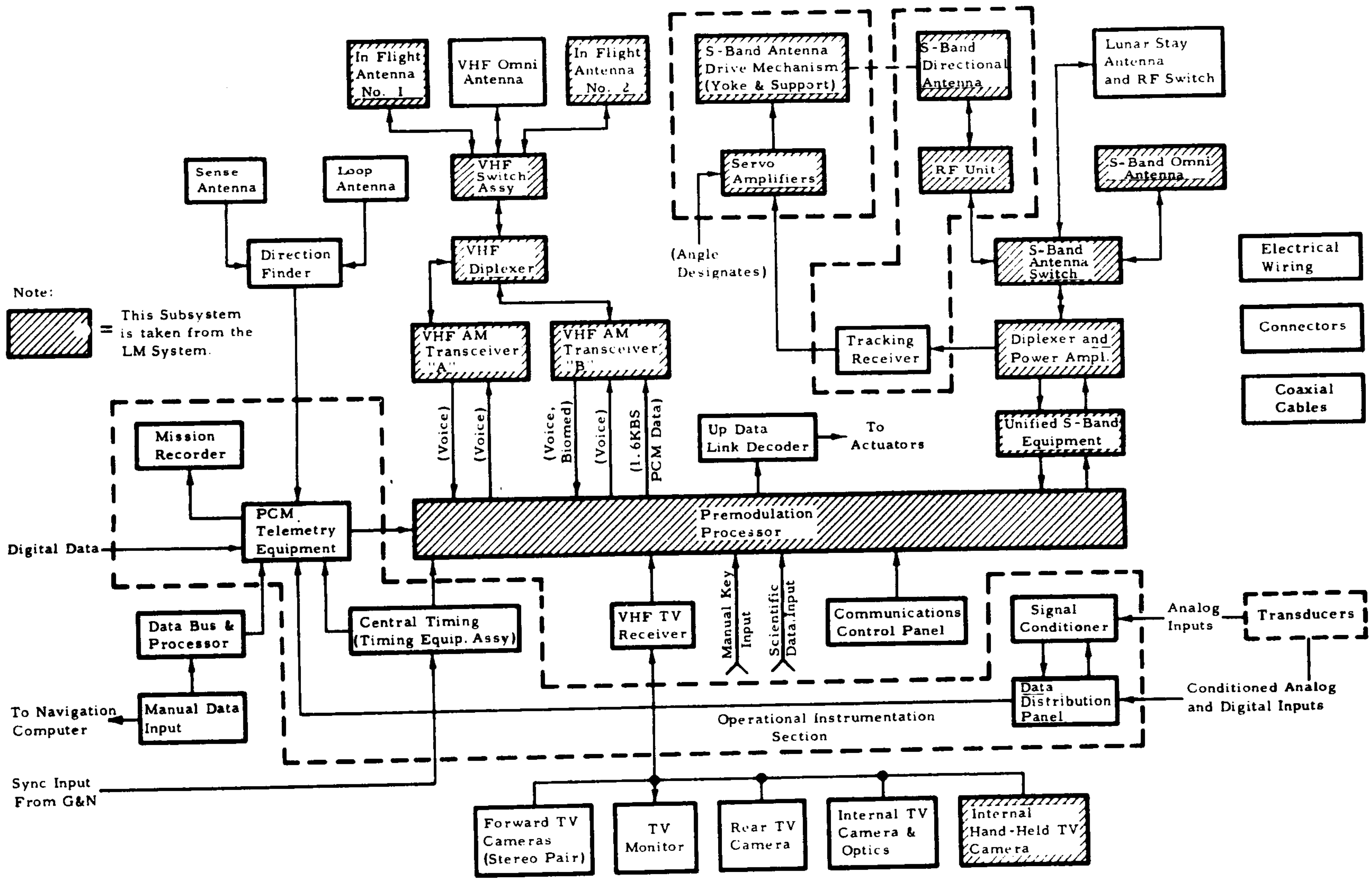


Figure 2-13 MOLEM Communications Subsystem Block Diagram

TABLE 2-20

DEGRADED MODE ANALYSIS. COMMUNICATIONS SUBSYSTEMS

Description of Astrionics, Communications. MOLEM System	Symptom	System Effect or Degradation	Percentage of Failures Per 1000 Hours	
			Grumman Ref. Data	Bendix Ref. Data
1. Antenna Subassemblies:				
1.1 S-band Directional Antenna	X Loss of Directional communications capability with Earth from mobility system.	No automatic antenna direction capability.		
1.2 Antenna Drive Mechanism	X Inability to automatically position S-band antenna.	No automatic antenna direction capability.		
1.3 Servo Amplifier Unit	X Inability to automatically activate antenna drive mechanism.	No automatic antenna direction capability.		
1.4 Tracking Receiver Unit	X Inability to develop tracking signal.	No automatic antenna direction capability.		6.170
1.5 S-band Omni Antenna	X Loss of S-band communications to CM or LM.	Partial reduction in capability.	.0025	
1.6 S-band Inflight Antenna (2 ea.)	X Loss of 1/2 hemisphere of coverage per antenna.	Partial reduction in capability.		
1.7 S-band Antenna Switch	X Loss of ability to automatically switch S-band antennas.	Loss of operational flexibility.		
1.8 VHF Omni Antenna	X		.0025	.001
1.9 VHF Inflight Antenna (2 ea.)	X Loss of 1/2 hemisphere of coverage per VHF antenna.	Reduced communications capability with EVA.		
1.10 Lunar Stay Antenna (S-band)	X Loss of capability to transmit TV data to Earth, real time.	Partial reduction in overall capability.		
1.11 VHF Antenna Switch	X Loss of ability to automatically switch VHF antennas.	Loss of operational flexibility.		
1.12 Sense Antenna, Direction Finding	X Loss of direction finding capability.	Partial reduction in mission duration.		
1.13 Antenna, Direction Finding	X Loss of ability of DF on local beacon signal.			
2. RF and Modulation Equipment (S-band)				(16.649)
2.1 Diplexer and Power Amplifier Unit	X Loss of S-band transmission capability.	Loss of S-band transmitter link.		9.300
2.2 Unified S-band Equipment	X Loss of unified S-band communications capability.	Loss of major S-band link.		7.349
3. RF and Modulation Equipment (VHF)				(7.613)
3.1 Diplexer Assembly	X Loss of capability of receivers to use common antenna.	Reduction in operational flexibility.	.170	.200
3.2 Transceiver AM (No. 1)	X Loss of primary voice capability (CSM to MOLEM).	Loss of VHF transceiver capability (primary).		2.869
3.3 Transceiver (No. 2)	X Loss of primary PCM and voice transceiver capability.	Loss of VHF transceiver capability (secondary).		2.869
4. Additional Modulation Support Equipment				
4.1 Pre-Modulation Processor (PMP)	X Loss of interface processing capability.	Major loss to system communications capability.		
4.2 Audio Center (Part of 4.1 Circuitry)	X Loss of aural reception and transmission capability.	Partial reduction in overall flexibility.		
4.3 Communications Control Panel	X			
5. Data Handling Equipment				
5.1 PCM TM Encoder	X Loss of capability for data encoding.	Reduction in capability to transmit data.		13.297
5.2 Central Timing Equipment	X Loss of spacecraft equipment synchronization capability.			
5.3 Data Bus and Processor	X			
5.4 Manual Data Input Unit	X Loss of capability to manually input data.			
5.5 Signal Conditioner Unit	X Impaired capability to route analog signals within system.			69.440
5.6 Data Distribution Panel	X Impaired capability to route signals through system.	Overall reduction in mission effectiveness.		
5.7 Data Modulators	X Loss of ability to process analog or level signals from scientific experiments.			11.961
5.8 Mission Recorder	X Loss of Data Recording Capability			
5.9 Emergency Key Unit	X Loss of Emergency Key Capability			
5.10 Teleprinter Unit (Future Capability)				
6. Television Equipment				
6.1 Forward TV Camera Assembly	X Loss of Capability to Remotely Drive Vehicle Forward	Major Loss of Remote Control Capability		
6.2 Rear TV Camera Assembly	X Reduced Capability to Remotely Drive Vehicle in Reverse	Partial Loss of Remote Control Capability		
6.3 Internal TV Camera Units (units)	X Partial Loss of Astronaut and Instrumentation Monitoring Capability	Partial Reduction in Overall TV Capability		
6.4 VHF Television Receiver	X Loss of Capability to Process Earth Generated Television Data	Partial Reduction in Overall TV Capability		4.207
6.5 Television Monitor Unit	X Loss of Ability to View Television Information.	Partial Reduction in Overall TV Capability		
7. Remove Control Support Equipment				
7.1 UP Data Link Decoder	X Loss of Ability to Decode Commands to Actuators	Major Reduction in Remote Control Ability		
7.2 Direction Finder Unit	X Loss of Navigation Capability During Auto or Remote Modes of Operation	Partial Reduction of Navigation Capability		

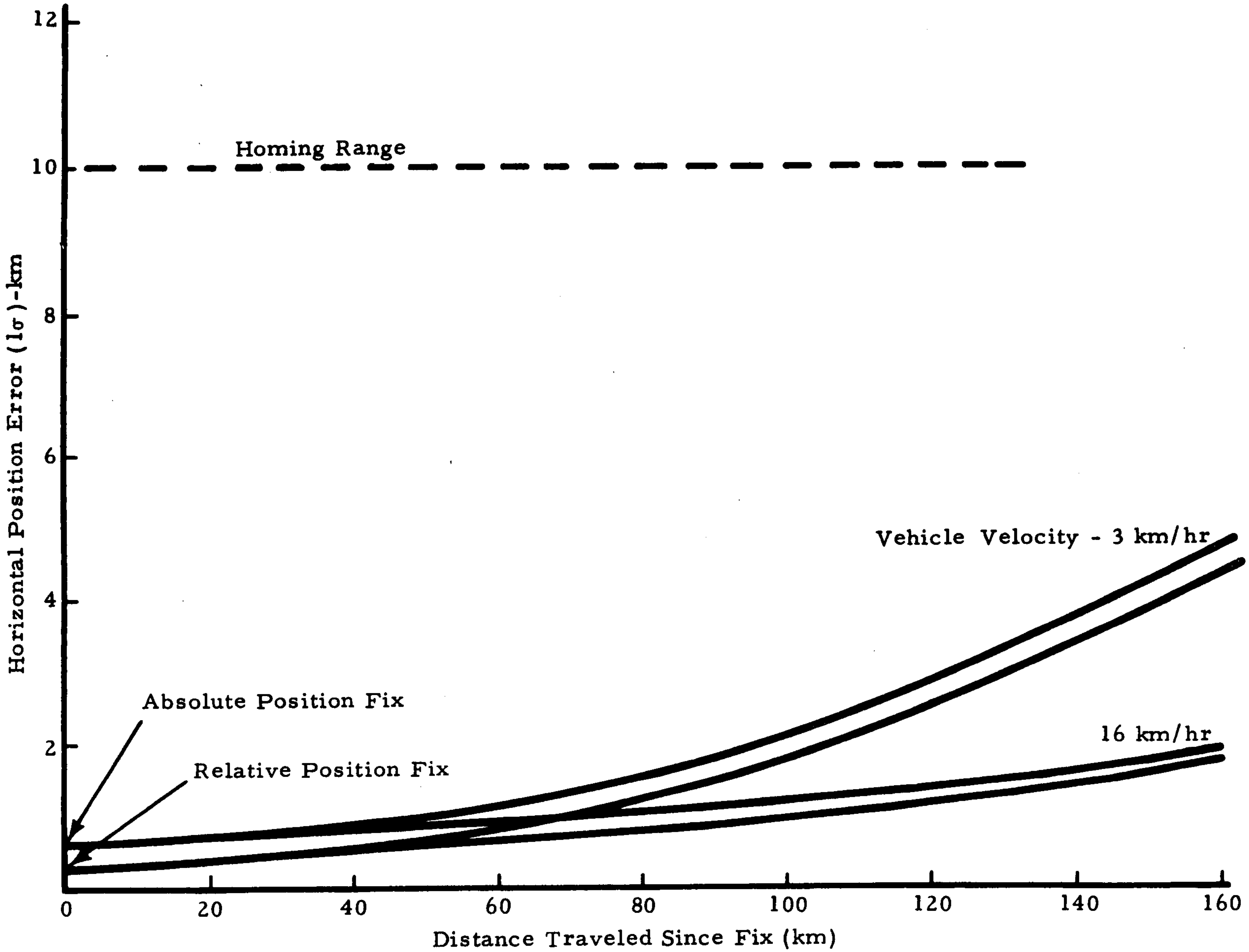


Figure 2-14 Horizontal Position Error

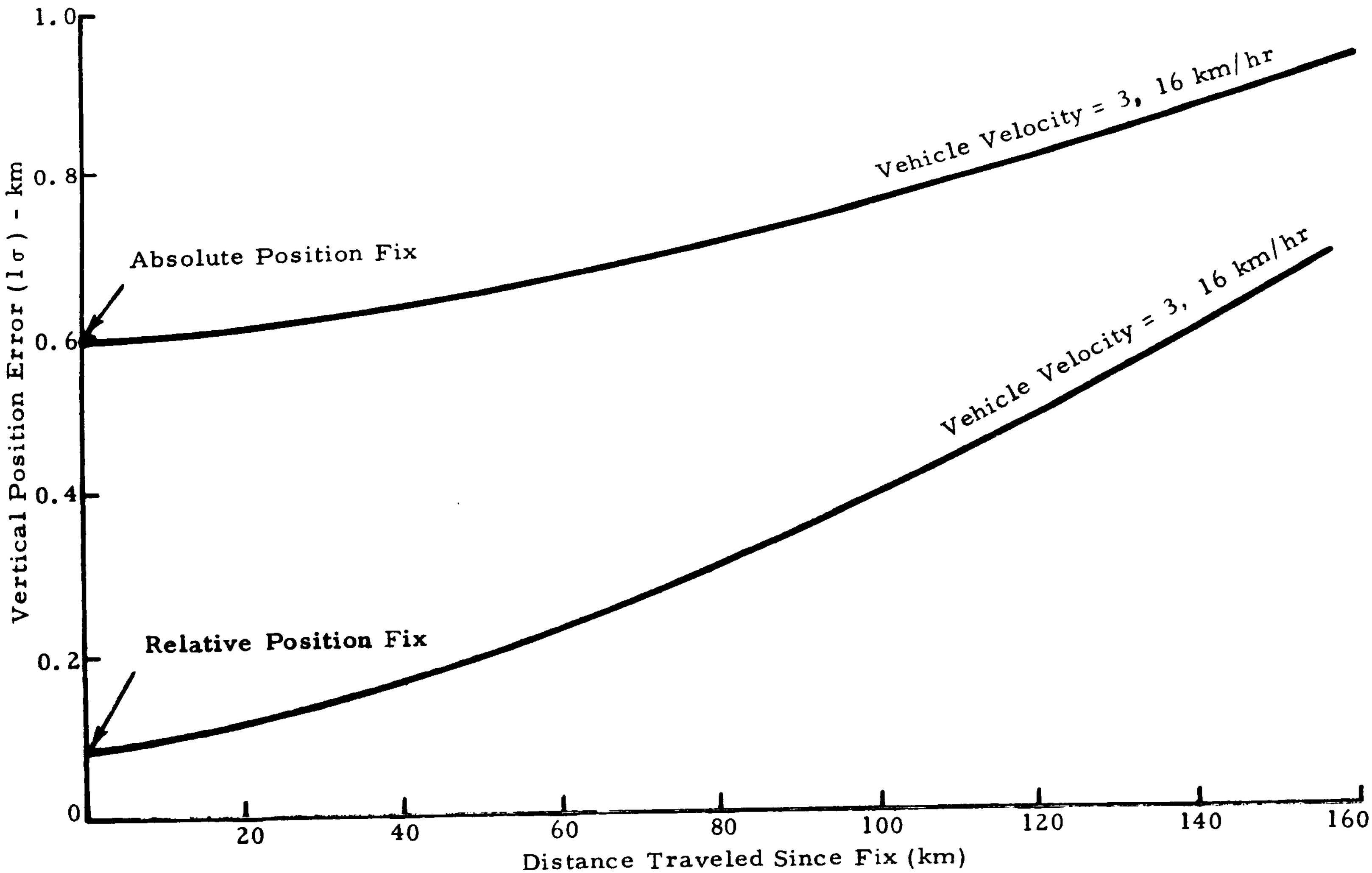


Figure 2-15 Vertical Position Error

2.4.3.2 Navigation

The performance of the vehicle navigation subsystems is described primarily by the accuracy achievable. Accuracy in turn is best discussed in terms of the basic navigation modes:

1. Position and heading fix
2. Dead-reckoning
3. Homing

In the interest of crew safety it would be ideal if each of these three modes could be used independently to navigate throughout the 80-km area. However, the first two modes are limited by equipment accuracies; the third is probably limited by line-of-sight.

The ordinary mode of navigation will therefore include all three of the above modes. Position and heading fixing will initialize the system prior to the first dead-reckoning phase. Thereafter, whenever the system error becomes excessive in the dead-reckoning mode, a position fix will be used to reduce the error. Finally, the return to LM will be aided by a homing beacon mounted on LM.

Using state-of-the-art accuracies, Figure 2-14 shows the approximate horizontal position error to be expected, while Figure 2-15 shows the same for the vertical error. The difference between the absolute and relative position determinations is mainly the error contribution of gravitational anomalies.

If the requirement for a maximum system error of 1.0 km absolute is imposed, then Figure 2-14 shows that a position fix would be required every 60 km.

The second factor in overall performance is reliability. Based primarily on MOLAB data, Table 2-21 presents estimated failure rates for the subsystem components. Since these figures are valid primarily in judging relative reliability, no probability figures have been computed. The table merely shows that the MOCAN subsystem will tend to be more reliable than the MOLEM/MOCOM subsystem on a total-failure rate basis.

TABLE 2-21

MOLEM NAVIGATION SUBSYSTEM ESTIMATED FAILURE RATES

Item	Estimated Failure Rate (%/1000 hours)
1. Inertial measurement unit	110.0
2. Sextant	2.5
3. LM/Apollo guidance computer	40.0
4. Coupling data units	10.0
5. Power servo assembly	20.0
6. Display and control	10.0
7. Odometer	1.0
Total	193.5

Failure Mode Effects

The effect on the mission by failure of each of the three navigation function or modes:

1. Position fix
2. Dead-reckoning
3. Homing

is summarized in Table 2-22.

TABLE 2-22

MOLEM NAVIGATION SUBSYSTEM FUNCTION FAILURE EFFECTS

Function	Effect of Function Failure	Seriousness of Failure
Position fix	Requires that vehicle return to radius 10 < R < 80. Radius is function of acceptable risk.	High
Dead-reckoning	Vehicle may still operate out to 80 km, but mission progress will be slowed by time required for position fixing.	Intermediate
Homing	Vehicle may still operate out to 80 km, but return-to-LM may require search pattern at terminus, if LM is not within sight.	Low

Loss of position fix capability has been judged most serious as this curtails the mission operational radius. The degree of curtailment depends upon how much risk will be allowed in proceeding beyond the 10 km homing range with the vehicle relying strictly on dead-reckoning.

Failure of the computer is not serious since its function can be performed by hand or from earth.

Position Fix

The position fix capability depends on the sextant and IMU. Loss of either component will destroy fix capability and from Table 2-22, restrict the range of operation.

Dead-Reckoning

Dead-reckoning depends upon the odometer and IMU. Each of four wheels will carry an independent odometer so that complete loss of the odometric capability is quite unlikely. Loss of the IMU will destroy the

the prime dead-reckoning capability. However, in this case a degraded capability could be achieved by using the S-band antenna for azimuth and assuming a flat moon (constant vertical).

Homing

Loss of any portion of the direction finding equipment would eliminate the homing capability.

In summary it is emphasized that the MOLEM system is dependent upon the IMU for both position fixing and dead-reckoning. In addition, the IMU is the most unreliable component within the system, as shown by Table 2-21.

2.5 SENSITIVITY

This section presents vehicle mass sensitivity to the following mission parameters:

1. Mission duration
2. Total range
3. Scientific equipment payload
4. Crew size
5. Astrionics capability
6. Locomotion capability.

2.5.1 Mission Duration

The curve shown in Figure 2-16 gives the vehicle mass sensitivity to changes in mission duration. The data are based on a 50% emergency stay contingency (i.e., 14 days + 7, 16 days + 8, etc.) and a total range of 400 km. The curve indicates that if the MOLEM mass is increased to 3859 kg, the mission duration can be increased from 14 days + 7 days contingency to 22 days + 11 days contingency.

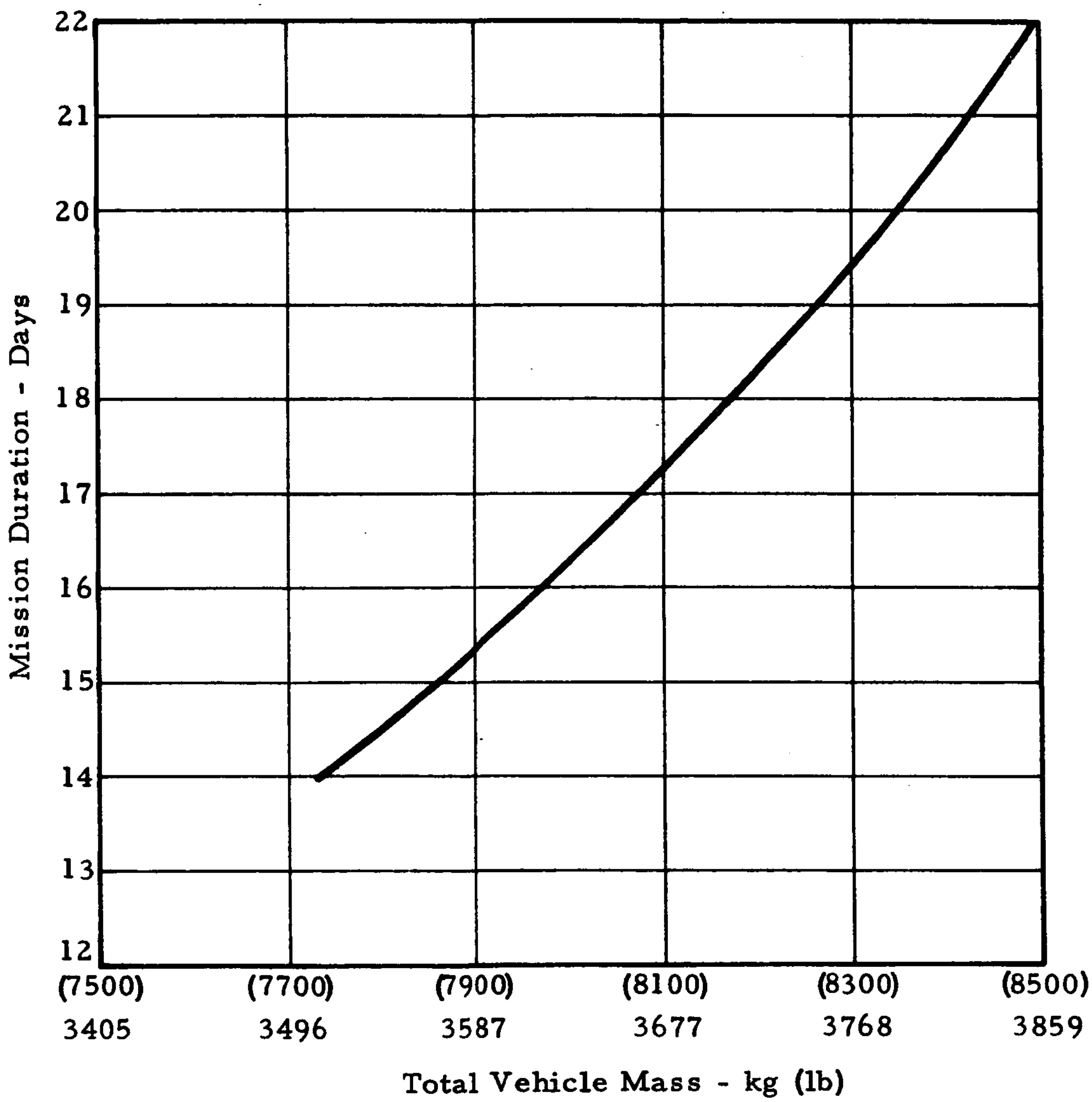


Figure 2-16 MOLEM Vehicle Mass Sensitivity to Changes in Mission Duration

2.5.2 Total Range

The curve shown in Figure 2-17 gives the vehicle weight sensitivity to changes in mission range. The data are based on a 14-day mission with a 7-day emergency stay period. The curve indicates that the total range for the MOLEM can be extended to approximately 1100 km if the total system mass is increased to 3859 kg.

2.5.3 Scientific Payload

The curve shown in Figure 2-18 gives the vehicle weight sensitivity to changes in scientific payload weight. The data are based on a 14-day mission plus 7 days contingency and a total range of 400 km. Under these restrictions the curve indicates that if the MOLEM vehicle is allowed to grow to 3859 kg, the scientific equipment payload can be increased to approximately 581 kg.

2.5.4 Crew Size

The MOLEM configuration was reviewed in terms of the crew size that the vehicle could support in terms of habitability and human factors consideration. Table 2-23 summarizes an analysis of each concept for crew sizes of from two to four men.

TABLE 2-23

MOLEM CREW SIZE

Item	Characteristic		
Crew size	2	3	4
Free volume per man, cu ft	75	50	37.5
Sleeping accommodations	Yes	No	No
Storage room	Marg.	No	No
Redundant compartment	No	No	No
Suit drying space	Marg.	No	No
Maximum crew size	X		

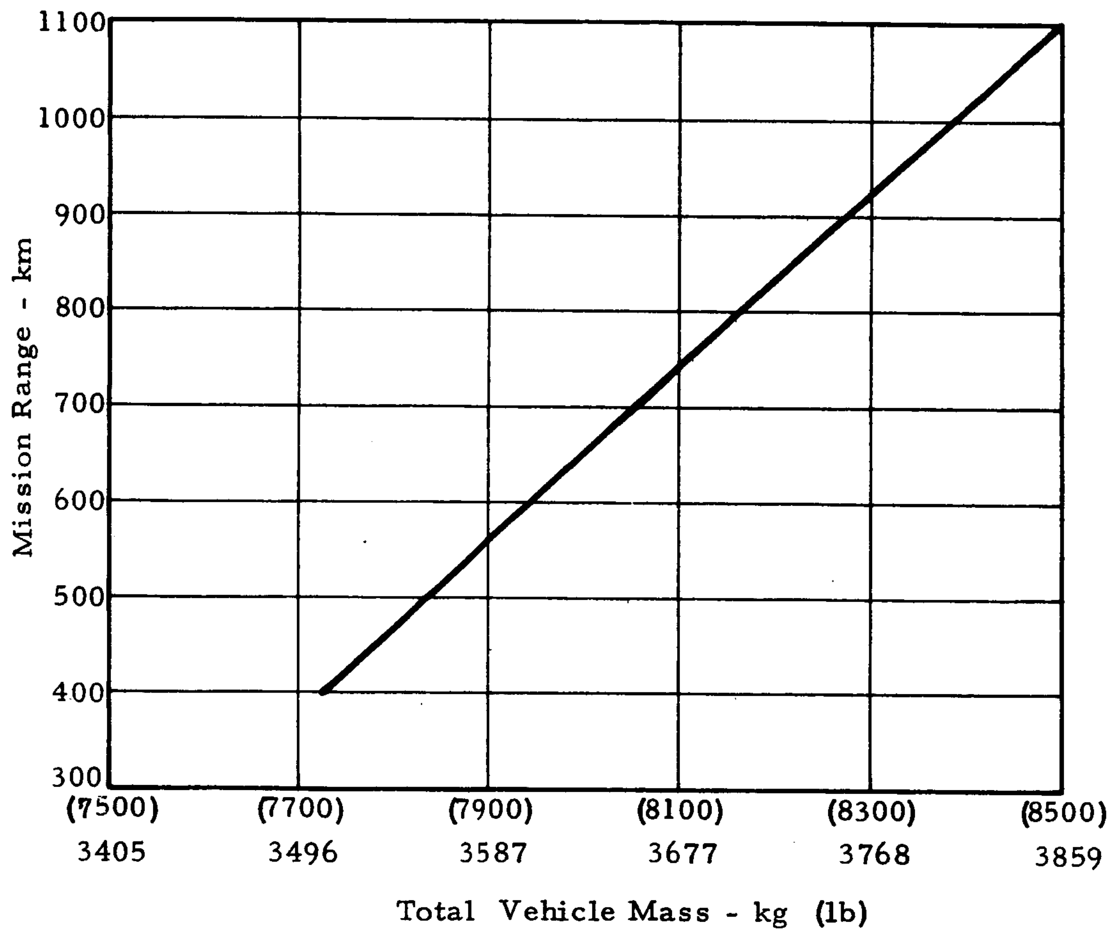


Figure 2-17 MOLEM Vehicle Mass Sensitivity to Changes in Mission Range

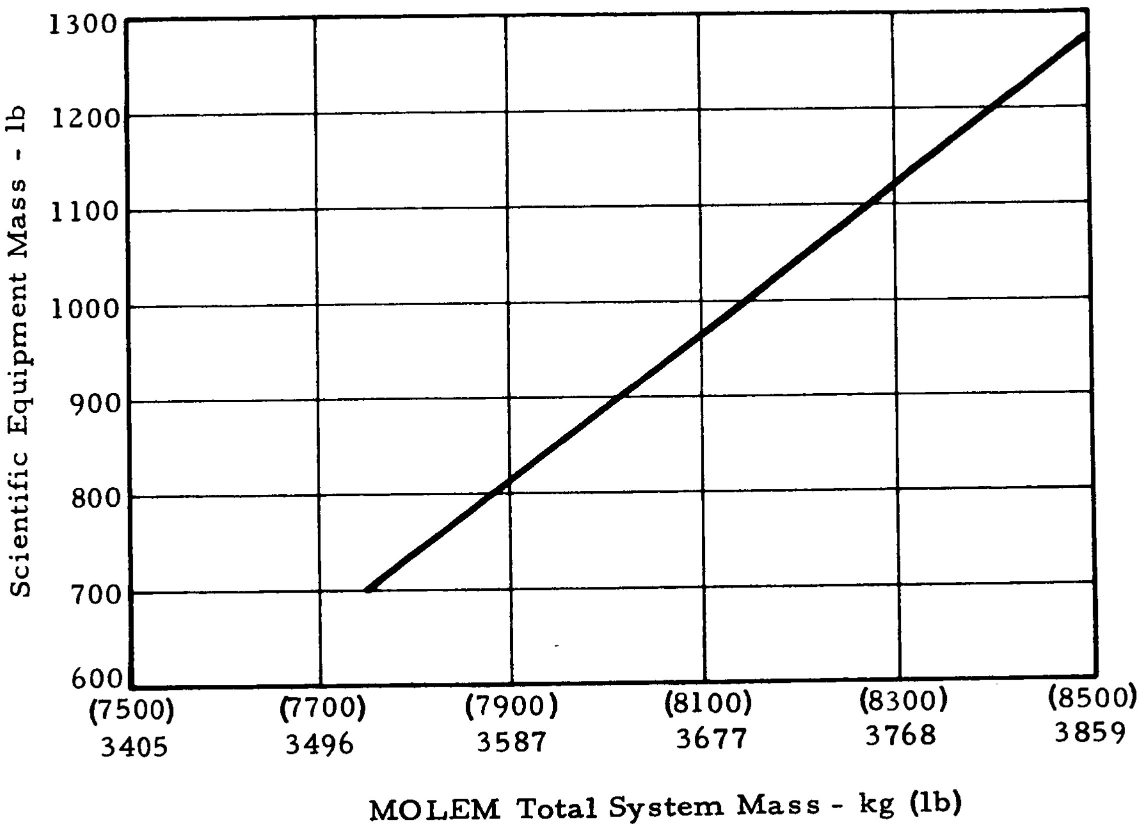


Figure 2-18 MOLEM Vehicle Mass Sensitivity to Changes in Scientific Equipment Payload Mass

The NASA-specified minimum free volume per man in connection with the MOLAB study was 87.5 cu ft. The MOLEM falls slightly short of this requirement for a two-man crew. Consequently, the MOLEM cannot be expected to accommodate 3- and 4-man crews. Lack of available volume prevents adequate provisions for sleeping, storage, and suit drying space for the larger crews.

2.5.5 Astrionics Capability

This section evaluates the effects of mission variations on the subsystem designs established in Section 2.3. Six mission parameters were selected for this purpose:

1. Mission duration
2. Mission radius of operation
3. Crew size
4. Total distance traveled
5. Surface model
6. Initial separation (vehicle from LM)

2.5.5.1 Navigation

The navigation subsystem for MOLEM is insensitive to mission variations. Once the ability to operate beyond line of sight is established, the major effect of increasing stay time or extending the radius of operations is an added mission risk because of lower expected reliability over the mission.

Mission Duration

The number of days spent in vehicular travel affects the navigation subsystem primarily in expected reliability. The subsystems would function satisfactorily as long as required if the reliability were adequate. Specifically, the greatest problem would be with the IMU. Since this component is used for both position fixing and dead-reckoning in the MOLEM/MOCOM subsystems, these vehicles would involve greater hazard to the astronauts for long missions. The homing equipment is used only during closure and is, therefore, independent of mission duration.

Mission Area

The MOLEM radius of operations is 80 km. Extension out to 150 km would involve higher astronaut risk. It would no longer be possible to return to the LM by dead-reckoning if the position fix equipment failed. However, position fix could be used if the dead-reckoning equipment failed. Therefore, increased mission area merely reduces backup capability with attendant lower astronaut safety.

Crew Size

Crew size has no effect on navigation. Increasing the crew to three or four would have no appreciable effect on navigation since the navigation requirements do not change.

Total Distance Traveled

Total distance traveled would have little effect on the navigation subsystem other than reduction in reliability. This effect would be especially important for the odometer.

Surface Model

The accuracy of the navigation subsystem is somewhat dependent upon the surface model. A model somewhat less severe than ELMS might mean smaller gravitational anomalies with a slightly higher positional accuracy; greater accuracy might also result with a less restrictive model because of less slip during travel. A very flat surface would increase line of sight with an attendant increase in homing distance.

Initial Vehicle-to-LM Separation

The assumption is made that the initial separation between the vehicle and LM on the surface is 10 km or less. That is, the vehicle is within homing range of the LM. If the separation exceeds 10 km or the actual homing range, the vehicle position must be determined from earth tracking (two days per fix). Heading would be determined from the S-band antenna. The time required for rendezvous would be increased by this additional position fix time and the additional travel to rendezvous.

2.5.5.2 Communications

Generally the communications system does not vary in weight and volume as mission parameters change. Additional earphones, microphones, and jacks will be incorporated into the audio control center, should the crew size increase to four. With this exception the communications subsystem is relatively insensitive to mission variations. Table 2-24 summarizes the communications subsystem sensitivity to changes in mission requirements.

2.5.6 Locomotion Capability

Figure 2-19 depicts the mobility system weight sensitivity with respect to vehicle weight. This is the only mission variation that will affect the mobility system weight. The assumptions were:

Soil	ELMS 50/50
Wheel diameter	80 in.
Wheel width	12 in.
Ground pressure	1.0 psi
I_{opt}	0.1
Hysteresis loss	0.06
A/L	0.5

2.5.7 Power Capability

Fuel cell data based on using improved P&W Apollo fuel cells are shown in Figure 2-20. These cells are more efficient and lighter (lb/kw) than the Apollo cells. The data used for generating the attached graphs were furnished by P&W for the ALSS study.

Figure 2-20 shows the fuel cell assembly weight vs. maximum continuous power for two specific reactant consumption (SRC) rates: cells A and B at 0.937 and 0.756 lb/kwh, respectively, for the maximum continuous power. The fuel cell assembly weight includes the fuel cells and their controls excluding the fuel cell radiator and the accessory package.

TABLE 2-24

MOLEM COMMUNICATIONS SENSITIVITY DATA TO MISSION VARIATIONS

Mission Parameter			Effect (Sensitivity)
Radius of operation			
Case 1	40 km		No effect; system operation is well within maximum marings of operations.
Case 2	80 km		This is the nominal mode of operation, no effect.
Case 3	160 km		Communications links dependent on earth and periodic C-M relay.
Crew size			
Case 1	None		Requirements for remote control, television, navigation, and direction aids.
Case 2	2 men		This is the nominal condition, no change required.
Case 3	4 men		Additional equipment is required at audio center to support personnel voice and biomed.
Mission duration			
Case 1	7 days		Communication requirement unchanged.
Case 2	14 days		Communication requirement unchanged.
Case 3	21 days		Depending on types of services, power requirements will increase by 20-23%.
Case 4	28 days		Depending on types of services, power requirements will increase by 40-50%.
Total distance travelled			
	Radius (km)	Distance (km)	
Case 1	40	200	This case less than nominal, no change.
Case 2	80	400	Nominal condition for system.
Case 3	120	600	Communications links dependent on earth and CM relay.
Case 4	160	800	Communications links dependent on earth and CM relay.
Initial vehicle—LM Separation			
0.5 km			This separation is possible within astronaut walking distance.
5.0 km			Remote control of vehicle from MSFN required.
50.0 km			Remote control of vehicle from MSFN required.

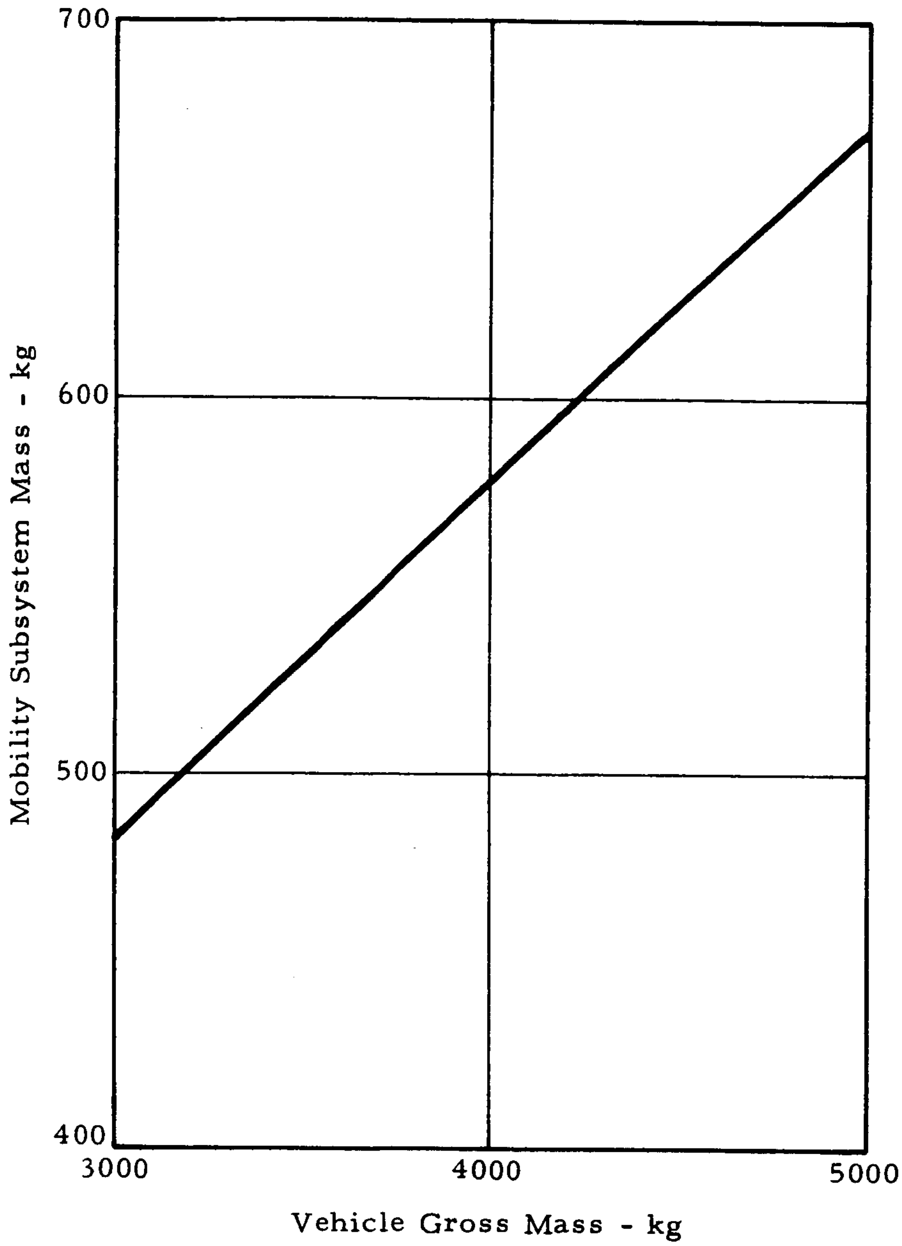


Figure 2-19 Mobility System Mass Sensitivity with Respect to Vehicle Mass

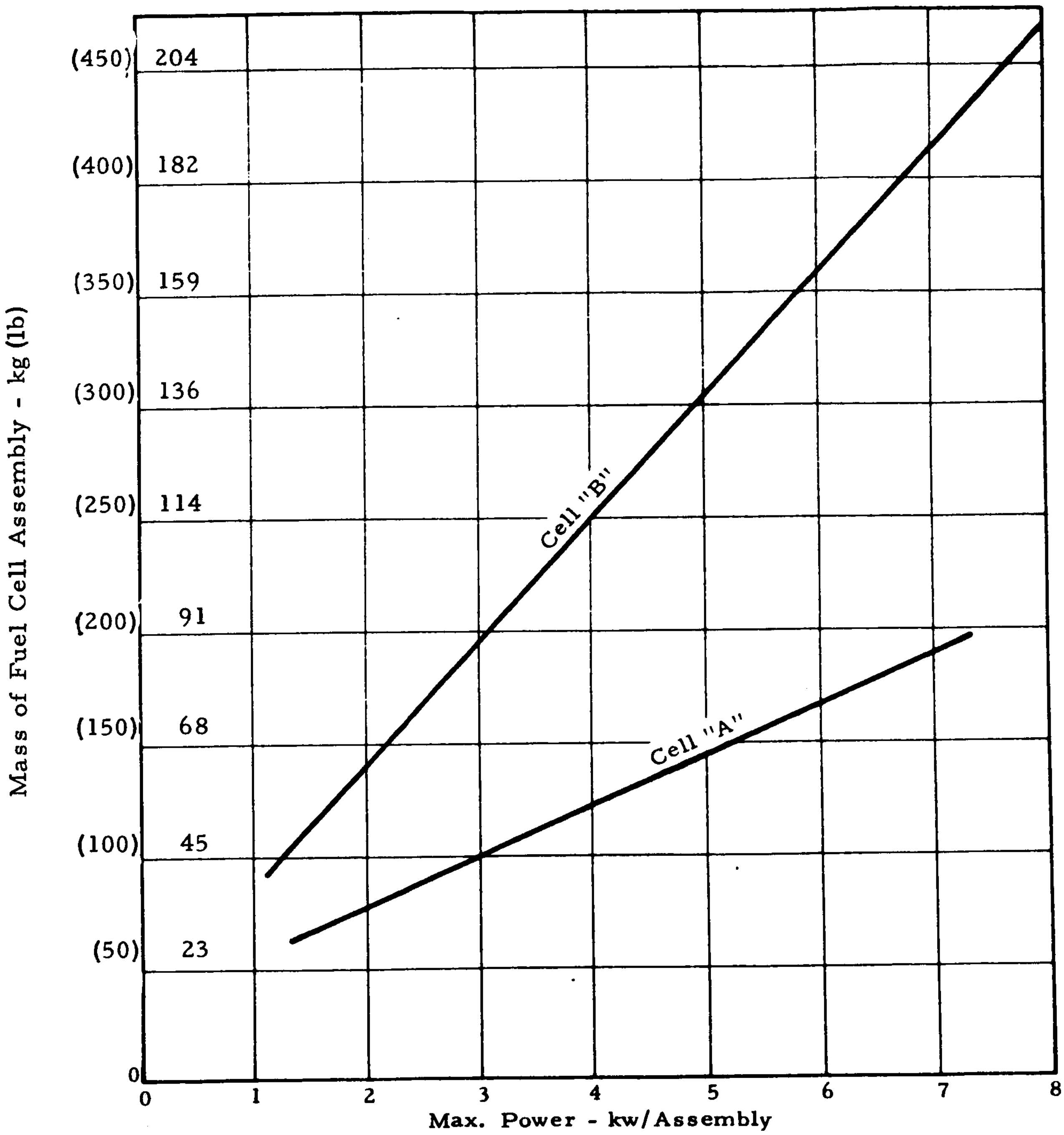


Figure 2-20 Weight of Fuel Cell Assembly vs. Fuel Cell Power

Figure 2-21 shows the reactants consumption vs energy curves. As can be seen from these figures, the reactant consumptions (efficiency) are dependent on fuel cell designs and their operating power (or % of the maximum continuous power). The fuel cell efficiency increases with decreasing load until an optimum level is reached for the respective cells. The optimum power for cells A and B (Figure 2-21) are 30 and 35% of their maximum continuous power, respectively. Operating at lower than the optimum power level will decrease the efficiency because of higher parasitic losses (pumping and heat power).

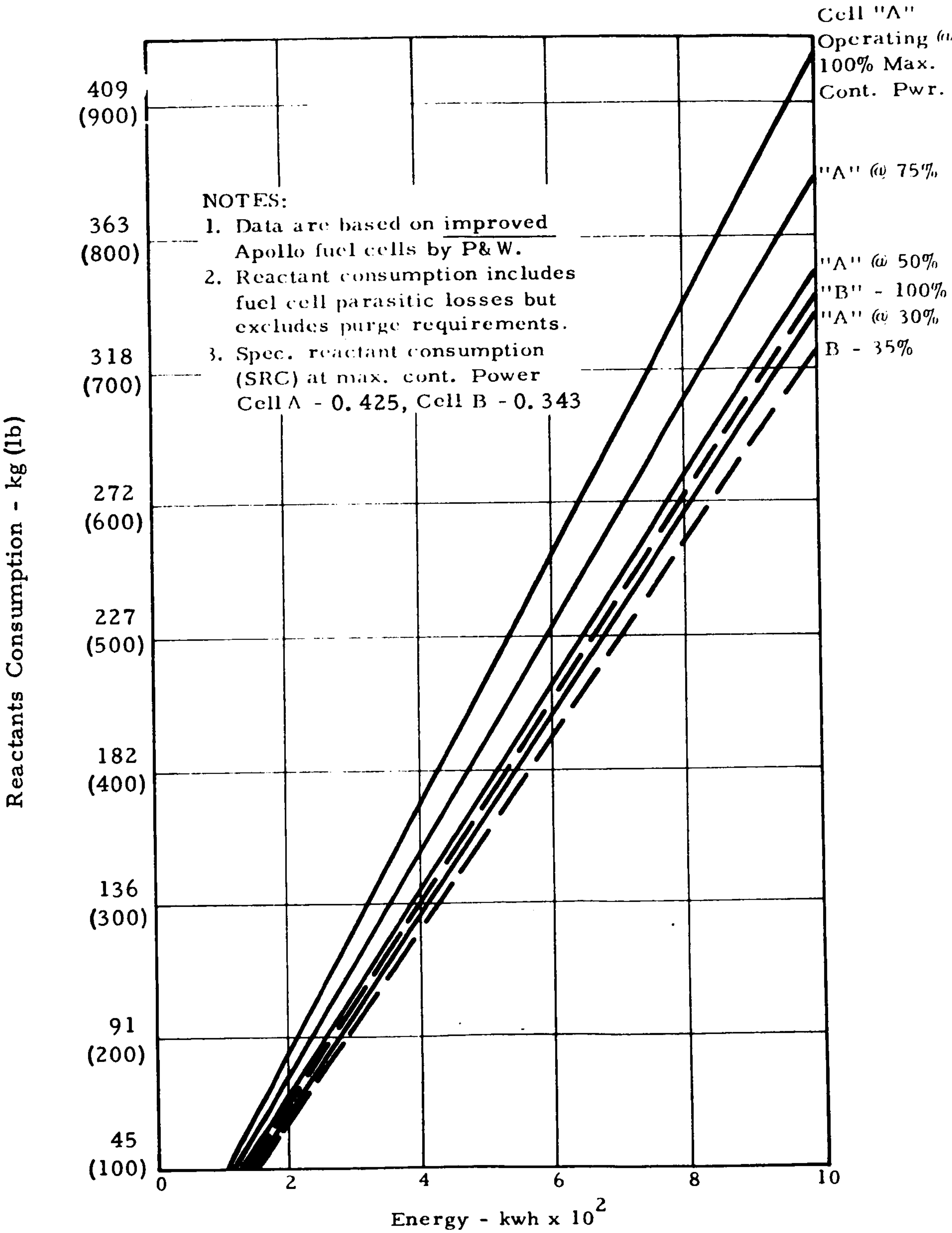


Figure 2-21 Fuel Cell Reactants Consumption vs. Energy

SECTION 3

MOCOM

3.1 MOCOM STRIPPED SPACECRAFT DEFINITION

This section defines the stripped version of the Command Module (CM) spacecraft. Each subsystem is reviewed and evaluated, and those which do not function in a lunar surface vehicle system are removed. At this point, no attempt is made to determine whether or not the equipment is adequate to meet fully the performance requirements prescribed for the MOCOM. The basis for retaining or deleting subsystems or portions of subsystems is based on whether or not the associated function is required in a mobility system.

The performance of the remaining stripped CM spacecraft components is examined in Section 3.3 to determine if the equipment is adequate to meet MOCAN mission requirements and what, if any, modifications are necessary.

3.1.1 Structure

An evaluation was conducted of the existing Apollo CM structure to determine the major structural elements to be retained, and those elements to be removed, consistent with the MOCOM vehicle derivative. The evaluation showed that the basic CM pressure shell designed for a 5-psia operating pressure could be adapted with modifications consisting of the removal of the outer heat shield, insulation, and meteoroid protection, side hatch, crew couches, and flight control and display equipment panels. The resulting stripped spacecraft structure is defined in Table 3-1.

3.1.2 Crew Provisions

Considerable change to the CM is necessary to accommodate crew provisions in MOCOM. The overriding constraints have been the necessity to reorient the vehicle with respect to the crew for driving and the requirement to locate the principal ingress/egress hatch to the rear of the vehicle.

TABLE 3-1

STRIPPED SPACECRAFT STRUCTURE SUMMARY

Item	Retained	Removed	Comments
Pressure Shell	x		
Heat Shields (3) and Insulation		x	
Meteoroid Protection		x	
Flight Control Equipment and Display Panels		x	
Mounting Attachments (4) to Service Module	x		Used as chassis attachments
Docking Adapter Receptacle	x		
Crew Couches		x	
Side Hatch		x	
Rendezvous Windows (2)	x		
Side Observation Windows (2)	x		

Therefore, windows have to be cut into the opposite side of the basic CM structure to provide visibility for the MOCOM crew. In addition, all of the CM interior equipment has been reoriented. The resulting MOCOM provides for two astronauts seated side-by-side during driving operations. Two principal driving windows are provided, one forward of each crew station. Two additional windows are also provided for observation to each side. As in MOLEM, a TV monitor is added and located so that the driver can monitor it while driving for increased visual coverage. For scientific operations the right-hand station is considered the scientific station, and controls and displays are grouped on the right side of this station. This permits the inside astronaut to monitor the EVA through the right window, monitor the biomedical instrumentation to the right of the window, and have access to the vehicle secondary driving control if it is necessary to move the vehicle.

Normal ingress and egress is provided via an airlock and hatch (which is actually the CM side hatch enlarged). The airlock is a structural addition to the CM and is large enough to permit one astronaut to sleep in it, or two to don and doff their suits, if necessary. (The latter may not be possible with hardsuits.) As in MOLEM, emergency ingress/egress is provided by the upper hatch. (This is the same as the CM docking hatch.)

In MOCOM, a remote manipulator has been added to reduce the EVA requirements for working on lunar samples.

Two stowable bunks have also been added to the basic CM for MOCOM, one in the airlock and the other in the main compartment. This permits greater flexibility in scheduling sleep cycles than in MOLEM and prevents loss of both crew memebers if a sudden decompression occurs during a sleep period.

For solar flare protection, an erectable shelter is provided just forward of the airlock bulkhead. No special eating area will be added to the CM structure. However, a variety of locations can serve this function on a time-shared basis, as in MOLEM. Waste management canister and relief tube mounting brackets will also be located on the forward part of the airlock bulkhead.

As with MOLEM, additional space is provided for storage of extra pressure suits and PLSSs required for extravehicular activity. The increased number of ingress/egress cycles, added times spent in EVA, and more difficult EVA task necessitate this additional equipment.

The current CM personal hygiene equipment should prove adequate for MOCOM use.

3.1.3 Environmental Control

The environmental control system for the Apollo CM is designed for use by three men for fourteen days. Its use for two men requires that the system be off-loaded and reduced to the two-man level, yet expendables must

TABLE 3-2

STRIPPED SPACECRAFT SUMMARY—CREW SYSTEMS

Item	Retained	Removed	Added	Modified	Comments
Basic System	x				
Radiator			x		
RTG			x		Integrate for heating
Airlock System			x		
Suits, PLSSs			x		Extras
Earth Survival Kit		x			
Earth Landing Restraint System		x			
Lunar G Restraint System			x		
Stored Water			x		18 lb
LiOH, Oxygen			x		For metabolic rate differential

reflect the generally higher metabolic rates associated with lunar exploration. The CM thermal control system utilizes a space radiator, but it is integral with the spacecraft skin and cannot be used for lunar operations. A larger horizontal radiator must be provided. The ECS should be repackaged to achieve maximum utilization of space in light of space requirements for the lunar mission. The addition of an airlock and pump will result in sizable weight savings for ingress/egress. Table 3-2 summarizes the stripped spacecraft definition.

3.1.4 Controls and Displays

As a result of the reorientation of the CM structure for MOCOM, none of the original command module panels have been retained. This has permitted considerable latitude in control/display layout; therefore, MOCOM follows the MOLAB arrangement guidelines more closely than does MOLEM. The MOCOM arrangement provides a central placement of all controls and displays required to drive and navigate, as well as to monitor and control other subsystems. This concentration of control/display elements in the forward cockpit area facilitates an effective distribution of the work load between the two crew members with a minimum of movement from the forward work station. At the same time, space is available to provide ample windows for external viewing and monitoring of external operations. The positioning of most operational control/display elements in the forward cockpit area also facilitates one-man operation in the event of incapacitation of one crew member. The scientific station controls and displays have been added to the right of the navigator's station between the two right windows where the inside astronaut can monitor exterior activity, have access to the secondary driving controls, if necessary, and also perform scientific functions. This location is also adjacent to the remote manipulators which permit the inside astronaut to work on lunar samples placed by the interior astronaut in the remote handling box located just outside and below the navigator's side window.

The primary display provided on the driver's side is the mobility system panel. The TV, communications, and warning panels are given prime space which is accessible to both crew members, the TV being considered a visual aid to the driver, although these panels will normally be operated by the navigator. The navigator's prime space is devoted to the nagivation panel while the scientific panel is located to his right since the navigator's station is considered the scientific station during scientific operations. Panels which demand little attention are placed to the driver's left and overhead. These are the life support, primary power, circuit breaker, and heat exchanger panels.

The principal driving control is a joystick at the driver's station. This permits steering by means of a right or left motion, acceleration by a forward motion, and braking by a rearward motion. A secondary driving capability will also be provided at the navigator's station.

3.1.5 Electrical Power Subsystem

The Command and Service Module power system uses thre H_2-O_2 fuel cell assemblies, each capable of delivering 2.1 kw of power. This primary source of power is applicable to a surface vehicle.

3.1.6 Communications

Table 3-3 contains a summary of the Applicable and Nonapplicable CM communications equipment. The earth tracking, recovery, and rendezvous equipment has been removed and all other equipment has been retained.

3.1.7 Navigation and Guidance

The navigation/guidance equipment aboard the CM is very similar to that aboard the LM. The major differences between the two are:

1. The CM system contains no Landing Radar.

2. The CM uses a sextant rather than AOT for IMU alignment.

3. The CM includes a scanning telescope for landmark viewing.

Table 3-4 lists the components within the CM navigation and guidance system along with recommendations for stripping.

3.1.8 Stripped Spacecraft Summary

Table 3-5 contains mass summaries of initial removed and retained spacecraft subsystem.

3.2 MOCOM CONFIGURATION

The MOCOM utilizes a modified Apollo CM cabin adapted to mount on a four-wheel, rigid chassis mobility system. The remainder of the vehicle is very similar to the Bendix MOLAB design. The system is delivered unmanned on the LM-Truck with wheels folded. Six months of dormant storage on the lunar surface is provided along with remote checkout, unloading, and driving features.

TABLE 3-3

STRIPPED SPACECRAFT CONFIGURATION—CM SYSTEM

		Original Equipment Applicable	Original Equipment Nonapplicable	Comments
1.	Antennas			
1.1	C-Band (4 ea)		x	Earth tracking requirements to 5000 mi.
1.2	VHF/2 kMc Omni Antenna	x		
1.3	VHF Recovery Antennas No. 1 and 2		x	To assist recovery operations
1.4	2 kMc High Gain	x		
1.5	HF Antennas (2 ea)		x	To assist recovery operations
1.6	Rendezvous Radar Antenna		x	To assist rendezvous operations
2.	RF and Modulation Equipment			
2.1	VHF Equipment			
2.1.1	VHF Antenna Switch		x	To be modified to two antenna switch then retained.
2.1.2	VHF Multiplexer	x		
2.1.3	VHF/AM Transceiver	x		
2.1.4	VHF/FM Transmitter	x		
2.1.5	Up Data Link Subassembly	x		
2.1.6	VHF Recovery Beacon		x	Earth recovery support system. Not needed on mobility system
2.2	S-Band Equipment	(All)		
2.2.1	Antenna Switch Assembly	x		
2.2.2	S-Band Power Amplifier	x		
2.2.3	Unified S-Band Transponder	x		
2.2.4	High Gain Antenna Switch	x		
2.2.5	S-Band Antenna Control Unit	x		
2.3	Audio Center	x		
2.4	Communications Control Panel	x		
2.5	Premodulation Processor	x		
2.6	HF Equipment		x	
2.6.1	HF Transceiver		x	Used to assist recovery operations
2.6.2	HF Antenna Switch		x	
2.7	C-Band Transponder		x	Required for earth tracking to 5000 mi.
2.8	Rendezvous Radar		x	Rendezvous is not a mobility requirement
3.	LEM Audio Center	x		
4.	TV System	x		
5.	Signal Conditioning	x		
6.	Data Distribution Panel	x		
7.	Central Timing	x		
8.	PCM Telemetry	x		
9.	Electrical Provisions	x		
9.1	Electrical Wiring	x		
9.2	Coax	x		
9.3	Connectors	x		

TABLE 3-4

CM NAVIGATION/GUIDANCE SYSTEM APPLICATIONS TO SURFACE NAVIGATION

	Applicable	Non-applicable	Comments
1. Inertial Measurement Unit	x		Possible sensor of vehicle motion.
2. Sextant	x		Used to align IMU.
3. Rendezvous Radar (RR)		x	No requirement.
4. Scanning Telescope	x		Possible use in land-mark viewing.
5. Apollo Guidance Computer (AGC)	x		Will require new program along with possible increased capability.
6. Coupling Display Units (CDU)	x		Required for data transfer.
7. Power Servo Assy. (PSA)	x		Required for IMU, AGC, Sextant.
8. Display and Control (D&C)	x		Map and Data Viewer.

TABLE 3-5

MOCOM INITIAL STRIPPED SPACECRAFT
MASS SUMMARY

	Initial (kg)	Removed (Nonapplicable) (kg)	Stripped (Applicable) (kg)
1.0 Structure	2043	1235	808
2.0 Crew Provisions	436	195	241
3.0 ECS	161	0	161
4.0 Life Support Expendables	51	0	51
5.0 Controls and Displays	150	91	59
6.0 Navigation and Guidance	170	170	0
7.0 Communication	128	41	88
8.0 Instrumentation	114	0	114
9.0 Scientific Equipment	0	0	0
10.0 Electric Power System	275	0	275
11.0 Electrical Power Expendables	(SM)	0	0
12.0 Reaction Control System	272	272	0
13.0 Stabilization and Control	95	95	0
14.0 Earth Landing Subsystem	318	318	0
Total	4214	2418	1633

Figure 3-1 shows the MOCOM configuration. The cabin is mounted on the chassis with the major axis of the CM cone in a vertical position. This is done to accommodate the design of the docking adapter, and since the major load paths (structural strength) are in this direction, the astronaut position in the cabin and internal furnishings and operational equipment are revised to compensate for the attitude change between the MOCOM and the CM.

Two liquid hydrogen tanks are mounted under the radiators. The two spherical liquid oxygen tanks are mounted in the right and left rear corners of the vehicle.

Figure 3-2 shows the installation of the MOCOM under the Spacecraft to LM Adapter (SLA) shroud and on top of the LM-Truck. As shown, the vehicle wheels are folded for transportation. The tiedown and unloading rails are mounted on the top of the LM-Truck and fold out for support of the MOCOM as it is lowered to the lunar surface. LM station 200 is on top of the LM-Truck and LM station 316.9 is just under the Service Module. The VHF antenna and S-band antennas are folded during this mode.

The crew for the MOCOM consists of two astronauts who are provided with a 10.3 cubic meters (365 cubic feet) cabin for their 14-day mission. A scientific cargo capacity of 320 kg (705 lb) is available for lunar operations during the mission. The vehicle range capability is 400 km and requires 40 hours of driving time at a speed of 10.0 km/hr.

The specific mobility energy which is dependent upon a lunar operational mass is 0.487 kwh/km. The total energy for the MOCOM required to operate over the 400-km mission course is 695 kwh, of which 195 kwh are required for mobility. The maximum continuous mobility power is 6.55 kw.

Table 3-6 summarizes the MOCOM performance.

Table 3-7 contains a mass summary of the initial, stripped, and initially selected weights for the MOCOM system.

3.3 MOCOM SYSTEM DESIGN

This section examines each subsystem design to determine the extent of modification required to meet the subsystem requirements.

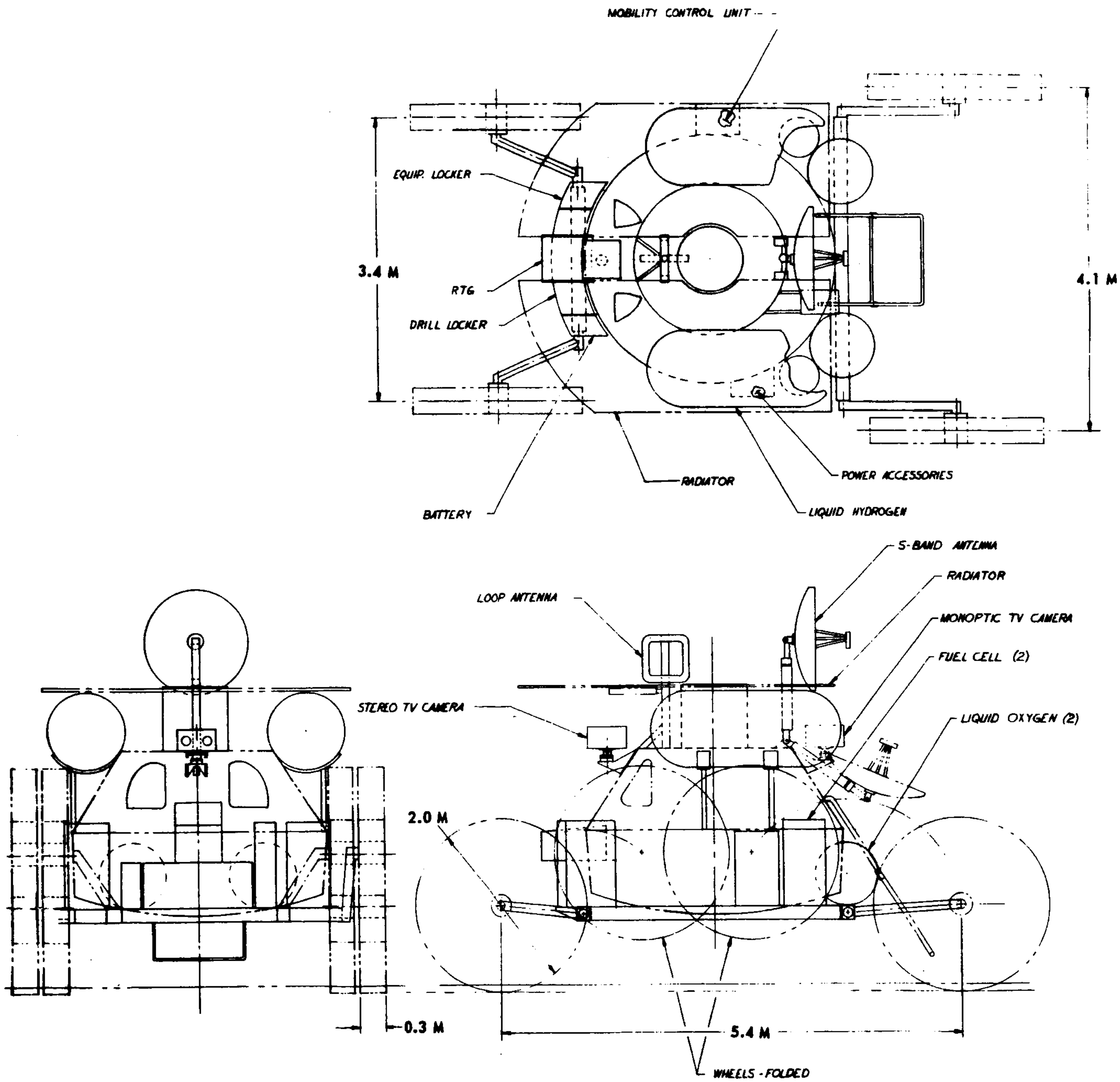
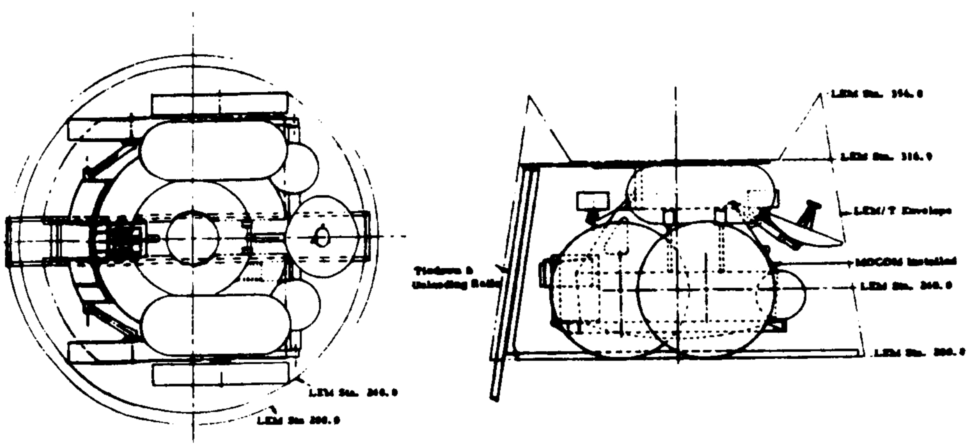


Figure 3-1 MOCOM Configuration



MOBEV-1-17-666

Figure 3-2 MOCOM Installation

TABLE 3-6

MOCOM PERFORMANCE SUMMARY

Crew	2 Astronauts
Cargo Capability	320 kg (705 lb)
Range	400 km
Cabin Volume	10.3 m^3 (365 ft^3)
Usable Floor Space	1.8 m^2 (19 ft^2)
Max Avg Speed (ELMS)	10 km/hr
Speed Hard Surface	16.7 km/hr
Speed Soft Soil	13.0 km/hr
Driving Time	40 hr
Obstacle Negotiability	70 cm
Crevice Negotiability	157 cm
Turn Radius	12.8 meters
Specific Mobility Energy	0.487 kwh/km
Total Energy	695 kwh

TABLE 3-7
MOCOM MASS SUMMARY

		Initial		Stripped	Selected		Remarks
		kg	(lb)	(lb)	kg	(lb)	
1.	Structure	2042	(4500)	(1780)	757	(1665)	
2.	Crew Provisions	435	(960)	(530)	146	(322)	
3.	ECS	161	(355)	(353)	201	(442)	
4.	Life Support Expendables	51	(113)	(113)	190	(417)	
5.	Controls and Displays	150	(330)	(130)	55	(121)	
6.	Navigation and Guidance	170	(375)		38	(84)	MOLAB Navigation MOLAB Required
7.	Communication	128	(283)	(193)	160	(353)	
8.	Instrumentation	114	(250)	(250)	91	(200)	
9.	Scientific Equipment	0		0	320	(705)	
10.	Electric Power System	274	(605)	(605)	342	(752)	695 kw/hr (400) km
11.	Electric Power Expendables	(SM)		0	255	(561)	
12.	Stabilizer and Control System	686	(1510)	0	0		
13.	Mobility	N/A		N/A	568	(1250)	
14.	Tiedown and Unloading	N/A		N/A	211	(465)	
15.	Thermal Control	—		—	42	(94)	
16.	Cryogenic Tankage	—		—	370	(815)	
	Total	4211	(9281)	(3950)	3746	(8246)	

3.3.1 Structure—Cabin

The modifications required for the CM are summarized in Sections 3.1.2.1, 3.2.4.1 and Figure 3-3.

Initial design concepts were centered on the use of the existing CM egress/ingress side hatch aperture, modified for a front viewing window installation and with the driver centrally placed. Egress from the cabin was through the removable hatch/window. This concept, although desirable from a minimum structural change standpoint, was not selected as the preferred concept for the following reasons:

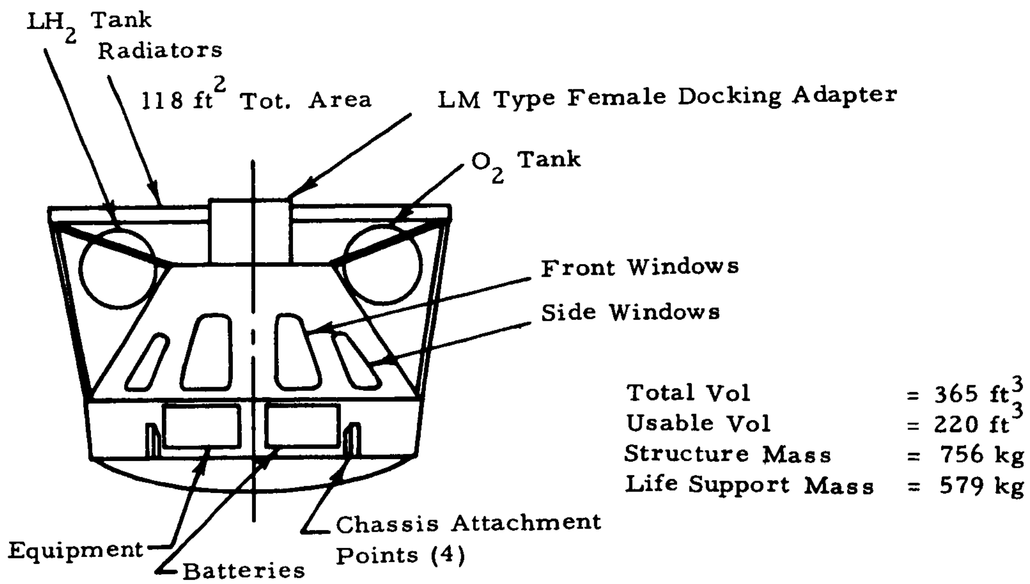
1. Egress would be difficult for a suited astronaut having to climb up through the hatch in the immediate vicinity of the controls.

2. It did not provide the preferred side-by-side arrangement where both men have simultaneous external visibility.

3. Due to vehicle cg requirements, equipment was located externally in the immediate vicinity of the egress hatch, making egress extremely difficult and hazardous.

The manned cabin of the MOCOM vehicle consists of a modified Apollo CM and is shown in Figure 3-3. The cabin structure consists of three sections, an upper (forward) section containing the docking adapter, a center section containing the windows and the airlock door, and a lower section containing the attachment points for the chassis. The upper section consists of a cylinder attached to a flat bulkhead with external stiffeners. The center section is built up on honeycomb skin panels, longerons, and ring stiffeners. The lower section is a large-radius aluminum honeycomb spherical segment. The entire cabin is covered by a thermal shield consisting of a 1-in.-thick blanket of superinsulation and an outer meteoroid skin of aluminum supported by phenolic washers.

On top of the cabin are mounted radiators, TV cameras, and antennas. Below the radiators are mounted LH_2 tanks, O_2 tanks and the RTG, all supported by a tubular truss structure which is attached to the cabin frame and longerons. Below the front windows are mounted equipment and batteries, and below the outside airlock door is a stationary platform, a handhold, and a hinged stepladder. A viewing port is provided in the airlock door.



	APOLLO CM/MOCOM COMPARISON		
ITEM	ADDED	MODIFIED	COMMENTS
Pressure Shell		X	4 windows and one air-lock door added.
Internal Airlock Bulkhead	X		
Meteoroid Protection and Insulation	X		Outer skin 0.015
Chassis Attachments		X	Use existing CM attachments.
Crew Station	X		2-man side-by-side. All COM equipment flight control and display panels removed. Mobility panels & controls added.
Bunks	X		
Airlock	X		
Floor	X		2-man internal and pump.
Docking Adapter	X		Add LM type female adapter.

Figure 3-3 MOCOM Cabin External Arrangement

The internal configuration provides for a two-man side-by-side arrangement with seats, mobility controls, and displays encompassing a left-hand driver's station and a right-hand navigator's station divided by a center console. The cabin contains two separate compartments; a forward crew station compartment, and an aft two-man internal airlock. Both compartments are interconnected by a 30 x 60 in. door in the dividing bulkhead. Normal egress from the cabin is through the rear hatch located in the airlock.

A one-man scientific work station including a glove box is provided along the right-hand side of the cabin. Equipment and storage space is located on both sides of the cabin. The upper section contains the docking adapter with a pressure hatch which also serves as an emergency exit from the cabin. One bunk can be erected across the cabin in front of the airlock door with sufficient space for a second bunk in the airlock. A flat floor with 73 in. of headroom is provided in the forward compartment. Storage space is provided at both sides in the airlock for spacesuits and equipment. Table 3-8 summarizes the weight breakdown for the preferred configuration. Figure 3-4 shows the preferred internal arrangement and Figure 3-5 the weight and center of gravity.

3.3.2 Power System

This section presents a description of the MOCOM power system and a discussion of the power system concepts. As noted in Section 3.1, the CM fuel cells can be used as the primary power subsystem for the MOCOM power system. However, from vehicle weight considerations, an improved P&W fuel cell design is recommended.

The major mission and system restraints and power requirements are as follows:

1. The power system shall be capable of being stored on the lunar surface in a standby mode for at least 6 months.

2. The power system shall be designed for a 14-day operating capability plus a 7-day emergency survival requirement.

3. The power system shall provide the necessary tankage and controls for the life support oxygen. The life support oxygen requirement is 94 kg for the 14-day operation and the 7-day survival.

TABLE 3-8

MOCOM STRUCTURE WEIGHT

Structure	kg	(lb)
Forward Section		
Honeycomb and stiffeners	44.5	(98)
Docking Adapter and mech.	25.9	(57)
Fittings and attachments	22.7	(50)
Center Section		
Honeycomb panels	99.2	(218)
Longerons, frames, and rings	101.4	(223)
Windows and reinforcement frames	43.6	(96)
Fitting and attachments	46.8	(103)
Aft Section		
Honeycomb panel	55.0	(121)
Rings and stiffeners	45.6	(99)
Attachments and supports	27.3	(60)
Floor	4.55	(10)
Airlock		
Bulkhead, door, hardware	91.0	(200)
Display panels	40.9	(90)
Crew station (includes instruments, controls and seats)	27.3	(60)
Storage compartments	22.7	(50)
Scientific Station	27.3	(60)
Meteoroid Shielding	31.8	(70)
Total	756.9	(1665)

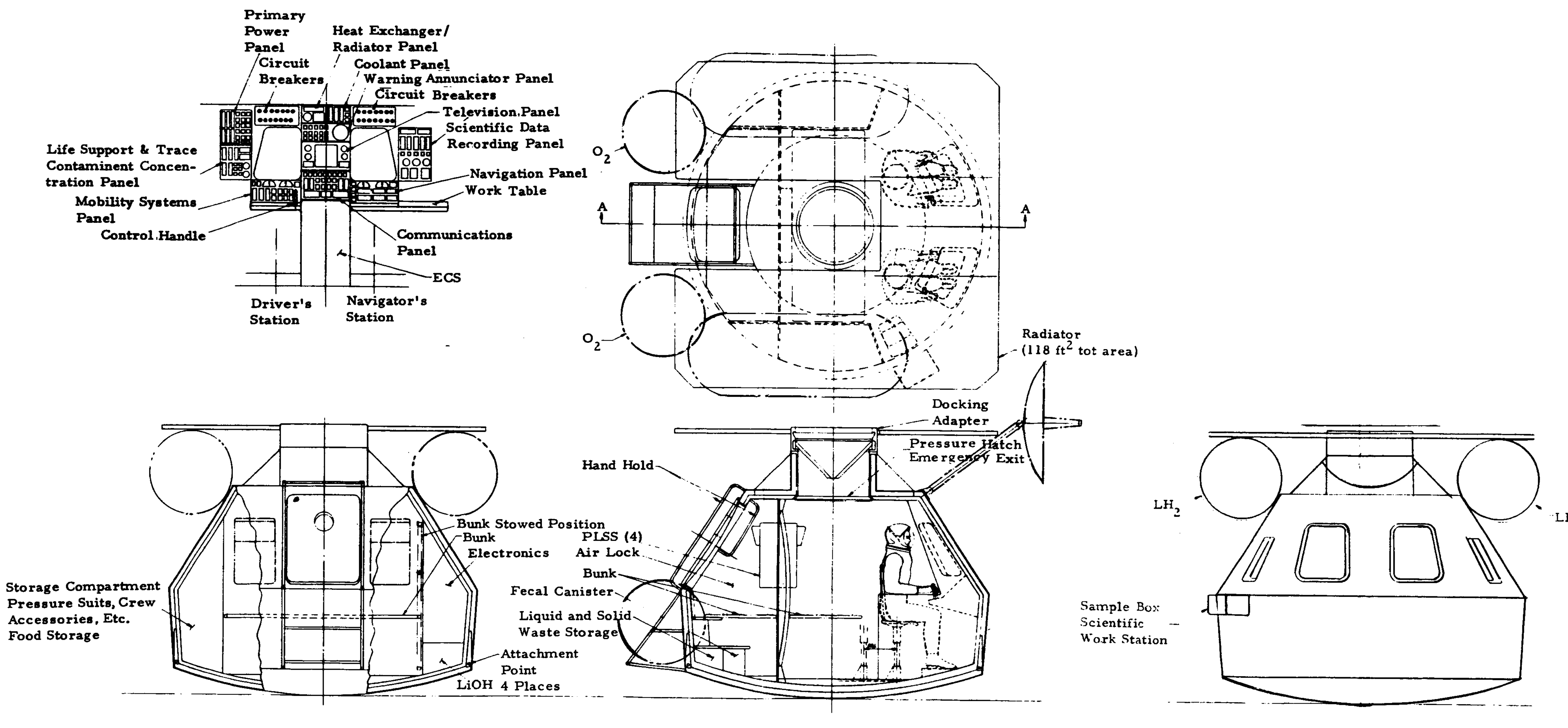


Figure 3-4 MOCOM CabinPhase I Study

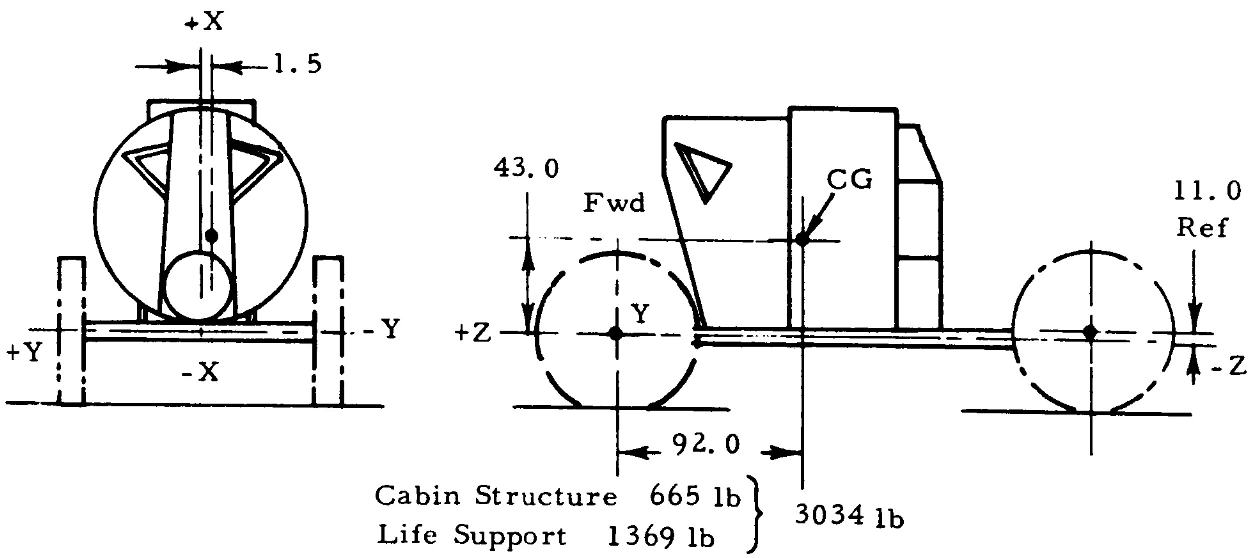


Figure 3-5 Weight and CG for MOCOM Cabin System

4. The power and energy requirements are summarized in Table 3-9.

Two fuel cell designs were considered for the MOCOM primary power subsystem:

1. Existing P&W Apollo fuel cells

2. Improved P&W fuel cells.

Table 3-10 summarizes the power system weight for Apollo fuel cells. The improved fuel cell design was selected from weight considerations.

The power system provides electrical power during the inflight, debarking, lunar storage, and scientific mission phases. The electrical power requirements vary from 50 w during the lunar storage phase nighttime to a maximum continuous demand of 7.55 kw during the scientific mission phases. The short-duration (<1 minute) peak power demand is approximately 10 kw. The power system also furnishes thermal power for the lunar storage phase thermal control and provides storage for 206 lb of life support oxygen.

Figure 3-6 shows the power system block diagram. This system consists of five major subsystems: primary power utilizing two P&W fuel cells sized specifically for the MOCOM requirements; secondary power consisting of rechargeable batteries; auxiliary power, utilizing a radioisotope thermoelectric generator (RTG); cryogenic storage and supply, consisting of two cylindrical hydrogen tanks, two spherical oxygen tanks, cryogens and controls; and power conditioning and distribution.

The MOCOM power system operation and interfaces are the same as those for the MOLEM power supply. The subsystem designs, except the cryogenic subsystem, are also same as for MOLEM.

The cryogenic storage and supply subsystem operations and designs are similar to MOLEM. The design requirement differences are as follows:

	MOCOM	MOLEM
No. of H_2 Tanks	2	1
Total H_2 Requirement	65 lb	64 lb
Total Fuel Cell O_2 Requirement	496 lb	493 lb

TABLE 3-9

MOCOM POWER AND ENERGY SUMMARY

		14-Day Mission	7-Day Emergency Extension
1.	Mobility		
	a. Max continuous power	6.55 kw	0
	b. Peak power	10 kw	0
	c. Avg power and duty cycle	4.87 kw x 40 hr	0
	d. Energy	195 kwh	0
2.	Experiments		
	a. Avg power and duty cycle	0.5 kw x 126 hr 0.25 kw x 40 hr	0
	b. Energy	75 kwh	0
3.	Astrionics		
	a. Comm avg power and duty cycle	0.412 kw x 336 hr	0.15 kw x 100 hr
	b. Navigation avg power and duty cycle	0.141 kw x 63 hr	0
	c. Energy	150 kwh	15 kwh
4.	Cabin and Thermal		
	a. Energy (100% duty cycle)	175 kwh	90 kwh
5.	Total Load energy	590 kwh	105 kwh

TABLE 3-10

MOCOM POWER SYSTEM MASS (FOR APOLLO C/SM FUEL CELL ASSEMBLIES)

		Three Existing P&W Apollo C/SM Fuel Cell Assemblies (kg)
I.	Primary power	381
II.	Secondary power	34
III.	Auxiliary power	18
IV.	Power cond. and dist.	18
V.	Cryogenic excluding usable fluids	440
	Total excludes usable fluids	892
VI.	Usable fluid for fuel cells	
	H_2	48
	O_2	375
	Total includes usable fluids	1314

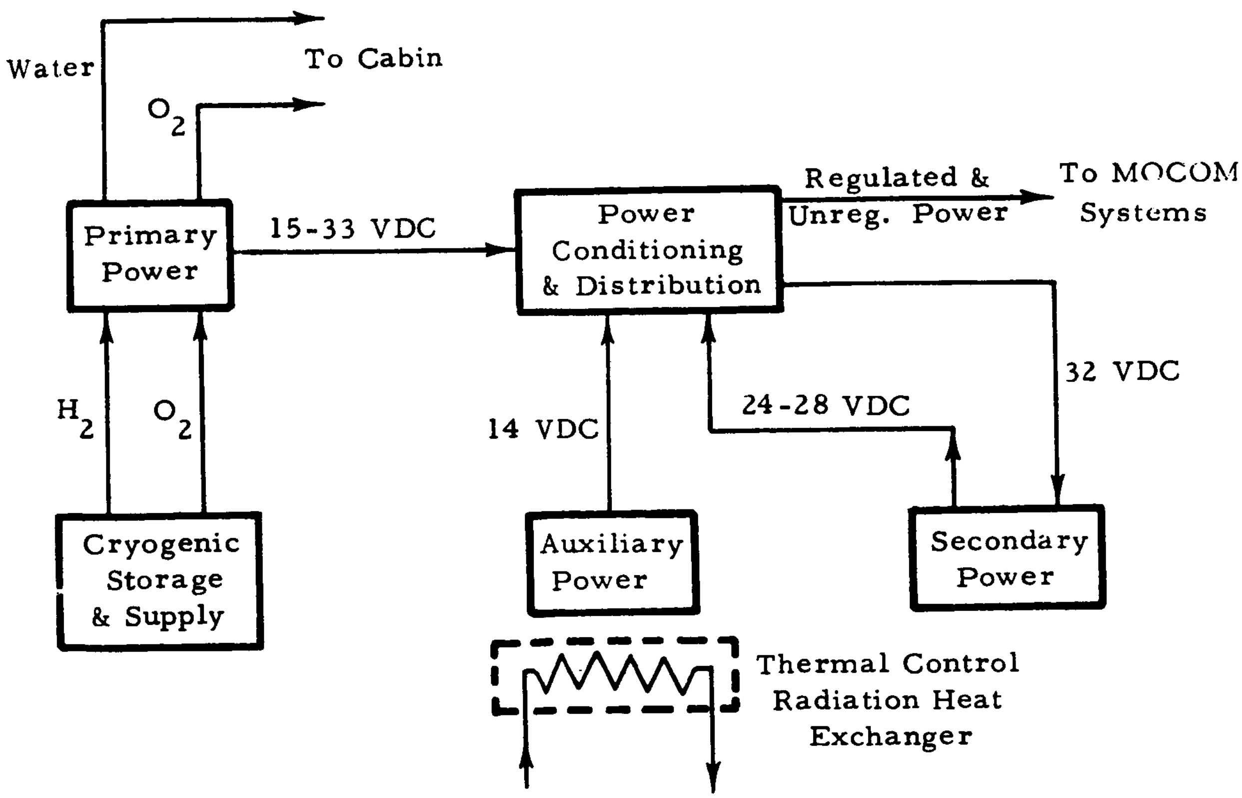


Figure 3-6 MOCOM Power System Block Diagram

Table 3-11 summarizes the power system mass. As shown, the total power system mass including fuel cell expendables is 966 kg. The oxygen tanks are also sized to store 91 kg of oxygen for life support.

The fuel cell radiator area is 54 sq ft and is sized for 7.55 kw power.

TABLE 3-11

MOCOM POWER MASS SUMMARY
(P&W IMPROVED FUEL CELLS)

		Mass (kg)
Primary Power		
a.	Two Fuel Cell Assemblies and Controls	218
b.	Fuel Cell Radiator	30
c.	Fuel Cell Accessories, Batteries, and RTG	93
Cryogenic (excludes usable fluids)		
a.	H_2 System	272
b.	O_2 System	98
Usable Fluids for Fuel Cells		
a.	Hydrogen	30
b.	Oxygen	225
	Total Includes Usable Fluids	(966)

3.3.3 Mobility

The mobility system chosen for the selected MOCOM concept is based on the MOLAB design consisting of the following components:

		kg	(lb)
1.	Traction Drive Mechanism (TDM) Assy. (4)	145.5	(320)
2.	Wheels (4)	175	(385)
3.	Steering Drive Mechanism (SDM) Assy. (2)	18.2	(40)
4.	Suspension Assy.	84.1	(185)
5.	External Cabling, Mobility Controller, Relay	38.6	(85)
6.	Chassis	106.8	(235)
		568.2	(1250)

The mass of mobility was based on a vehicle lunar surface operational mass of 3743 kg.

3.3.4 Life Support - Environmental Control

The MOCOM life support system was defined by analyzing the functions and estimating system characteristics. Figure 3-7 presents the results of an ingress/egress trade-off conducted for MOCOM. As with MOLEM, the use of an airlock plus pump results in weight savings substantial enough to justify their use in the spacecraft. The thermal control system for the MOCOM is identical to that of the MOLEM except for additional insulation required to limit the vehicle heat leak out to 51 w compared to the 60 w of MOLEM. The ECS schematic for MOCOM is also identical to MOLEM except for minor differences arising from peculiarities in the components. Life support sensitivity data are shown in Figure 3-8; additional sensitivity data appear in Section 5.

Life support system mass, cost, and development schedule estimates for MOCOM are presented in Table 3-12.

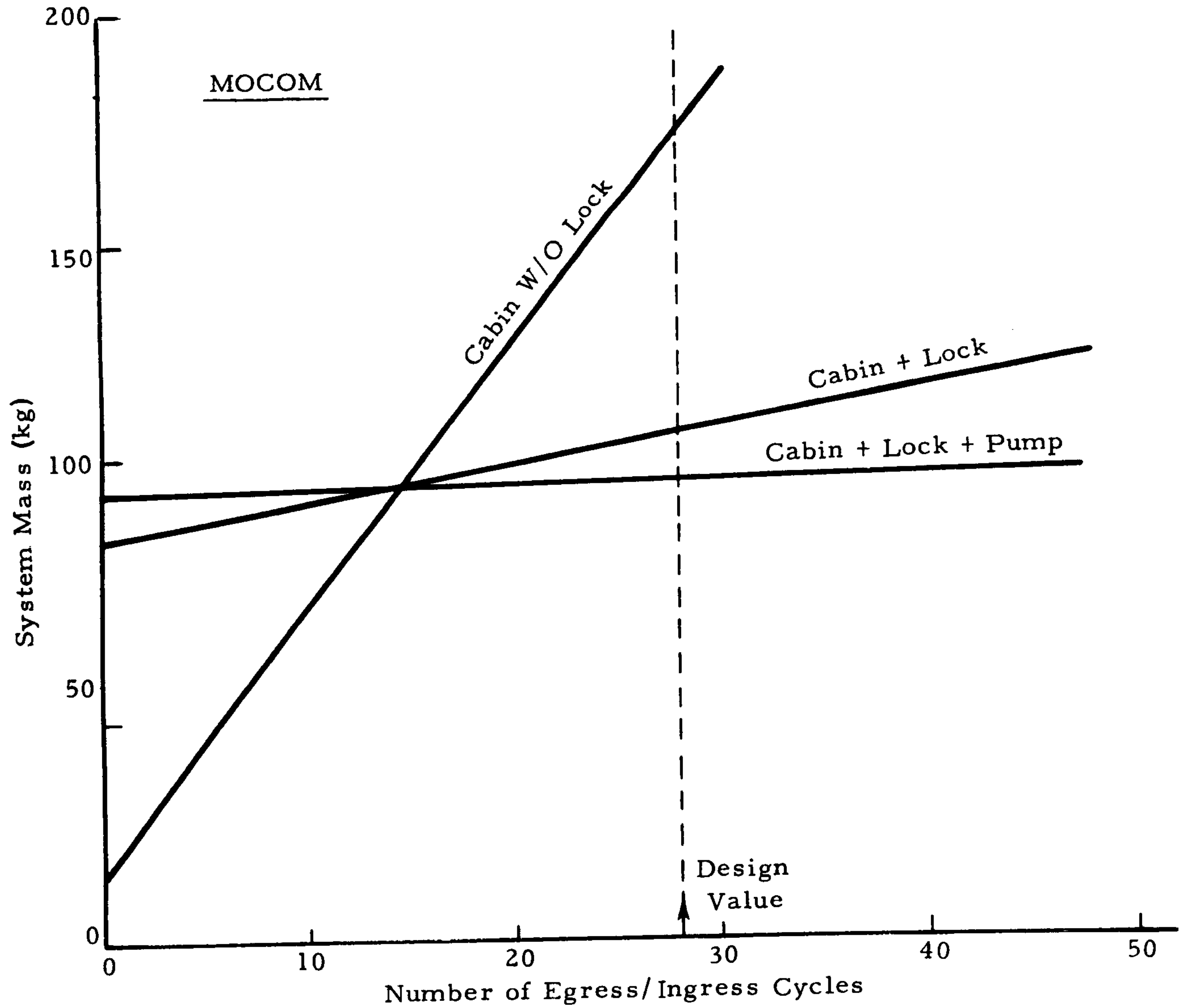


Figure 3-7 MOCOM Ingress/Egress Trade-off

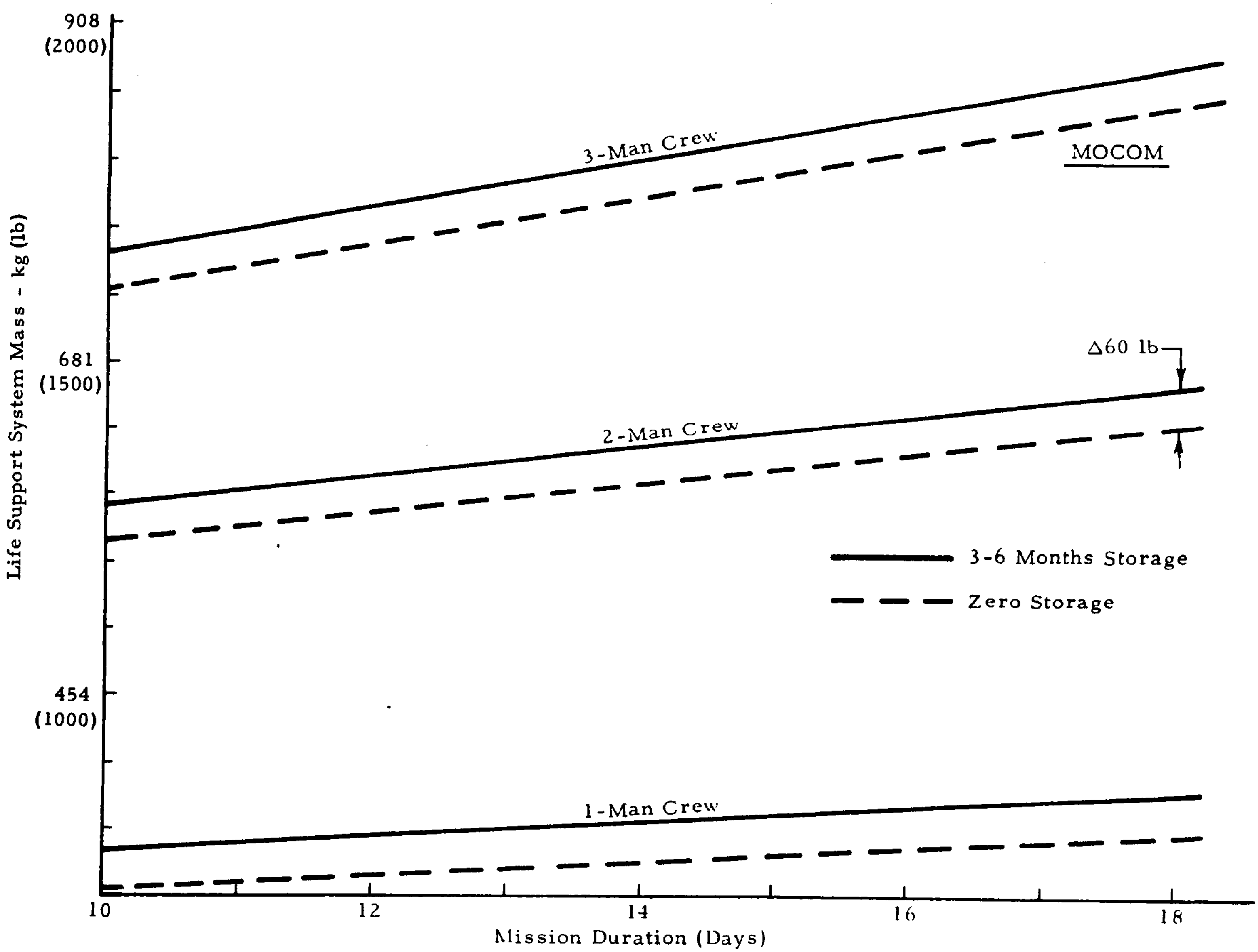


Figure 3-8 Life Support System Sensitivity Data

TABLE 3-12

MOCOM LIFE SUPPORT SYSTEM DATA

	Mass (lb)		Mass (kg)	
Environmental Control System				
Suit and Cabin Atmosphere Conditiong	120		54	
Radiator Cooling System	192		87	
Oxygen Supply and Pressure Control	50		23	
Water Management	35		16	
Control, Wiring and Support	45		20	
		442		201
Crew Provisions				
Suits and Suit Accessories	130		59	
Portable Life Support System	92		42	
Waste Management	20		9	
Food Preparation and Personal Hygiene	20		9	
Emergency Equipment and Accessories	60		27	
		322		146
Misc Thermal Control				
Cabin Insulation Weight	34		15	
Storage Phase Heating System	60		27	
		94		42
Expendables				
Lithium Hydroxide and Charcoal	193		88	
Oxygen	206		93	
Water	18		8	
		417		189
Grand Total		1275		578

3.3.5 Communications

The communications system concepts considered were as follows:

1. Use the existing command module equipment with only the re-entry systems removed.

2. Use the MOLAB communications system (160 kg total mass), Table 3-13.

3. Use a system that would be composed of units of both the command module and MOLAB systems. Such a system is shown in Table 3-14 and has a total mass of 238 kg (523.9 lb).

The recommended communications system for MOCOM is the MOLAB system. It is recommended on the basis of least mass.

3.3.6 Navigation

Table 3-15 lists the MOCOM components for surface navigation. The block diagram is shown as Figure 3-9. Retained items are the same as those listed as retained in Section 3.1. The Scanning Telescope is being carried for possible use in landmark viewing, although it is not now regarded as essential to the prime surface navigation subsystem. Otherwise the MOCOM and MOLEM navigation subsystems are identical.

3.3.7 Tiedown and Unloading

Unloading is to be accomplished automatically or manually by means of flanged wheels attached to the MOCOM main axles and rolling down a 21-ft (from forward hinge point) pair of rails 48 in. apart. The MOCOM may be rotated 360° on a turntable and unloaded in any direction. The 21-ft rails fold into two sections in front of the MOCOM. The wheels are extended straight up at the time of unloading.

TABLE 3-13

RECOMMENDED MOLAB COMMUNICATIONS SUBSYSTEM
MASS SUMMARY

	Mass (lb)	Mass (kg)
S-band directional antenna - RF unit	10	5
S-band directional antenna - servo and drive	17	8
S-band directional antenna - yoke and support	10	5
Omni antennas - S-band and VHF	11	5
S-band antenna switch	3	1
Diplexer and power amplifier	17	8
Unified S-band equipment	30	14
Premodulation processor	14	6
PCM TM Equipment	14	6
Signal conditioners	31	14
Up-link data decoder	5	2
Central timing equipment	10	5
VHF-AM transceiver	7	3
Loop antenna	18	8
Sense antenna	2	1
Direction finder	3	1
Audio center	10	5
Manual data input unit	15	7
Data processor and data bus	30	14
Mission recorder	22	10
Signal distribution and test panel	10	5
Communications Subtotal	289	131
Forward camera unit	26	12
Rear camera unit	17	8
Internal cameras (3)	12	5
TV monitor	7	3
Signal distribution and test panel	2	1
Television Subtotal	64	29
System Total	353	160

TABLE 3-14

MOCOM INITIAL STRIPPED SPACECRAFT COMMUNICATIONS EQUIPMENT DESCRIPTION

Equipment	Equipment Origin		Weight	Mass	
	New	CM	(lb)	(lb)	(kg)
S-band Antenna (2-ft Dish)	x		20	20	9.1
Antenna Drive Mechanism	x		8.6	8.6	3.9
Servo Amplifier Unit	x		2.0	2.0	0.9
Transmitter/Receiver Unit	x		5.0	5.0	2.3
S-band Omni Antenna		x	4.4	4.4	2.0
S-band In-Flight Antenna		x	3.3	3.3	1.5
S-band Antenna Switch		x	3.0	3.0	1.4
VHF Omni Antenna	x		4.3	4.3	2.0
VHF In-Flight Antenna	x		3.3	3.3	1.5
Lunar Stay Antenna	x		10.6	10.6	4.8
VHF Antenna Switch		x	1.1	1.1	0.5
Sense Antenna (DF)	x		2.0	2.0	0.9
Loop Antenna (DF)	x		18.0	18.0	8.2
Diplexer and Power Amp. S-band		x	31.0	31.0	14.1
Unified S-band Equipment		x	31.0	31.0	14.1
Diplexer Assembly (VHF)		x	3.5	3.5	1.6
Transceiver AM (VHF)		x	11.0	11.0	5.0
Transceiver FM (VHF)		x	7.0	7.0	3.2
Premodulation Processor		x	15.0	15.0	6.8
Audio Center		x	8.0	8.0	3.6
Communications Control Panel	x		15.0	15.0	6.8
PCM T/M Encoder		x	49.0	49.0	22.2
Central Timing Equipment		x	6.5	6.5	3.0
Data Processor	x		30.0	30.0	13.6
Manual Data Input Unit	x		15.0	15.0	6.8
Signal Conditioner		x	40.0	40.0	18.2
Data Distribution Panel		x	1.5	1.5	0.7
Modulators	x		2.0	2.0	0.9
Mission Recorder	x		49.0	49.0	22.2
TV Cameras (Stereo Pair)	x		16.0	16.0	7.3
TV Camera Az. & El. Control Assy.	x		4.0	4.0	1.8
Combiner Synchronizer	x		1.0	1.0	0.5
Illuminator	x		5.0	5.0	2.3
Rear TV Camera Assembly	x		17.0	17.0	7.7
Internal TV Cameras		x	22.0	22.0	10.0
VHF TV Receiver	x		2.0	2.0	0.9
TV Monitor Unit	x		7.0	7.0	3.2
Remote Control Equipment	x		13.0	13.0	5.9
Cabling & Harness	x		37.3	37.3	16.9
Total			523.9	524.4	238.1

TABLE 3-15

PRELIMINARY MOCOM NAVIGATION COMPONENT CHARACTERISTICS

Item	Retained	New	Estimated Values		
			Mass (kg)	Power (w)	Volume (in.^{3})
1. Inertial Measurement Unit (IMU)	x		25	210	1000
2. Sextant (SXT)		x	5	-	500
3. Scanning Telescope (SCT)	x		2	-	500
4. Apollo Guidance Computer (AGC)	x		32	100	2000
5. Coupling Display Unit (CDU)	x		11	30	1000
6. Power Servo Assembly (PSA)	x		16	35	1000
7. Display and Control (D&C)	x		14	40	800
8. Odometer		x	4	10	1000
Total			108	425	7800

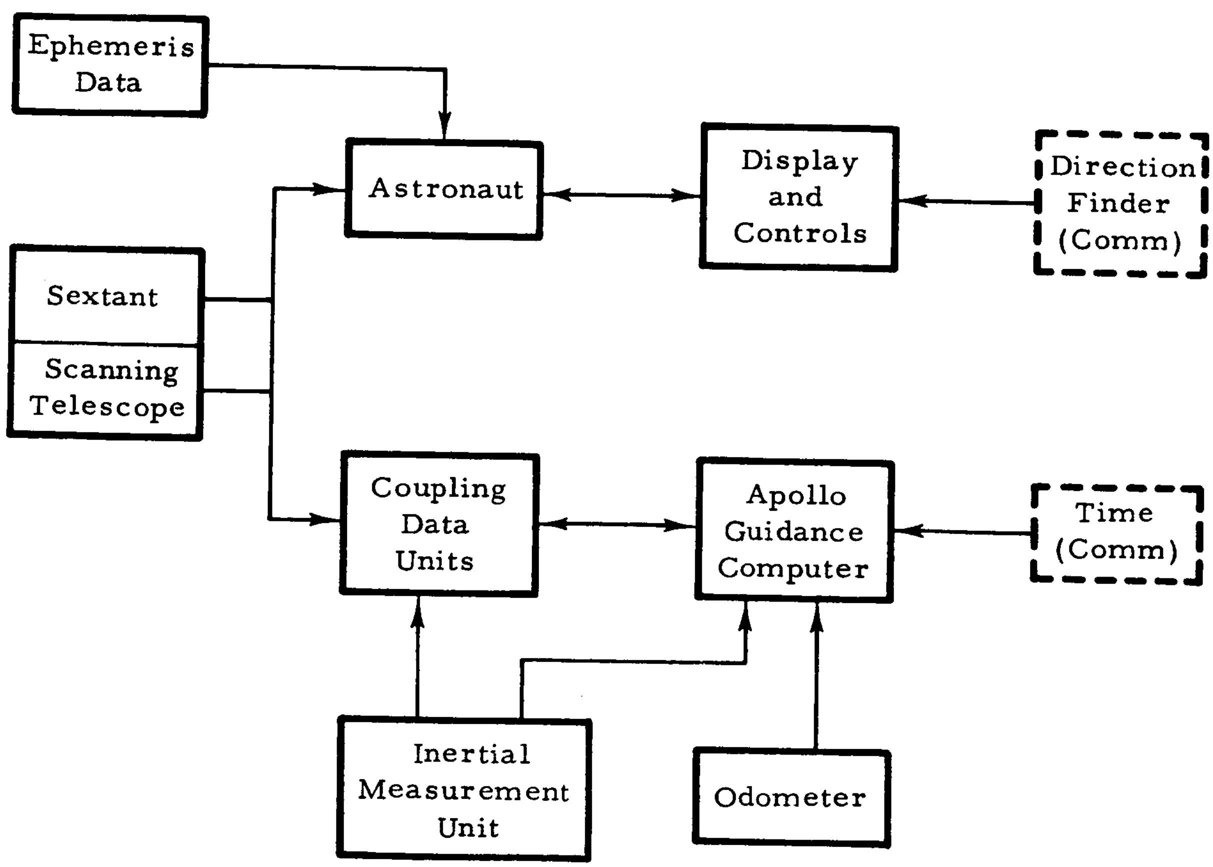


Figure 3-9 MOCOM Navigation Subsystem Block Diagram

3.4 MOBILITY AND PERFORMANCE CAPABILITY

This section examines the performance capabilities of each of the subsystems of the MOCOM recommended design.

3.4.1 Mobility Performance

The mobility power requirements and speed vs. slope for the MOCOM vehicles an[illegible] ne 3178 kg vehicle have been completed. The assumptions were:

Soil: ELMS 50/50
Wheel Diameter: 2.03 m
Wheel Width: 0.305 m
Ground Pressure: 1.0 psi
I_{OPT}: 0.1
Hysteresis Loss: 0.06
A/L: 0.5

Table 3-16 shows the performance data for MOCOM.

3.4.2 Scientific Mission Performance

The MOCOM provides 75 kwh of energy for 320 kg of scientific equipment. The MOCOM can transport this equipment over a total range of 400 km with a radius of operation of 80 km from the LM/T landing point. Allowance for a core drill is made as part of the scientific payload.

3.4.3 Degraded Mode Analysis Summary

Table 3-17 summarizes the major degraded modes which are capable of enhancing MOCOM mission success and crew safety.

In the Mission Success column, an x has been used to delineate those equipment items (or groups) which have effective backup to allow mission continuation in the event of a single item failure. The (x) identifies those equipment items which have a backup of very limited nature - to allow the mission to continue but with significant limitations on operating range, radius, or total time on the lunar surface.

In the Emergency Return column, an x delineates degraded mode capabilities for safe vehicle return from up to 80-km radius. Where a given function has more than one degree of crew safety backup, an xx is shown.

TABLE 3-16

MOCOM PERFORMANCE DATA

Parameter	Value
Mass	3746 kg (8246 lb)
Obstacle Negotiability	70 cm
Crevice Negotiability	157 cm
Slope Negotiability	35^{o}
Draw Bar Pull	686 lb
Maximum Speed (Hard Surface, Level)	16.7 km/hr
Average Speed	10 km/hr
Static Stability	48^{o}
Maximum Continuous Power	6.55 kw
Specific Energy	0.487 kwh/km
Static Turn Radius	13 m

TABLE 3-17

MOCOM MAJOR DEGRADED MODE CAPABILITIES FOR MISSION CONTINUATION AND EMERGENCY RETURN DURING THE 14-DAY MANNED MISSION PHASE

Compartment or Equipment	Backup Modes	
	Mission Success	Emergency Return
Cabin Compartments	(x)	x
Heat Rejection (Radiators & Water Boilers)	(x)	x
Oxygen Supplies	(x)	x
Hydrogen Supplies	(x)	x
Traction Drive Mechanisms	x	xx
Steering Drive Mechanisms	x	x(x)
Brakes (Elect. and Elect./Mech.)	x	xx
Suspension (Wheel and Arm Assys)	(x)	x
Fuel Cells (Primary Power)	(x)	x
Power Conditioning and Distribution	(x)	x
TV Cameras (external)	x	xx
VHF (EVA)	x	xx
S-band Earth Links	x	xx
Navigation	xx	xx
Unloading	x*	NA

*Manual vs. automatic, and TV camera redundancy.

x - Effective backup mode exists.
(x) - Degraded backup mode exists - mission may be continued with serious limitations.
xx - Multiple backup for emergency return.
NA - Not applicable.

3.5 SENSITIVITY DATA

3.5.1 Crew Size

Each configuration was reviewed in terms of the maximum crew size that it could accommodate. Figure 3-10 summarizes an analysis of each concept for crew sizes varying between two and four men. The MOCOM provides ample volume for a two-man crew but is marginal in terms of accommodating a three-man crew. With a three-man crew, available free volume per man is 73 ft^3 or 14.5 ft^3 below the NASA MSFC specified minimum for MOLAB. The MOCOM is marginal with respect to allowing sufficient space for suit storage (six suits and six PLSSs) and suit drying. In addition, provision of a second compartment large enough to permit simultaneous suit donning in the event of a main compartment failure is questionable and should be verified with mockup design verfication techniques. The MOCOM does offer sufficient room for simultaneously erecting three bunks. In summary, the MOCOM offers satisfactory living and working quarters for two crew members but can only marginally accommodate three crew members.

3.5.2 Astrionics

In general, the astrionics subsystems are insensitive to variations in such mission parameters as:

1. Mission duration (days)
2. Mission area (radius of operation)
3. Crew size
4. Total distance traveled
5. Surface model
6. Initial operation (vehicle from LM).

	MOLEM			MOCOM			MOCAN		
CREW SIZE	2	3	4	2	3	4	2	3	4
Free Volume Per Man (cu ft)	75	50	37.5	109.5	73	54.8	405	270	205
Sleeping Accommodations	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes
Storage Room	Marginal	No	No	Yes	Marginal	No	Yes	Yes	Yes
Redundant Compartment	No	No	No	Yes	Marginal	No	Yes	Yes	Yes
Suit Drying Space	Marginal	No	No	Yes	Marginal	No	Yes	Yes	Yes
Maximum Crew Size	✓				✓				✓+

Figure 3-10 Crew Size Analysis

3.5.2.1 Navigation

The navigation subsystem for MOCOM is generally insensitive to mission variations. Once the capability to operate beyond line of sight is established, increasing stay time or extending radius of operations does not affect the navigation subsystem.

1. Mission Duration

   The number of days spent in vehicular travel affects the navigation subsystem primarily in that the expected mean time to failure might be exceeded. The most critical component to mission success is the IMU. Since this component is used for both position fixing and dead reckoning, longer mission durations would pose a greater mission safety hazard to the astronauts. The homing equipment is used only during closure and is independent of mission duration.

2. Mission Area

   The MOCOM radius of operation is 80 km. Extension out to 150 km would involve higher astronaut risk. Return to the LM by dead reckoning could no longer be accomplished if the position fix equipment failed.

3. Crew Size

   Crew size has no effect on navigation. The requirement to operate unmanned already exists, and increasing the crew to three or four has no appreciable effect on the navigation subsystem since the basic system requirements would not change.

4. Total Distance Traveled

   Total travel distance has little effect on the navigation subsystem other than the associated increase in operating time might exceed the system mean time to failure.

5. Surface Model

The accuracy of the navigation subsystem is somewhat dependent upon the surface model. A model somewhat milder than ELMS might result in smaller gravitational anomalies with a slightly higher positional accuracy. Greater accuracy might also result with the milder ELMS because of less slip during travel. A very flat surface would increase the line-of-sight capability with a corresponding increase in homing distance.

6. Initial Vehicle-to-LM Separation

The assumption is made that the initial separation between the vehicle and the LM is 10 km or less. If the separation exceeds 10 km (the actual homing range), the vehicle position must be determined from earth tracking(two days per fix). The time required for rendezvous would be increased by this additional position fix time and the additional travel to rendezvous.

3.5.2.2 Communications

Table 3-18 summarizes the MOCOM communications subsystem sensitivity to the listed mission variations. Generally the communications subsystem does not vary in weight and volume as mission parameters change. Additional equipment would be incorporated into the audio control center should the crew size increase. With this exception, the communications subsystem is relatively static.

3.5.3 Locomotion Capability

Figure 3-11 depicts the mobility system weight sensitivity with respect to vehicle weight. This is the only mission variation that will affect the mobility system weight. The assumptions were:

Soil	ELMS 50/50
Wheel diameter	2.03 m
Wheel width	0.305 m
Ground pressure	1.0 psi
I_{opt}	0.1
Hysteresis loss	0.06
A/L	0.5

TABLE 3-18

SENSITIVITY TO MOCOM MISSION VARIATIONS DATA-COMMUNICATIONS

Mission Parameter					Effect (Sensitivity)
1.	Radius of Operation	Case 1.		40 km	No effect. System operation is well within maximum margins of operation.
		Case 2.		80 km	This is the nominal mode of operation, no effect.
		Case 3.		160 km	Communications links dependent on earth and periodic CM relay.
2.	Crew Size	Case 1.		None	Requirement for remote control, TV, navigation, and direction aids.
		Case 2.		2 Men	This is the nominal condition, no change required.
		Case 3.		4 Men	Additional equipment is required at audio center to support personnel voice & biomed.
3.	Mission Duration	Case 1.		7 Days	Communication requirement unchanged.
		Case 2.		14 Days	Communication requirement unchanged.
		Case 3.		21 Days	Depending on types of services, power requirements will increase by 20-25%.
		Case 4.		28 Days	Depending on types of services, power requirements will increase by 40-50%.
4.	Total Distance Traveled		Radius (km)	Distance (km)	
		Case 1.	40	200	This case less than nominal, no change.
		Case 2.	80	400	Nominal condition for system.
		Case 3.	120	600	Communications links dependent on earth and CM relay.
		Case 4.	160	800	Communications links dependent on earth and CM relay.
5.	Initial Vehicle-LM Separation			0.5 km	This separation is possibly within astronaut walking distance.
				5.0 km	Remote control of vehicle from MSFN required.
				50.0 km	Remote control of vehicle from MSFN required.

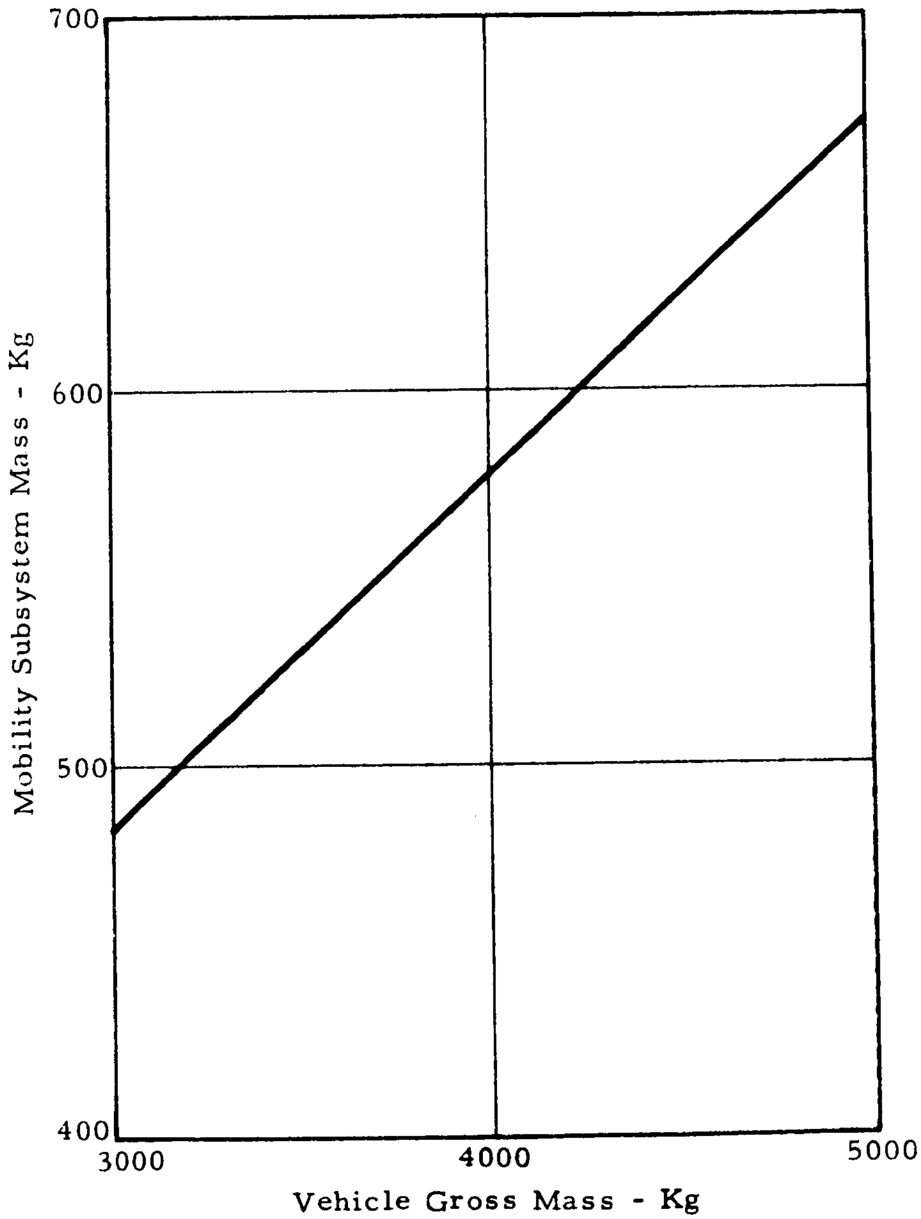


Figure 3-11 Mobility System Mass Sensitivity
With Respect to Vehicle Mass

3.5.4 Power Capability

Fuel cell data based on using improved P&W Apollo fuel cells are shown in Figure 3-12. These cells are more efficient and lighter (lb/kw) than the Apollo cells. The data used for generating the attached graphs were furnished by P&W for the ALSS study.

Figure 3-12 shows the fuel cell assembly weight vs. maximum continuous power for two specific reactant consumption (SRC) rates: cells A and B at 0.937 and 0.756 lb/kwh, respectively, for the maximum continuous power. The fuel cell assembly weight includes the fuel cells and their controls, excluding the fuel cell radiator and the accessory package.

Figure 3-13 shows the reactants consumption vs. energy curves. As can be seen from these figures, the reactant consumptions (efficiency) are dependent on fuel cell designs and their operating power (or percentage of the maximum continuous power). The fuel cell efficiency increases with decreasing load until an optimum level is reached for the respective cells. The optimum powers for cells A and B (Figure 3-13)are 30 and 35% of their maximum continuous power, respectively. Operating at lower than the optimum power level will decrease the efficiency because of higher parasitic losses (pumping and heat power).

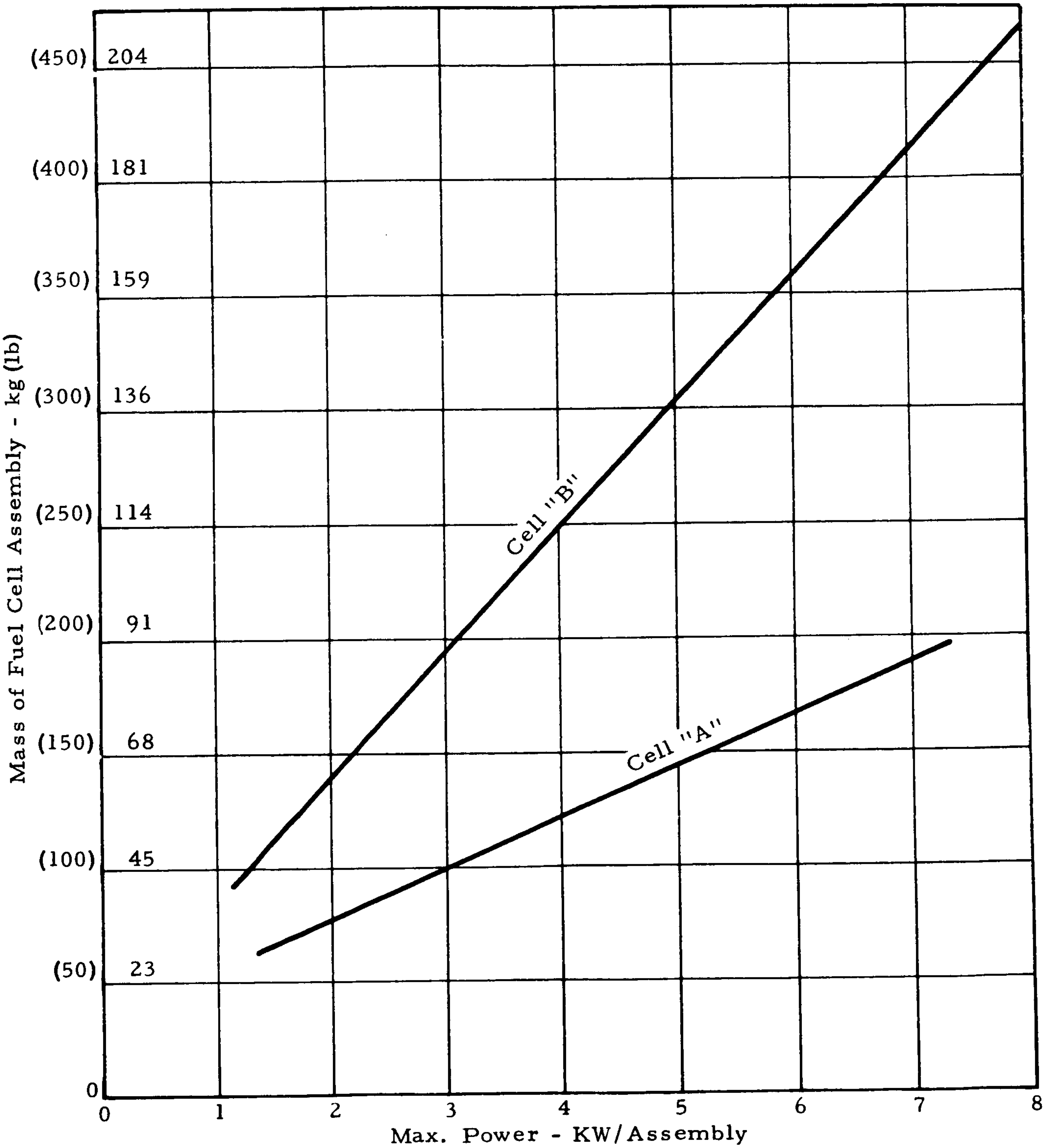


Figure 3-12 Mass of Fuel Cell Assembly Vs. Fuel Cell Power

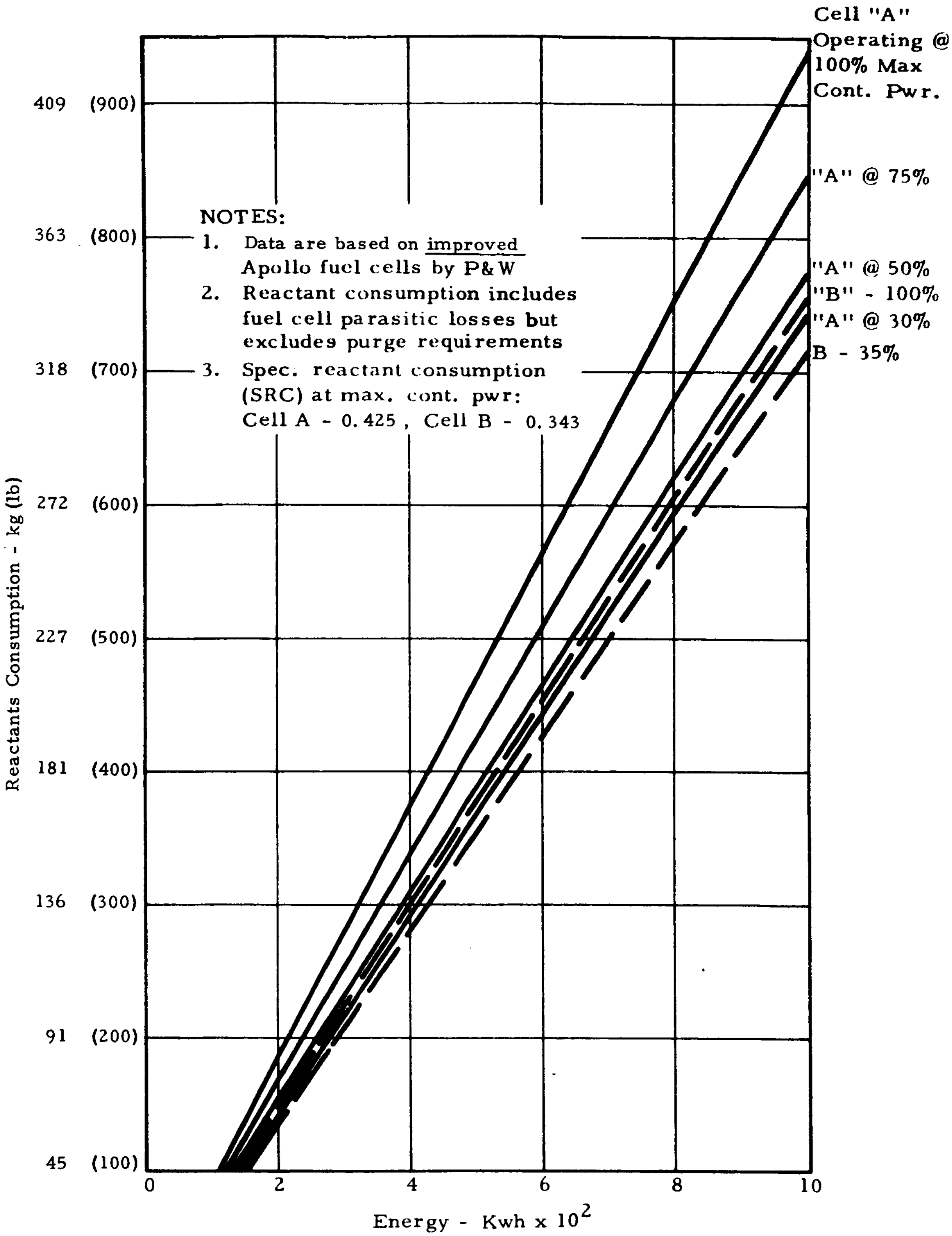


Figure 3-13 Fuel Cell Reactants Consumption vs. Energy

SECTION 4

MOCAN

4.1 STRIPPED SPACECRAFT DEFINITION

The CAN, shown in Figure 4-1, is a right circular cylinder 102 in. high with a diameter of 183 in. The floor-to-ceiling height is 84 in. The floor area is 170 sq ft, and the pressurized volume is 1350 cu ft. The module is designed for a crew of three men in a shirtsleeve atmosphere. The CAN is sized such that a module and the LM descent propulsion unit can be installed within the LM adapter.

4.1.1 Structure

An evaluation was conducted of the proposed AES Laboratory CAN to determine the major structural revisions required to enable its use as the MOCAN mobility vehicle. The evaluation showed that the basic CAN pressure shell designed for a 5-psia operating pressure is adequate and can be used with appropriate modifications for limited mobility missions. The CAN,of course, presently exists only as a study concept definition and does not represent hardware such as LM and the CM; consequently, the stripped spacecraft definition represents a paper design change rather than a hardware revision.

The required modifications for the stripped spacecraft definition consist of the removal of the outer meteoroid skin and insulation, bottom hatch, and all flight control and display equipment panels. These revisions together with the retained items are summarized in Table 4-1.

4.1.2 CAN Power System

The CAN power system includes a single fuel assembly as the primary power source and cannot be retained. Two P&W advanced fuel cell assemblies will be used.

TABLE 4-1

STRIPPED MOCAN STRUCTURE SUMMARY

Items	Retained	Removed	Comments
Pressure Shell and Bulkheads	X		
Meteoroid Protection and Insulation		X	
Rack Mounting Attachments	X		Use 4 as chassis attachment
Docking Adapter	X		
Bottom Hatch		X	
Flight Control and Display Equipment Panels		X	

4.1.3 Crew Provisions

For MOCAN, provisions have been made for two astronauts seated side-by-side for driving. The window arrangement follows the MOCOM-MOLAB concept with two principal windows for driving and two additional windows for side observation. A TV monitor is also provided as part of the control/display arrangement and is located for maximum aid to the driver.

For scientific work, the related controls and displays are provided to the right of the right-hand station. As in MOCOM, this permits ready access to driving controls and to biomed instrumentation while observing the EVA.

Normal MOCAN ingress and egress is provided via a rear airlock and hatch, and emergency ingress/egress by an upper hatch. The airlock contains one collapsible bunk and will permit the two astronauts to don and doff either type of pressure suit within it. As in MOCOM, manipulation of exterior lunar specimens by the interior astronaut can be performed by means of the remote handling apparatus which has been provided.

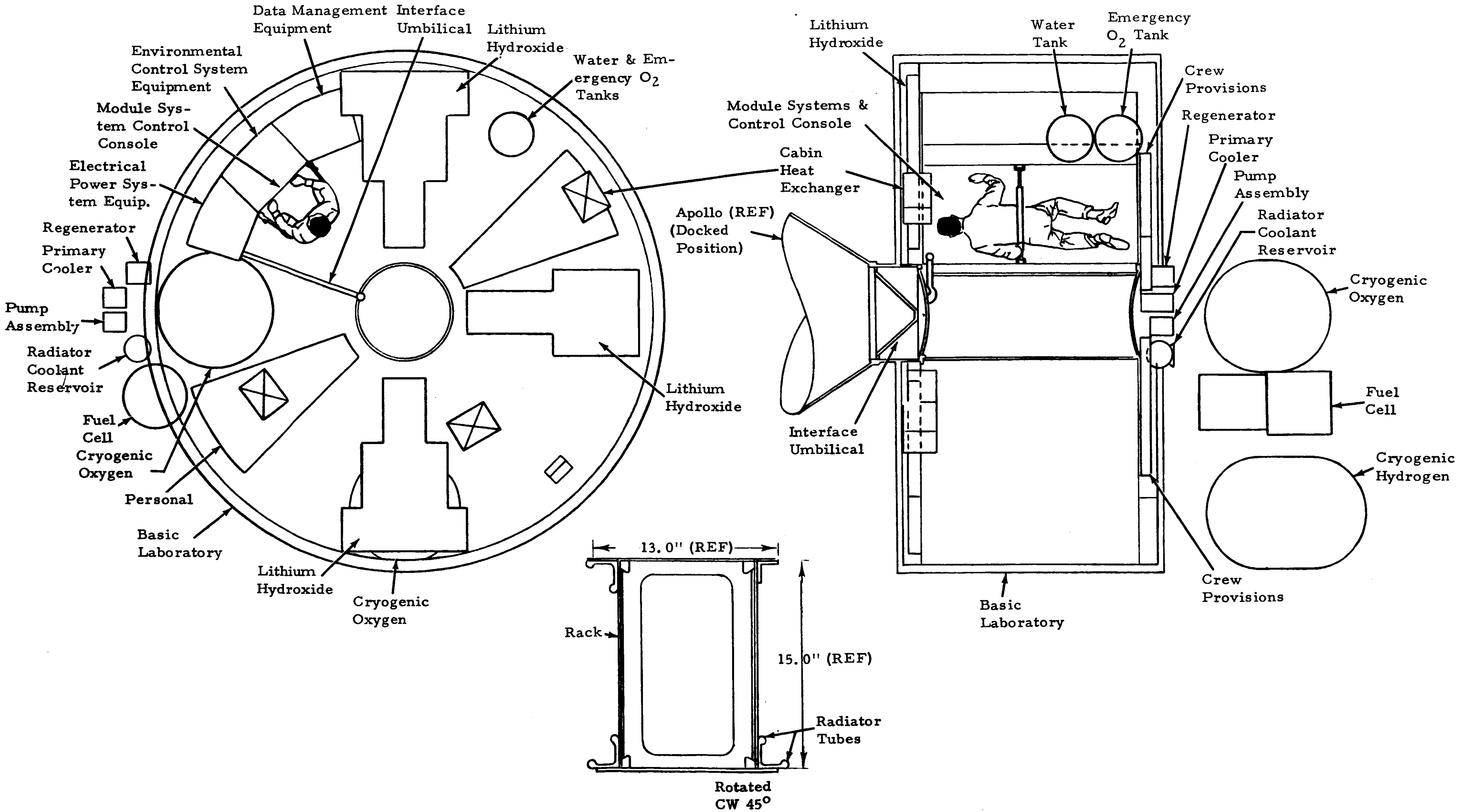


Figure 4-1 CAN Configuration

Sleeping accommodations on MOCAN are similar to those on MOCOM: one collapsible bunk is provided for the airlock and the other is in the main compartment. As in the MOLEM and MOCOM, no special eating space is provided in MOCAN. However, for waste management the additional room in MOCAN permits the canisters and relief tubes to be enclosed by a folding partition; thus, adding a degree of privacy not afforded in the other two vehicles.

The MOCAN provides ample room for storage of additional pressure suits and PLSSs required for EVA. The CAN personal hygiene equipment is adequate for the lunar mission.

4.1.4 Environmental Control

The environmental control system for the CAN is designed for a crew of three on missions of from 14 to 90 days. Considerable weight can be saved by reducing the life support system expendables and equipment needed to support three men and repackaging for two men. This approach will result in additional costs, but will provide a more compact unit with considerable weight savings over the CAN system. The CAN thermal control system must be redesigned to provide optimum radiator location above the cabin for lunar subsolar operation. Table 4-2 summarizes the stripped spacecraft definition.

4.1.5 Controls and Displays

On MOCAN, considerable freedom is afforded in laying out the control and display arrangement, since no previously existing panel structure needs to be considered. As was the case with MOCOM, this has permitted the MOCAN arrangement to follow the MOLAB guidelines. These are essentially as discussed for MOCOM and are described in Section 3.1.4.

4.1.6 Navigation and Guidance

All guidance and navigation functions needed by the CAN as an orbital lab are provided by the Apollo G&N system of the CMS. Therefore the only navigation equipment aboard the CAN is display equipment. This equipment should be deleted for surface vehicle use. The navigation and guidance equipment for the MOCAN has been adapted from MOLAB.

TABLE 4-2

STRIPPED SPACECRAFT DEFINITION

Item	Retained	Removed	Added	Modified	Comments
Basic System	X				
Radiator				X	Enlarged, relocated
RTG (Part of Electrical Power System)			X		Integrate for heating
Airlock System			X		
Suits, PLSSs			X		Extras
LUNARG Restraint			X		
Stored Water			X		18 lb
LiOH, Oxygen				X	As appropriate for this mission

4.1.7 Communications

Table 4-3 summarizes the stripped CAN communications equipment.

4.1.8 Stripped Spacecraft Summary

Table 4-4 provides a description of the stripped CAN design with the initial mass, the mass when nonfunctional items are removed, and the recommended stripped spacecraft components to be used in MOCAN vehicle design.

The only item determined to be nonfunctional was the item listed as growth at 251 kg (552 lb). This resulted in a stripped spacecraft mass of 2490 kg (5483 lb).

TABLE 4-3

COMMUNICATIONS EQUIPMENT FOR STRIPPED CAN SPACECRAFT

		Original Equipment		Comments
		Retained	Removed	
1. Communications (Equipment)				
Incremental Recorder	(Note 1)	-	-	
Data Storage Unit	(Note 1)	-	-	
PCM Unit (2 ea)		(1 ea)	(1 ea)	Only one PCM unit is required.
Equipments Data Panel	(Note 1)	-	-	
Audio Control Center (2 ea)		(1 ea)	(1 ea)	Only one Audio Control Center is required.
Intercom Head Set (2 ea)		x		
Signal Conditioner		x		
Control Box	(Note 1)	-	-	
Experiment Sequences	(Note 1)	-	-	
Command Decoder	(Note 1)	-	-	
Cables and Wiring		x		

Notes: (1) Information is lacking regarding this equipment.
(2) In general, this table is not representative of the CAN system. This system is interfaced with the command service module for the majority of its communications support.
(3) The basis for this table is a brief description in reference document (D2-90648-1-BAC).

The deletion of items that did not provide the required performance resulted in the retention of only the basic structure and the docking drogue. The basic structure of the spacecraft and the docking drogue were retained. The thermal coating, insulation, and meteroid bumper are removed since they are designed for 90 days instead of 14 and will be replaced with lighter items. The laboratory support rack is removed, since it will be replaced by the mobility chassis. The environmental control system is removed, since it is designed for three men instead of two. The life support expendables are removed, because they will also be increased. The communications system is removed, since it is dependent on the service module communications system and does not have complete capability. The instrumentation system, which should include the cables, is removed, since it does not perform the required functions. The power system is removed, since it has only a 1.1-kw capability and a larger one is required for the mobility system. Additionally, the electric power and conversion system is removed.

Systems replacing those systems removed from the spacecraft are discussed in detail in Section 4.3.

4.2 MOCAN CONFIGURATION

Figure 4-2 shows the MOCAN configuration. The MOCAN uses the MOLAB wheels and the Boeing CAN basic structure. The Apollo Multipurpose Mission Module (CAN) is mounted on a rectangular aluminum box beam frame and supported by four 203-cm (80-in.)-diameter metal-elastic wheels. The CAN is designed to utilize fully the volume on top of the LM-Truck and within the Spacecraft LM-Adapter (SLA).

Figure 4-3 shows the installation of the MOCAN in the required envelope aboard the LM-Truck. At LM station 316.9, the 178-in.-diameter MOCAN is tangent and clears the SLA adapter by 5 in.

The four wheels are folded and stowed underneath the MOCAN during the in-transit mission phase. The S-band antenna is folded down and stowed against the MOCAN shell.

The MOCAN vehicle is designed for the required mission range of 400 km, and a maximum average speed over the ELMS model of 10 km/hr. The reduced speed increases the required driving time to 40 hr for the 400-km range. Its high mass results in a mobility specific energy requirement of 0.585 kwh/km which contributes to a total energy requirement of 734 kwh. The performance and mass summary are shown as Tables 4-5 and 4-6.

TABLE 4-4

MOCAN STRIPPED VEHICLE DEFINITION

		lb	Initial kg (lb)	Stripped Initial Spacecraft
1.0	Structures			
	Basic Bulkheads (2)	1397	1521 (3347)	1521 (3347)
	Cylindrical Section	446		
	Hatches	50		
	Fittings & Penetrations	75		
	Thermal Coating and Insulation	136		
	Meteoroid Bumper	265		
	Docking Drogue	150		
	Box Beam	782		
	LM Adaptor Section Fittings	16		
	CAN Support Fittings	30		
2.0	Environmental Control System		206 (454)	206 (454)
	Cabin Air System	20		
	Water Evaporation	56		
	Glycol Water Exchange	27		
	O_2 System	64		
	O_2	25		
	Water Tank & Valves	10		
	Water	56		
	Radiator Ducting & Coolant	55		
	Plumbing & Fittings	24		
	CO_2 Removal	117		
3.0	Life Support		48 (106)	48 (106)
	Food	65		
	Medical & Hygiene	11		
	O_2	30		
4.0	Communications		120 (265)	120 (265)
	Incremental Recorder	25		
	Data Storage Unit	41		
	PCAR Unit (2)	92		
	Experiments Data Panel	10		
	Audio Center	11		
	Signal Conditioner	45		
	Control Box	5		
	Experiment Sequences	10		
	Command Decoder	20		
	Cables & Wiring	6		
5.0	Instrumentation	30	14 (30)	14 (30)
6.0	Power Subsystem (Housekeeping Only)		527 (1160)	527 (1160)
	Fuel Cell	264		
	Plumbing, Wiring Supports	205		
	H_2 Tank	174		
	O_2 Tank	265		
	H_2	28		
	O_2	224		
7.0	Electric Power and Conversion	121	55 (121)	55 (121)
8.0	System Growth		251 (552)	
	Subsystem	207		
	Lab Support Rack	83		
	Structure	262		
Total			2742 (6035)	2491 (5483)

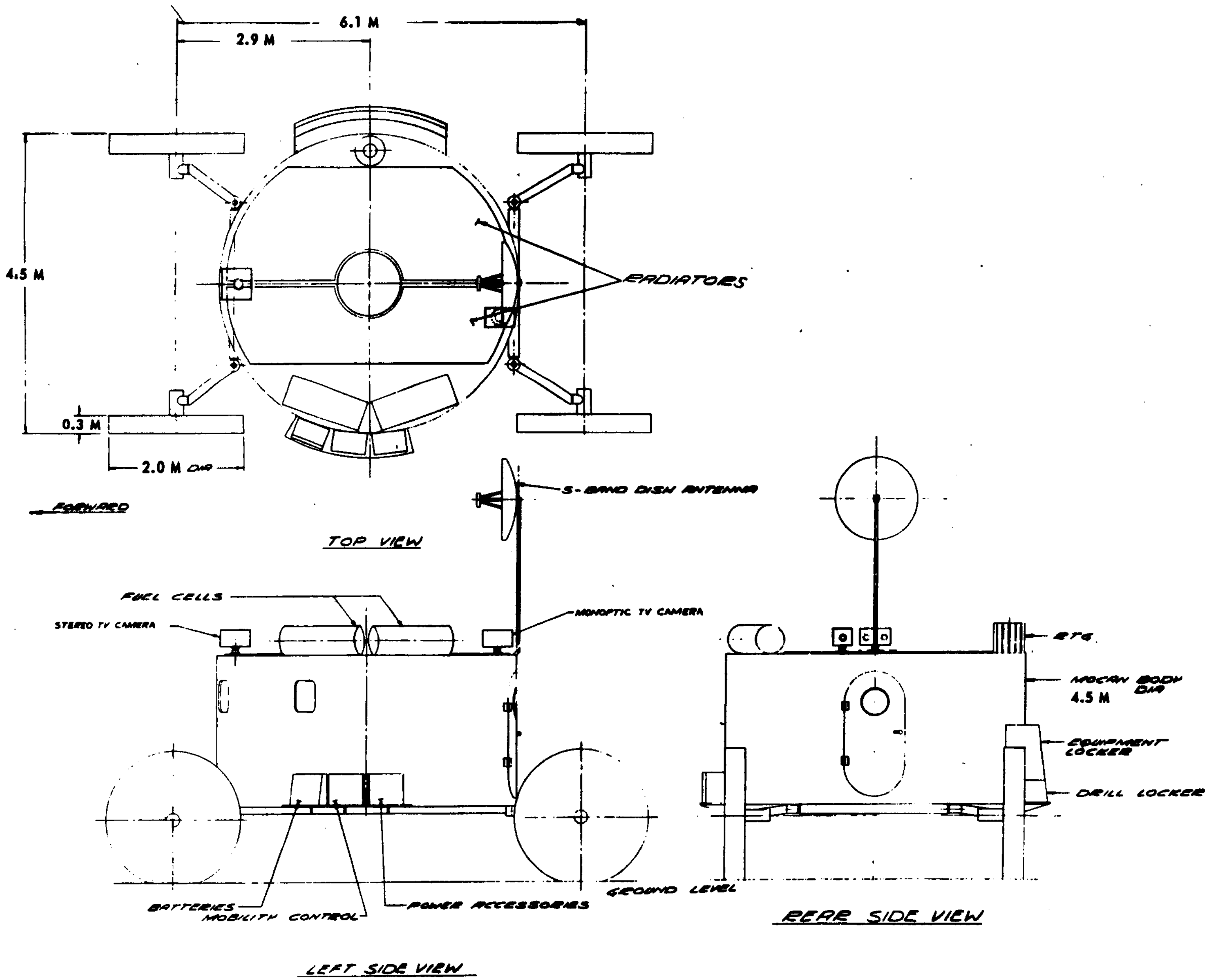


Figure 4-2 MOCAN Configuration

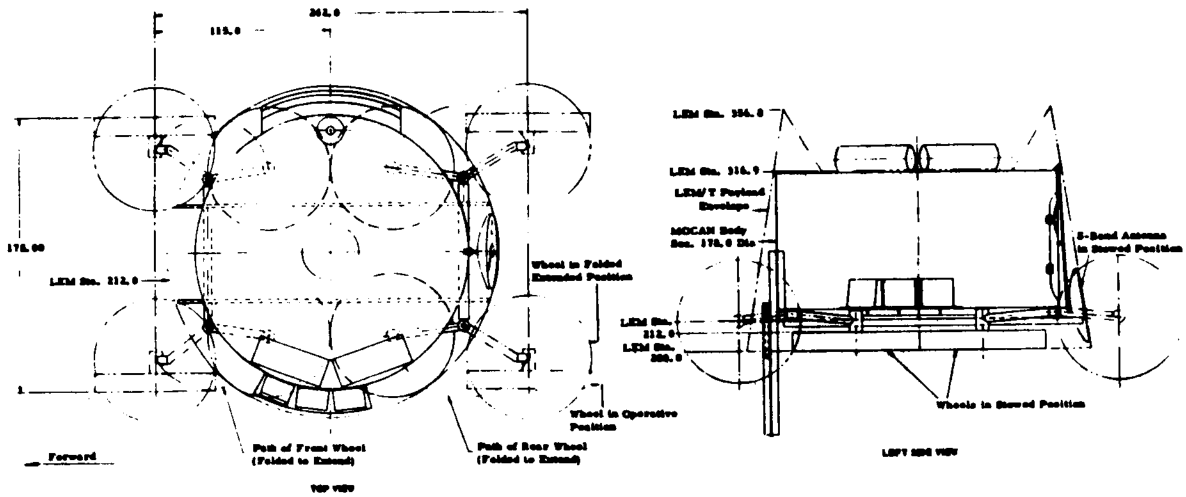


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Figure 4-3 MOCAN Installation

Since the total vehicle mass exceeds the LM-Truck delivery capability, a reduced mission to 8-day duration and 200 km range was analyzed. The results of this mission on the vehicle characteristics and performance are shown in comparison with the standard 14-day, 400-km mission.

TABLE 4-5

MOCAN PERFORMANCE SUMMARY

	14-Day Mission (+ 7-Day Contingency)	8-Day Mission (+ 4-Day Contingency)
Crew	2 Astronauts	2 Astronauts
Cargo Capability	320 kg (705 lbm)	32 kg
Range	400 km	200 km
Cabin Volume	38.2 m^3 (1350 ft^3)	38.2 m^3 (1350 ft^3)
Usable Floor Space	7.9 m^2 (85 ft^2)	7.9 m^2 (85 ft^2)
Max Average Speed (ELMS)	10.0 km/hr	10.0 km/hr
Speed Hard Surface	16.7 km/hr	23.4 km/hr
Speed Soft Soil	13.0 km/hr	13.0 km/hr
Driving Time	40.0 hr	20.0 hr
Obstacle Negotiability	60 cm	60 cm
Crevice Negotiability	146 cm	146 cm
Turn Radius	11.7 m	11.7 m
Specific Mobility Energy	0.585 kwh/km	0.526 kwh/km
Total Energy	734 kwh	435 kwh
Gross Mass	4326 kg	3990 kg

TABLE 4-6

MOCAN MASS SUMMARY

Subsystem	14-Day Mission (kg)	(lb)	8-Day Mission (kg)	(lb)
Inert				
Structure	1127	(2480)	1127	(2480)
Crew Provisions	146	(322)	146	(322)
Environmental Control System	219	(482)	218	(482)
Life Support Expendables	203	(447)	145	(319)
Controls & Displays	55	(121)	55	(121)
Navigation & Guidance	38	(84)	38	(84)
Communications	160	(353)	160	(353)
Instrumentation	91	(200)	91	(200)
Scientific Equipment	320	(705)	320	(705)
Electrical Power System (EPS)	372	(820)	347	(764)
EPS (Expendables)	277	(609)	161	(356)
Mobility	614	(1350)	580	(1275)
Tiedown & Unloading	250	(550)	204	(450)
Thermal Control	72	(157)	71.3	(157)
Cryogenic Storage	342	(840)	322	(710)
Total Delivered Mass	4326	(9520)	3990	(8778)

4.3 MOCAN SYSTEM DESIGN

4.3.1 Structure—Cabin

The approach taken for the design of the MOCAN cabin was based on the rationale that since existing hardware was not involved, the cabin structure could be designed to the specific requirements of a mobility vehicle without the necessary compromises associated with existing hardware such as for MOLEM and MOCOM. Hence, the design guidelines for MOCAN were based on MOLAB requirements and maximum use was made of the large 1350-cu ft volume available in the CAN.

The internal configuration of the preferred structure provides for a two-man side-by-side arrangement with seats, mobility controls and displays encompassing a left hand driver's station, and a right-hand navigator's station divided by a center console. The cabin contains two separate compartments; a forward crew station compartment and an aft two-man internal airlock. Both compartments are interconnected by a 30 x 60 in. door in the dividing bulkhead. Normal egress from the cabin is through the rear outer door located in the airlock. A one-man scientific work station is provided along the right side of the cabin. Equipment and storage space is located on both sides of the cabin. LH_2 and O_2 tanks are located to the rear at one side and separated from the rest of the cabin by a cryogenic bulkhead.

The upper bulkhead contains a pressure hatch covering the docking adapter which also serves as an emergency exit from the cabin. One bunk can be erected along the left side of the cabin with sufficient space for a second bunk inside the airlock. A flat floor providing 78 in. of headroom is located on top of the lower bulkhead. Storage space is provided at both sides in the airlock for spacesuits, equipment, food, and waste. Table 4-7 summarizes the weight breakdown for the preferred configuration. Figure 4-4 shows the preferred internal arrangement, and Figure 4-5 the weight and center of gravity.

4.3.2 Power System

This section describes the MOCAN power system and discusses the power system concepts. From vehicle weight considerations, an improved P&W fuel cell design is recommended and used for mass and vehicle performance estimates.

TABLE 4-7

MOCAN STRUCTURE MASS

Structure	Mass (lb)	kg
Cylindrical section including longerons	380	173
Forward and aft bulkheads including beams	1146	520
Floor	100	45
Docking adapter	50	23
Fittings and penetration	74	34
Cryogenic bulkhead	140	64
Crew station (Includes instruments, controls, and seats)	60	27
Display panels	90	41
Scientific station	60	27
Airlock (bulkhead, doors, hardware)	200	91
Meteroid shielding	180	82
Total	2480	1126

The major mission and system restraints and power requirements are as follows:

1. The power system shall be capable of being stored on the lunar surface in a standby mode for at least six months.

2. The power system shall be designed for a 14-day operating capability plus a 7-day emergency survival requirement.

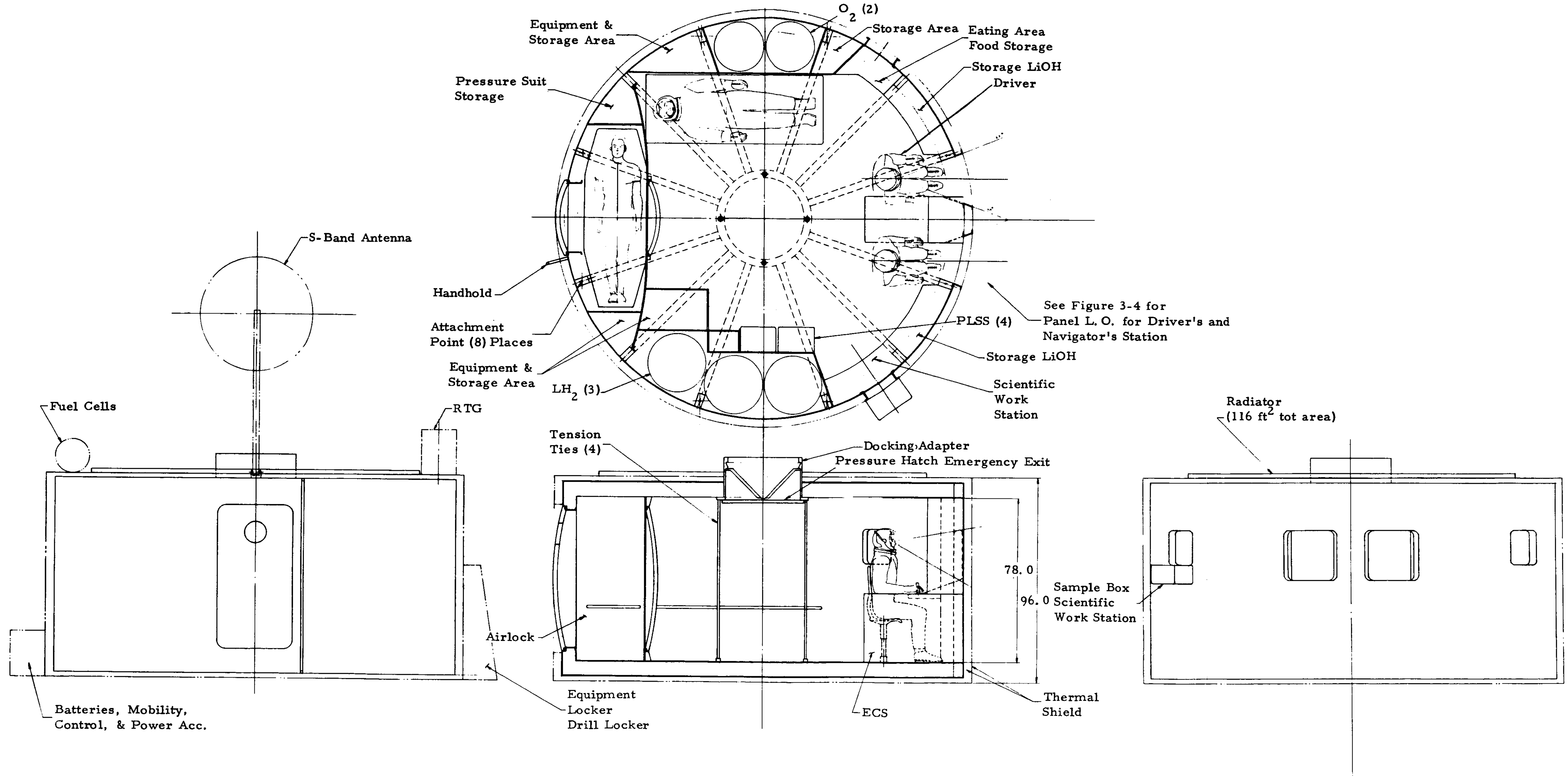


Figure 4-4 MOCAN Cabin Phase I Study

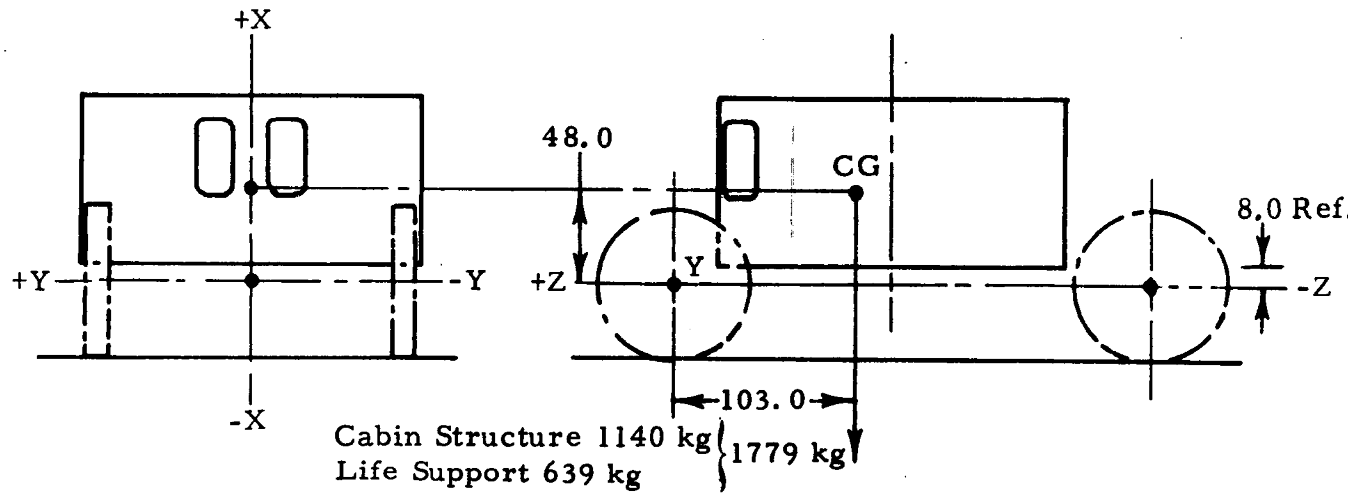


Figure 4-5 Mass and CG for MOCAN Cabin System

3. The power system shall provide the necessary tankage and controls for the life support oxygen. The life support oxygen requirement is 107 kg for the 14-day operation and the 7-day survival.

4. The power and energy requirements are summarized in Table 4-8.

The power system provides electrical power during the inflight, debarking, lunar storage, and scientific mission phases. The electrical power requirements vary from 50 w during the lunar storage phases at nighttime to a maximum continuous demand of 9.56 kw during the scientific mission phases for the 14-day mission or 7.75 kw for a modified 8-day mission. The short-duration (< 1 minute) peak power demand is approximately 10 kw. The power system also furnishes thermal power for the lunar storage phase thermal control and provides storage for 236 lb of life support.

Figure 4-6 shows the power system block diagram. This system consists of five major subsystems: primary power utilizing two P&W fuel cells sized specifically for the MOCAN requirements; secondary power consisting of rechargeable batteries; auxiliary power, utilizing an RTG; cryogenic storage and supply, consisting of two cylindrical hydrogen tanks, two spherical oxygen tanks, cryogens, and controls; and power conditioning and distribution.

The MOCAN power system operation and interfaces are the same as those for the MOLEM power supply. The subsystem designs, except the cryogenic subsystem, are also the same as for MOLEM. For MOLEM power system and subsystem descriptions, see Section 2.3.2.2.

The cryogenic storage and supply subsystem operations and designs are similar to MOLEM. The design requirement differences are as follows:

	MOCAN (14-Day Mission)	MOCAN (8-Day Mission)	MOLEM
No. of H_2 Tanks	2		1
Total H_2 Requirement	32 kg	17 kg	30 kg
Total Fuel Cell O_2 Requirement	245 kg	143 kg	234 kg

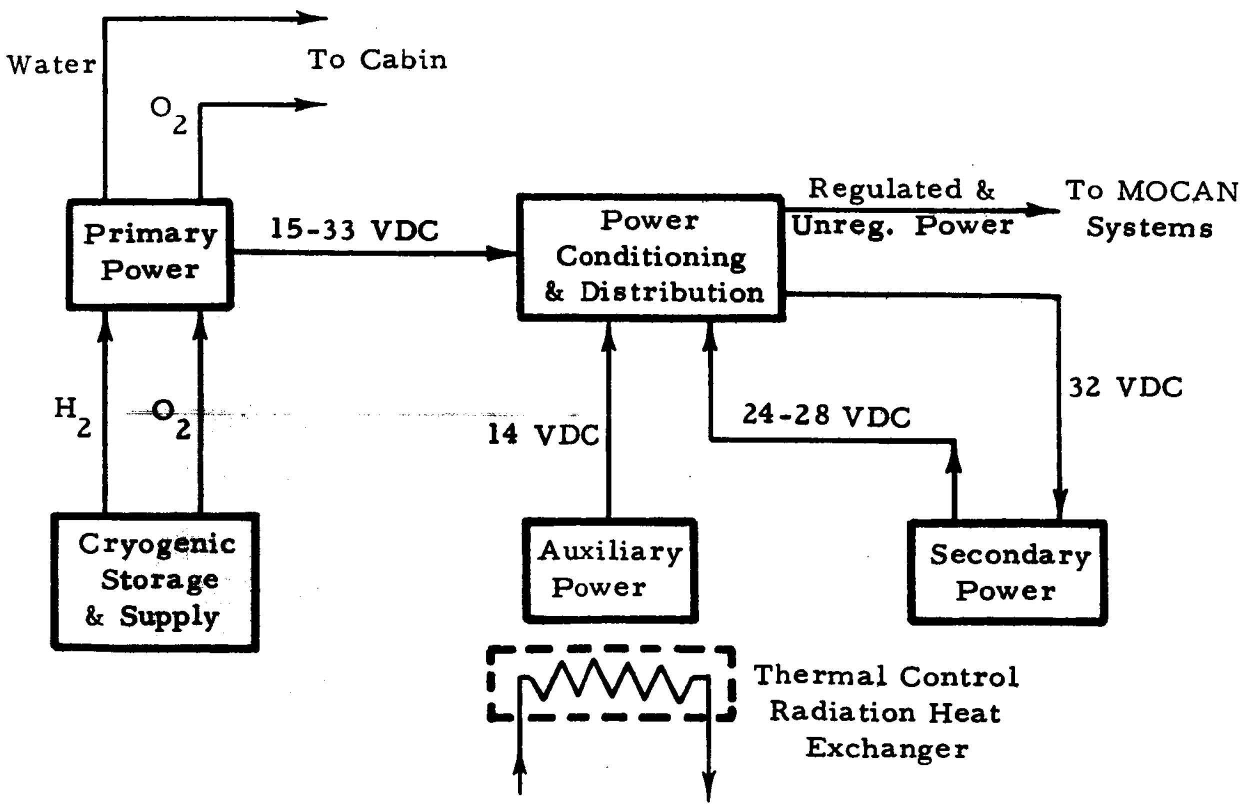


Figure 4-6 MOCAN Power System Block Diagram

TABLE 4-8

MOCAN POWER AND ENERGY SUMMARY

	14-Day Mission	7-Day Emergency Extension	8-Day Mission	4-Day Emergency Contingency
1. <u>Mobility</u>				
a. Max Continuous Power	8.56 kw	0 0	6.75 kw	0
b. Peak Power	10 kw	0 0	10 kw	0
c. Avg Power & Duty Cycle	5.85 kw x 40 hr	0	5.26 kw x 20.0 hr	0
d. Energy	234 kwh	0 0	104 kwh	
2. <u>Experiments</u>				
a. Avg Power & Duty Cycles	0.5 kw x 126 hr 0.25 kw x 40 hr	0 0	0.5 kw x 126 hr 0.25 kw x 40 hr	
b. Energy	75 kwh	0	75 kwh	
3. <u>Astrionics</u>				
a. Comm Avg Power & Duty Cycle	0.412 kw x 336 hr	0.15 kw x 100 hr	0.412 x 192 hr	0.15 kw x 100 hr
b. Navigation Avg Power & Duty Cycle	0.141 kw x 63 hr	0	0.141 x 29 hr	0
c. Energy	148 kwh	15 kwh	83 kwh	15 kwh
4. <u>Cabin & Thermal</u>				
a. Energy (100% duty cycle	175 kwh	90 kwh	100 kwh	60 kwh
5. <u>Total Load Energy</u>	629 kwh	105 kwh	360 kwh	75 kwh

Table 4-9 summarizes the power system mass for a 14-day mission. As shown in this table, the total power system mass, including fuel cell expendables, is 1030 kg for a 14-day mission or 831 kg for an 8-day mission. The oxygen tanks are also sized to store 107 kg of oxygen for life support.

TABLE 4-9

MOCAN POWER SYSTEM WEIGHT
(APOLLO P&W FUEL CELLS)

	Two Improved P&W Fuel Cell Assemblies			
	14 day mission		8 day mission	
	(kg)	(lb)	(kg)	(lb)
I. **Primary Power**	279	615	254	559
II. **Secondary Power**	57	125	57	125
III. **Auxiliary Power**	18	40	18	40
IV. **Power Cond. & Dist.**	18	40	18	40
V. **Cryogenic Excluding Using Fluids**	381	840	322	710
Total Excludes Usable Fluids	754	1660	669	1474
VI. Usable Fluid for Fuel Cells				
H_2	32	70	19	41
O_2	245	539	143	315
Total Includes Usable Fluids	1030	2269	831	1830

4.3.3 Mobility

The MOCAN mobility system is very similar to the MOLAB mobility concept. The concept utilizes a folded wheel configuration to achieve stowage within the LM-Truck envelope. Remote deployment is accomplished during unloading. Major elements of the system are: (1) two pairs of 203-cm (80-in.) diameter, 30.5-cm (12-in.) wide, metal elastic wheels constructed of titanium, aluminum, and nonmetallic treads and side walls (the front pair being slightly stiffer than the rear), (2) two pairs of suspension and wheel deployment mechanisms consisting of axis cranks, torsion bars, deployment drives, and dampers (the front pair being slightly stiffer and shorter than the rear), (3) two traction and steering drive assemblies located inside the front wheel hubs featuring a hermetically sealed DC series traction motor, nutator transmission, two-stage brake systems, and a dynamically sealed steering actuator, (4) two traction drive assemblies similar to those in Item (3) without steering actuators located inside the rear wheel hubs, (5) a chassis frame constructed of welded aluminum beams with box type cross sections sized to distribute concentrated loads to the tiedown points and the wheel supports, and (6) a mobility control unit which distributes controlled power to the drive and steering motors. The weight summary is contained in Table 4-10.

TABLE 4-10

MOBILITY SUBSYSTEM MASS SUMMARY

	14-Day Mission (kg)	14-Day Mission (lb)	8-Day Mission (kg)	8-Day Mission (lb)
TDM Assembly (4)	159	350	148	325
Traction Assembly (4)	191	420	182	400
SDM Assembly (2)	20	45	18	40
Suspension Assembly	89	195	84	185
Controls and Cabling	43	95	41	90
Chassis	111	245	107	235
Total	613	1350	579	1275

4.3.4 Life Support—Environmental Control

The MOCAN life support system was defined in the same manner as were the MOCOM and MOLEM. Figure 4-7 presents the results of an ingress/egress trade-off conducted for MOCAN. As with other vehicles but even more so for MOCAN, the use of an airlock with pump results in weight savings more than adequate to justify their use in the spacecraft. The thermal control system for the MOCAN is identical to that of the MOCOM except for additional insulation required to limit the vehicle heat leak out to 149 w compared to the 60 w of MOLEM. The ECS schematic is identical to MOLEM's except for a slightly different arrangement of components and addition of zone coolers and blowers in the cabin.

Life support system mass, cost and development schedule estimates for MOCAN are presented in Table 4-11.

4.3.5 Communications

Table 4-12 contains an equipment list of the CAN communications equipment plus the added equipment necessary to meet system requirements. As indicated, the total mass of this system is 224.1 kg. The Bendix MOLAB communication subsystem design has been substituted to reduce overall vehicle system mass. A mass breakdown of this design is given in Table 4-13.

The MOLAB design communications system will provide the following services to the MOCAN mission:

1. Voice communication between earth and MOCAN via S-band and via VHF-AM relay through the Apollo command module; between MOCAN and the command module via VHF-AM; and between MOCAN and the astronaut via VHF-AM

2. PCM telemetry from MOCAN to earth via S-band and emergency PCM telemetry relay via VHF-AM to the command module

3. Television, scientific data, and analog data (FM) from MOCAN to earth vis S-band

4. Command data from earth to MOCAN via S-band.

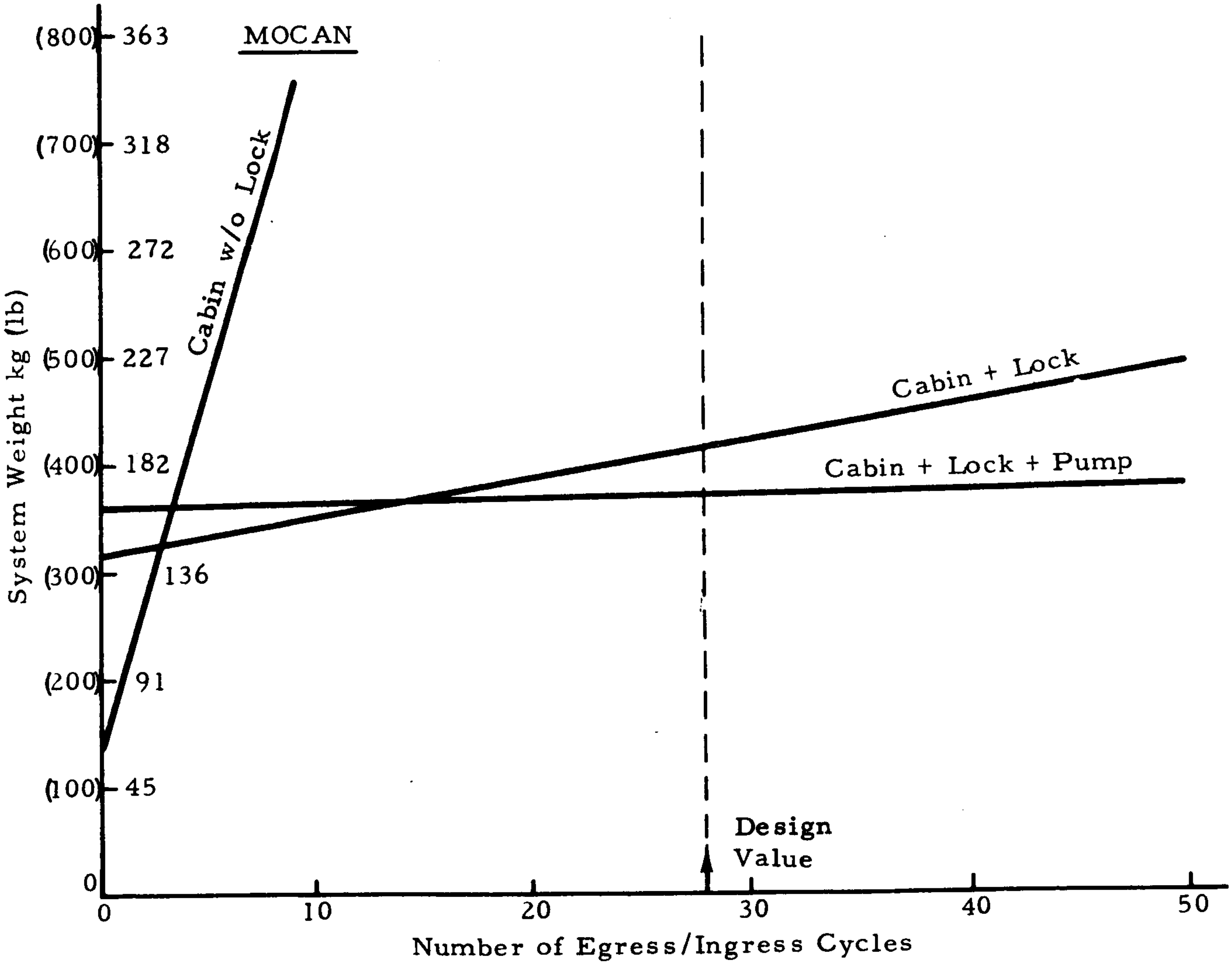


Figure 4-7 MOCAN Ingress/Egress Trade-Off

TABLE 4-11

MOCAN LIFE SUPPORT SYSTEM DATA

	Mass (kg)		Mass (lb)	
Environmental Control System				
Suit and Cabin Atmospheric Conditioning	68		150	
Radiator Cooling System	87		192	
Oxygen Supply and Pressure Control	23		50	
Water Management	16		35	
Controls Wiring and Supports	25		55	
		219		482
Crew Provisions				
Suits and Suit Accessories	59		130	
Portable Life Support System	42		92	
Waste Management	9		20	
Food Preparation and Personal Hygiene	9		20	
Emergency Equipment and Accessories	27		60	
		146		322
Misc Thermal Control				
Cabin Insulation Weight	44		97	
Storage Phase Heating System	27		60	
		71		157
Expendables				
Lithium Hydroxide and Charcoal	88		193	
Oxygen	107		236	
Water	8		18	
		203		447
ECS—Life Support Subsystem Total		639		1408

TABLE 4-12

MOCAN INITIAL STRIPPED SPACECRAFT SYSTEM COMMUNICATIONS

Equipment Description	Equipment Origin New	Equipment Origin CAN	Mass (lb)	Mass (kg)
1. Antenna Subassemblies			(85.6)	(38.9)
1.1 S-Band Directional Antenna				
1.1.1 Reflector (2 ft) Structure	X		12.0	5.4
1.1.2 Dipole Feed and Support	X		2.2	1.0
1.1.3 Rotary Joints	X		5.8	2.6
1.2 Antenna Drive Mechanism				
1.2.1 Pedestal, Yoke and Frame	X		4.0	1.8
1.2.2 Motors Drives and Take-offs	X		1.6	0.7
1.2.3 Cables	X		3.0	1.4
1.2.4 Servo Amplifier Unit	X		2.0	0.9
1.2.5 Tracking Receiver Unit	X		5.0	2.3
1.3 S-Band Omni Antenna	X		4.4	2.0
1.4 S-Band Inflight Antenna (2 ea)	X		3.3	1.5
1.5 S-Band Antenna Switch	X		3.0	1.4
1.6 VHF Omni Antenna (Whip 10 ft long)	X		4.3	2.0
1.7 VHF Inflight Antenna (2 ea)	X		3.3	1.5
1.8 Lunar Stay Antenna (S-Band)	X		10.6	4.8
1.9 VHF Antenna Switch	X		1.1	0.5
1.10 Sense Antenna Direction Finding	X		2.0	0.9
1.11 Loop Antenna (Direction Finding)	X		18.0	8.2
2. RF and Modulation Equipment (S-Band)			(62.0)	(28.1)
2.1 Diplexer and Power Amplifier	X		31.0	14.1
2.1.1 Power Amplifier Tubes (2 ea)				
2.1.2 Input Isolator (1 ea)				
2.1.3 Output Isolator (1 ea)				
2.1.4 Power Supplies (2 ea)				
2.2 Unified S-Band Equipment	X		31.0	14.1
2.2.1 Receiver(s)				
2.2.2 Exciters (2 ea)				
2.2.3 PM Modulators (2 ea)				
2.2.4 FM Modulator (1 ea)				
2.2.5 Power Supply				

TABLE 4-12 (CONT.)

3.	RF Modulation Equipment (VHF)	X		(21.5)	(9.8)
3.1	Diplexer Assembly	X		3.5	1.6
3.2	Transceiver AM (No. 1)	X		11.0	5.0
3.3	Transceiver FM (No. 2)	X		7.0	3.2
4.	Additional Modulation Support Equipment			(32.2)	(16.0)
4.1	Premodulation Processor	X		15.0	6.8
4.2	Audio Center		X	5.2	2.4
4.2.1	Astronaut Headsets				
4.2.2	Astronaut Microphones				
4.3	Communications Control Panel	X		15.0	6.8
5.	Data Handling Equipment			(171.1)	(77.7)
5.1	PCM 1/M Encoder		X	46.0	20.9
5.2	Central Timing Equipment	X		6.5	3.0
5.3	Data Sub and Processor	X		30.0	13.6
5.4	Manual Data Input Unit	X		15.0	6.8
5.5	Signal Conditioner Unit		X	45.0	20.4
5.6	Data Distribution Panel	X		1.5	0.7
5.7	Data Modulators	X		2.0	0.9
5.8	Mission Recorder, Incremental		X	25.1	11.4
5.9	Emergency Key Unit				
5.10	Teleprinter Unit (Future Capability)				
6.	Television Equipment			(68.0)	(30.9)
6.1	Forward TV Camera (Stereo Pr.)				
6.1.1	TV Cameras (2 ea)	X		16.0	7.3
6.1.2	Azim-Elev Control	X		4.0	1.8
6.1.3	Combiner-Synchronizer	X		1.0	0.5
6.1.4	Illuminator (2 units)	X		5.0	2.3
6.2	Rear View Camera Assembly	X		17.0	7.7
6.3	Internal TV Camera Installation (2 units)	X		16.0	7.3
6.4	VHF TV Receiver	X		2.0	0.9
6.5	TV Monitor Unit	X		7.0	3.2
7.	Remote Control Support Equipment			(13.0)	(5.9)
7.1	Up Data Link Decoder	X		10.0	4.5
7.2	Direction Finder Unit	X		3.0	1.4
8.	Electrical Provisions			(37.3)	(16.9)
8.1	Electrical Wiring	X		26.1	11.8
8.2	Coaxial Cables	X		5.2	2.4
8.3	Connectors	X		6.0	2.7
	TOTAL WEIGHT			493.7	224.1

TABLE 4-13

MOLAB COMMUNICATIONS SUBSYSTEM MASS SUMMARY

	Mass (lb)	Mass (kg)
S-band directional antenna - RF unit	10	5
S-band directional antenna - servo and drive	17	8
S-band directional antenna - yoke and support	10	5
Omni antennas - S-band and VHF	11	5
S-band antenna switch	3	1
Diplexer and power amplifier	17	8
Unified S-band equipment	30	14
Premodulation processor	14	6
PCM TM Equipment	14	6
Signal conditioners	31	14
Up-link data decoder	5	2
Central timing equipment	10	5
VHF-AM transceiver	7	3
Loop antenna	18	8
Sense antenna	2	1
Direction finder	3	1
Audio center	10	5
Manual data input unit	15	7
Data processor and data bus	30	14
Mission recorder	22	10
Signal distribution and test panel	10	5
Communications Subtotal	289	131
Forward camera unit	26	12
Rear camera unit	17	8
Internal cameras (3)	12	5
TV monitor	7	3
Signal distribution and test panel	2	1
Television Subtotal	64	29
System Total	353	160

In addition, the system provides for onboard data processing for performance and trend analysis, and operational computations; automatic direction finding with respect to the LFM; and recording of all data sampled during the mission.

The basic considerations of the design are: compatibility with the Apollo Deep Space Stations and ground network—primarily through the use of the unified S-band system and the command and telemetry formats—and maximum utilization of the Apollo spacecraft equipments.

The S-band communication modes indicated were chosen for the MOCAN vehicle considering the various phases of its mission. Of particular significance are the PCM data, normal voice-PCM data, normal voice-PCM data-television, the television-PCM data modes which correspond to the normal unmanned storage and remote control, and the manned local and remote control phases.

The present Apollo command system transmits 30 information bits per command, each containing 5 sub-bits, at a rate of 1000 sub-bits per second, thus allowing better than six 30-bit command messages per second. Eight bits are allotted to function select, which allows for 256 distinct commands.

Review of the MOCAN command requirements indicates a sufficient command capacity in the Apollo system to handle the MOCAN commands (154) and that the command information rate is consistent with the Apollo command rate.

The Apollo command system uses a validation word check technique which involves counting the information bits decoded and transmitting this count via the PCM telemetry. The procedure enables each command to be verified, if required, or only validated, as in the case of remote control where the added delay for verification retransmission cannot be tolerated.

The TV system is the "eyes" of the MOLAB during remote control operation and the visual monitor of the astronauts and of specific MOCAN operations for the earth control center during manned operation. Remotely or manually, the appropriate camera can be selected on the TV control panel and the power and signal are correctly routed by the signal distribution and test panel.

During the unmanned phase of operation, the TV signals will be sent to the communication signal distribution and test panel and, when manned, to the TV monitor also.

The forward camera unit is a stereo unit and includes these features: SEC vidicon cameras (2), an illumination source, a synchronizer, and an azimuth and elevation control. Using a stereo baseline of 0.2 m (8 in.), the cameras view ahead of the vehicle with the aid of the artificial illumination source. The synchronizer times the camera exposure with the pulsed light source and combines the output from the two cameras before the signal is sent to the signal distribution and test panel. The azimuth and elevation control changes the camera attitude to a manual setting or changes the setting automatically when slaved to the wheels.

The data format throughout the system will be analog and all cameras will use an SEC (secondary electron conduction) vidicon, which has a sensitivity of approximately 3×10^{-4} ft-c. Each raster will consist of 500 lines, noninterlaced. With a permissible bandwidth of 500 kc, the resultant frame rate is 2 frames/sec when a 4:3 aspect ratio is used.

By remote or manual control, the camera attitude can be varied $\pm 65^{\circ}$ in azimuth and -70° in elevation, and the camera field of view can be made $50^{\circ} \times 37^{\circ}$, $30^{\circ} \times 22^{\circ}$, or $5^{\circ} \times 4^{\circ}$. The azimuth variation permits observations from -90° to $+90^{\circ}$ when the 50° horizontal field of view is used. A declination of -70° allows the remote operator to look downward where the debarking ramp will be deployed and to observe the area immediately in front of the vehicle during debarkation or remote operation on the surface.

An exposure of 3 msec or less will minimize image smear when the camera is trained on the surface ahead of the vehicle and the vehicle velocity is approximately 5 km/hr. For lesser velocities, smearing will be even less.

4.3.6 Navigation System

Since the CAN did not contain any navigation equipment, the Bendix MOLAB system was used. Table 4-14 summarizes the MOLAB navigation subsystem equipment.

TABLE 4-14

MOCAN NAVIGATION COMPONENT CHARACTERISTICS

Item	Retained	New	Estimated Values Mass (kg)	Power (w)	Volume (in. ^{3})
1. Periscopic Theodolite		X	5	1	2000
2. Static Inclinometer		X	2	10	200
3. Directional Gyro		X	2	5	55
4. Vertical Gyro		X	2	4	65
5. Navigation Computer		X	5	30	200
6. Signal Distribution and Test Panel		X	5	5	800
7. Display and Control		X	14	40	800
8. Odometer		X	4	10	500
Total			38	105	4620

The navigation system is composed of equipment for manually establishing selenographic position and heading at discrete points throughout the mission (position fix) and automatically dead-reckoning between these points. This approach utilizes the skill and knowledge of the astronaut in precision measurements and frees him during the traverse to perform the vehicle driving tasks. The system block diagram is shown in Figure 4-8.

Position fix is a technique whereby the vehicle, while stopped, is referenced to measurements of known celestial body positions or mapped surface features. These measurements are made with a periscopic theodolite and static inclinometer using available ephemeris data and a time indicator.

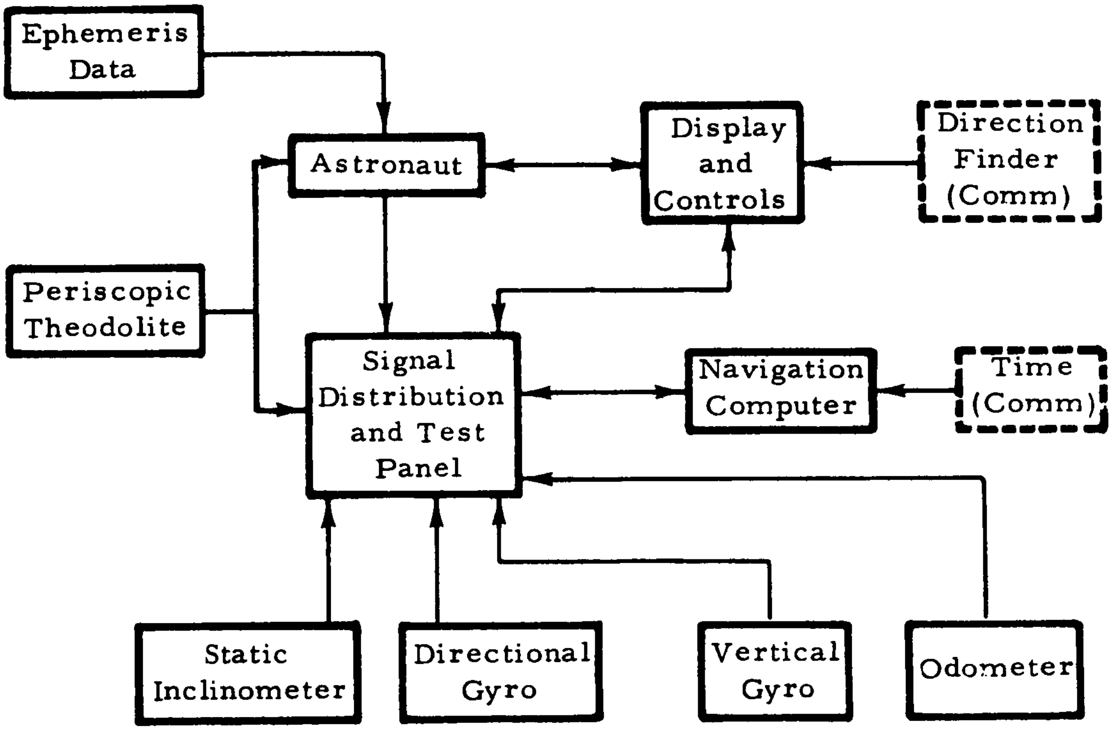


Figure 4-8 MOCAN Navigation Subsystem Block Diagram

In the dead-reckoning mode, the vehicle parameters are determined with respect to a previously known position through measurement of vehicle motion. These measurements are made using a directional gyro, a vertical gyro, and odometers attached to the four wheels of the vehicle.

To assist in the return to LM, a direction finding system is used on MOLAB to sense a transmitted signal from LM. A line-of-sight homing range (10 km) is assured, with ground wave propagation possibly providing increased range.

The design of the navigation periscopic theodolite is based on celestial sighting submarine periscopes. The accuracy of the systems, 6 sec of arc for visual readout and 15 sec for electrical readout, is within the state of the art for theodolite systems. The elevation range of -10° to $+75^{\circ}$ permits viewing of the navigation stars approximately 45° above the horizon and terrain features in the vicinity of MOLAB. The azimuth capability of 360° allows for ease in target acquisition. The field of view and magnification are typical of current navigational sighting instruments.

The inclinometer is composed of two identical assemblies joined at a right angle. Each contains a spirit level which can be rotated about an axis perpendicular to its length until the bubble is centered. Attached to the spirit level and colinear with the axis of rotation is a digital encoder which transmits the attitude information to the computer.

The directional and vertical gyros are designed so that their gimbal and spin axis bearings are precision antifriction instrument type miniature ball bearings. This design provides maximum reliability and resistance to boost and landing accelerations. A ball-bearing directional gyro which has a 0.25°/hr rms random drift rate in an earth 1-g environment can be approximated by an effective 0.045°/hr drift rate on the moon. The directional gyro alignment error of 0.12° is due to the synchro null error and heading fix error. The pitch and roll erection loops of the vertical gyro are operated continuously; thus, the effect of free drift of the gyro is limited.

The odometer system utilizes four tachometers, one on each wheel. The computer selects the least-slip wheel, lowest output odometer, as the distance-traveled sensor. Through calibration of the system for different soil conditions, the error of the odometer is reduced to an estimated 1% of the distance traveled.

The total navigation system error is a function of position fix definition (absolute or relative), the vehicle velocity, and heading, and the distance traveled from the point of the position fix.

The maximum scientific site separation of the representative mission is 37 km. In determining the maximum dead-reckoning error between scientific stations during a normal operation, an additional 20% was added for obstacle avoidance, yielding a 45-km distance traveled. The total error in position after traveling this distance is 1.1 km, including the absolute position fix error.

In navigating to a specific destination defined by a set of selenographic coordinates, dead-reckoning over the maximum site separation distance will place the MOCAN within 1.5 km of the destination. This total error results from a MOCAN position error (1.1 km) and the uncertainty of the destination position (assumed to be 1.0 km from the expected available maps). From this distance of 1.5 km, a destination landmark (if present) of 0.4 m per side can be visually resolved (1 arc min).

Homing on the LM vehicle can be accomplished by the RF LM beacon at a range of at least 10 km. This distance, a function of the undetermined lunar soil parameters, may extend to 80 km. The navigation accuracy of an unmanned dead-reckoning operation (an extreme condition) is adequate to place the MOCAN within the 10-km homing range from any point within the mission traverse at reasonable vehicle velocities. The maximum MOCAN-LM separation by a path retrace route on the Beathe traverse is 194 km (162 + 20%). A traverse of this length at a 3-km/hr velocity produces an error of approximately 9.2 km. This position uncertainty places the MOCAN within the minimum LM homing range.

4.3.7 Tiedown and Unloading

The MOCAN can be unloaded automatically or manually by means of flanged wheels attached to the MOCAN main axles which allow the vehicle to be rolled down a pair of rails. The rails are 21 ft long (from forward hinge point) and 60 in. apart. The vehicle can be rotated 360° on a turntable and may be unloaded over a 343° range in azimuth. The unloading rails are folded into three sections and are stowed in front of the MOCAN and on the side of the LM-Truck. The total mass of the tiedown and unloading system is 250 kg for the 14-day mission version and 204 kg for the 8-day mission version.

4.4 MOBILITY AND PERFORMANCE CAPABILITY

4.4.1 Mobility Performance

The MOCAN mobility assumptions used were:

1. Soil: ELMS 50/50
2. Wheel Diameter: 2.03 m
3. Wheel Width: 0.305 m
4. Ground Pressure: 1.0 psi
5. I_{OPT}: 0.1
6. Hysteresis Loss: 0.06
7. A/L: 0.5.

Table 4-15 shows the MOCAN mobility performance data.

4.4.2 Scientific Mission Performance

The MOCAN scientific mission performance characteristics are:

1. Scientific equipment location - lockers outside of cabin
2. Scientific equipment weight - 320 kg
3. Scientific equipment energy - 75 kwh
4. Total Range - 400 km (for 14-day mission)
   200 km (for 8-day mission)
5. Maximum radius of operation — 80 km.

4.4.3 Degraded Mode Analysis Summary

Table 4-16 summarizes the major degraded modes which are capable of enhancing MOCAN mission success and crew safety.

TABLE 4-15

MOCAN VEHICLE PERFORMANCE DATA

Parameter	MOCAN Vehicle	
	14-day mission	8-day mission
Mass	4322 kg	3985 kg
Obstacle Negotiability	60 cm	70 cm
Crevice Negotiability	140 cm	157 cm
Slope Negotiability	35^{o}	35^{o}
Draw Bar Pull	793 lb	733 lb
Maximum Speed (Hard Surface Level)	16. 7 kw/hr	16. 7 kw/hr
Average Speed	10. 0 km/hr	10. 0 km/hr
Static Stability	50^{o}	52^{o}
Maximum Vehicle Continuous Power	9. 56 kw	7. 75 kw
Specific Energy	0. 58 kwh/mi.	0. 526 kwh/mi.
Static Turn Radius	38. 5 ft	38. 5 ft

TABLE 4-16

MOCAN MAJOR DEGRADED MODE CAPABILITIES
FOR MISSION CONTINUATION AND EMERGENCY RETURN
DURING THE 14-DAY MANNED MISSION PHASE

Component or Equipment	Backup Modes	
	Mission Success	Emergency Return
Cabin Compartments	(x)	x
Heat Rejection (Radiators & Water Boilers)	(x)	x
Oxygen Supplies	(x)	x
Hydrogen Supplies	(x)	x
Traction Drive Mechanisms	x	xx
Steering Drive Mechanisms	x	x(x)
Brakes (Elect and Elect/Mech)	x	xx
Suspension (Wheel and Arm Assemblies)	(x)	x
Fuel Cells (Primary Power)	(x)	x
Power Conditioning and Distribution	(x)	x
TV Cameras (external)	x	xx
VHF (EVA)	x	xx
S-band Earth Links	x	xx
Navigation	(x)**	xx
Unloading	x*	NA

*Manual vs automatic, and TV camera redundancy.
**Highly dependent upon IMU.

x - Effective backup mode exists.
(x) - Degraded backup mode exists - mission may be continued with serious limitations.
xx - Multiple backup for emergency return.

In the Mission Success column, an x has been used to delineate those equipment items (or groups) which have effective backup to allow mission continuation in the event of a single item failure. The (x) identifies those equipment items which have backup of a very limited nature, to allow the mission to continue, but with significant limitations on operating range, radius, or total time on the lunar surface.

In the Emergency Return column, an x delineates degraded mode capabilities for safe vehicle return from up to 80-km radius. Where a given function has more than one degree of crew safety backup, an xx has been shown.

4.5 SENSITIVITY DATA

4.5.1 Mission Duration and Total Range

Figure 4-9 presents the total vehicle mass sensitivity to changes in mission duration and total range. The curves show two approaches to obtaining a MOCAN of nearly 3859 kg:

1. Reduce the mission duration to 7.5 days.

2. Reduce the mission duration to 8.0 days and the range to 233 km.

The assumptions used in the analysis were:

1. The power system used would have constant power capability.

2. Mission duration requirement includes capability for 7-day contingency.

3. Scientific equipment power is constant at 75 kwh for all mission variations.

4. There would be no driving on either the first or the last mission day.

5. In determining the reduced performance, the range is reduced proportionally with the reduction in mission duration.

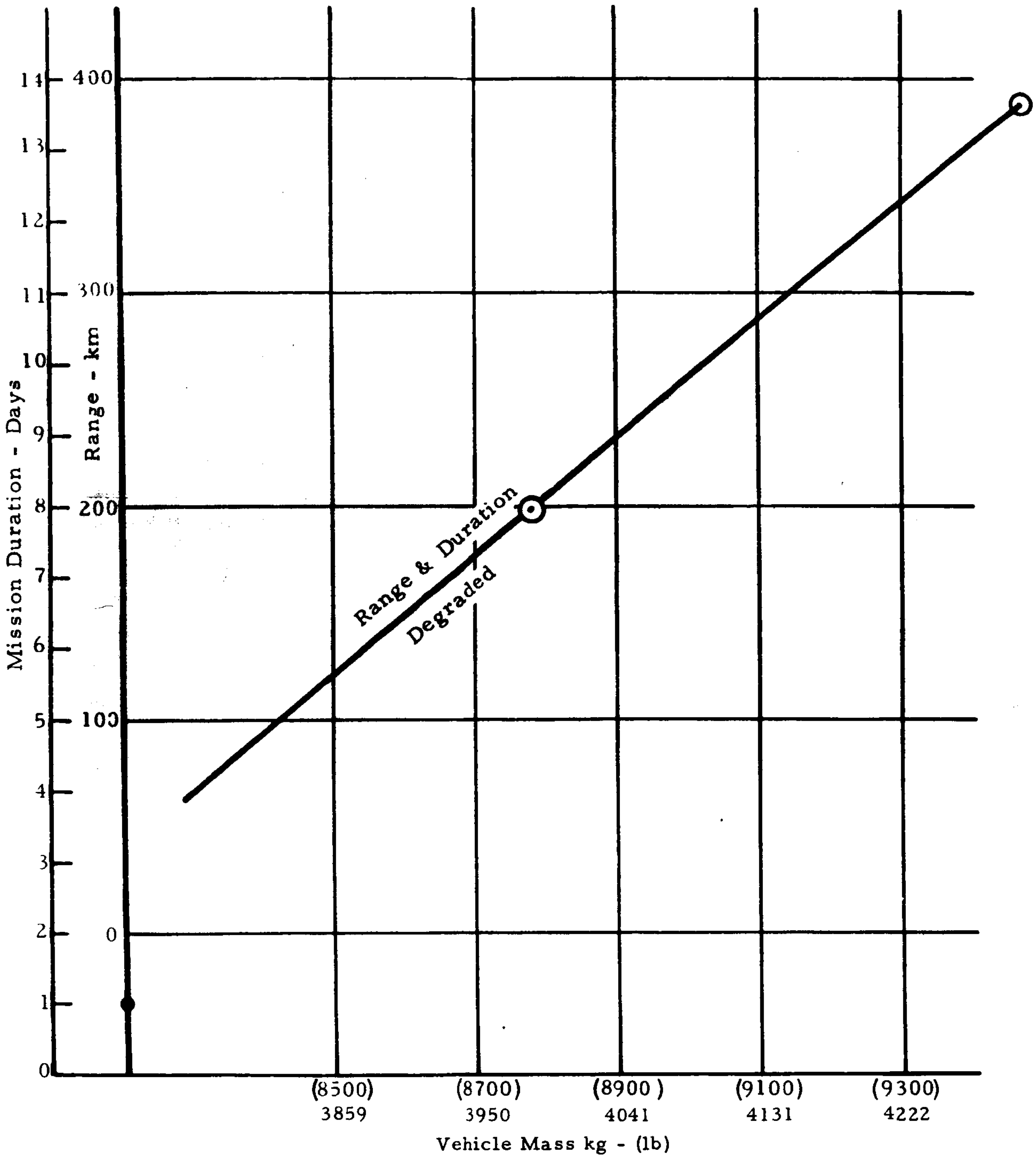


Figure 4-9 MOCAN Degraded Performance Analysis
(To Obtain 3859 kg Limit)

4.5.1.1 Study Procedure

The procedure for determining the degraded MOCAN performance was as follows:

1. Determine initial system mass.
2. Determine specific mobility energy for vehicle operational mass.
3. Determine range.
4. For specified range, determine mobility energy.
5. Determine energy for remaining systems.
6. Determine total system energy required (add 4 and 5).
7. Determine fixed system mass to be used (Table 4-17).
8. Determine life support expendables used.
9. Determine mobility system mass from Figure 4-10.
10. Determine power system weight from Figure 4-11 for total energy used.
11. Determine vehicle subtotal.
12. Determine tiedown and unloading mass.
13. Determine total system mass (add 11 and 12). See Table 4-18.
14. Check total system mass against initial system mass. Iterate as required.

4.5.2 Crew Systems

The configuration was reviewed in terms of the maximum crew size that it could accommodate. Due to the large available volume within

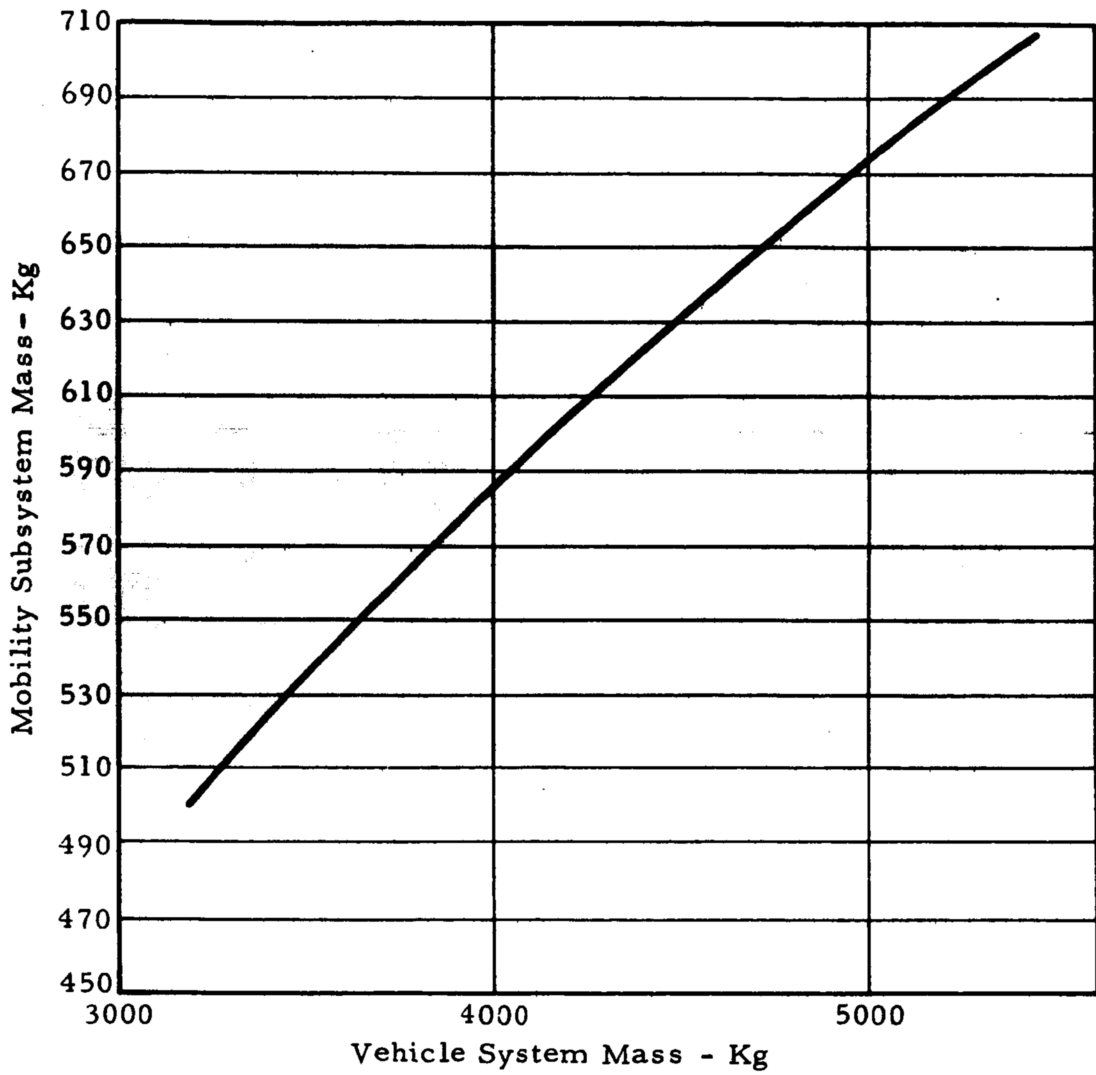


Figure 4-10 Mobility Mass vs. Gross Operating Mass

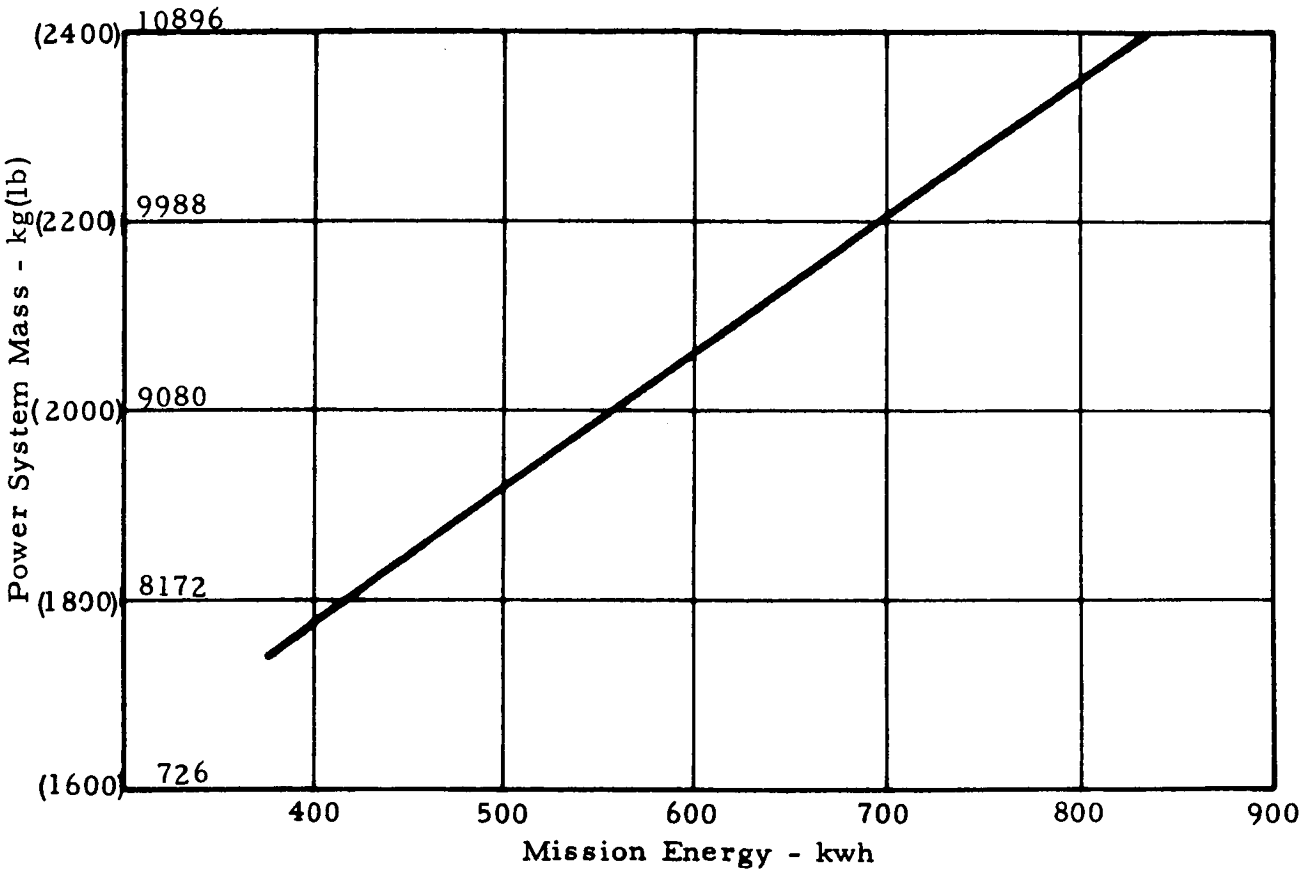


Figure 4-11 MOBEV Power System Mass vs. System Energy

TABLE 4-17

FIXED SYSTEM MASS

		lb	kg
1.	Structure	2480	1126
2.	ECS	482	219
3.	Crew Systems	322	146
4.	Controls and Displays	121	55
5.	Communications and Navigation	436	198
6.	Cables and Instrumentation	200	91
7.	Scientific Equipment	705	320
8.	Thermal Control	157	71
		4903	2226

the MOCAN, extreme flexibility is available to accommodate larger crew sizes. A crew size of four, with 200 ft^3 volume per man, is entirely feasible in terms of habitability and human factors considerations. In fact, mission durations from 30 to 90 days are feasible with this concept.

Figure 4-12 summarizes the weight penalties associated with different types of ingress-egress facilities. The MOCAN cabin with air-lock and pump is the recommended configuration.

Figure 4-13 represents the life support subsystem weight sensitivity to mission duration.

TABLE 4-18

MOCAN SYSTEM MASS SENSITIVITY

	14 day 400 km	8 day 200 km
1. Initial System Mass, kg (lb)	4312 (9520)	3990 (8778)
2. Specific Energy	0. 585	0. 526
3. Range, km	400	200
4. Mobility Energy, kwh	234	104
5. Other System Energy, kwh	500	331
6. Total System Energy, kwh	734	435
7. Fixed System Mass, kg (lb)	2226 (4903)	2226 (4903)
8. Life Support Expendables, kg (lb)	203 (447)	145 (320)
9. Mobility System Mass, kg (lb)	613 (1350)	579 (1275)
10. Power System Mass, kg (lb)	1031 (2270)	831 (1830)
11. Subtotal, kg (lb)	4077 (8980)	3781 (8328)
12. Tiedown & Unloading Mass, kg (lb)	250 (550)	204 (450)
13. System Total Mass, kg (lb)	4322 (9520)	3985 (8778)

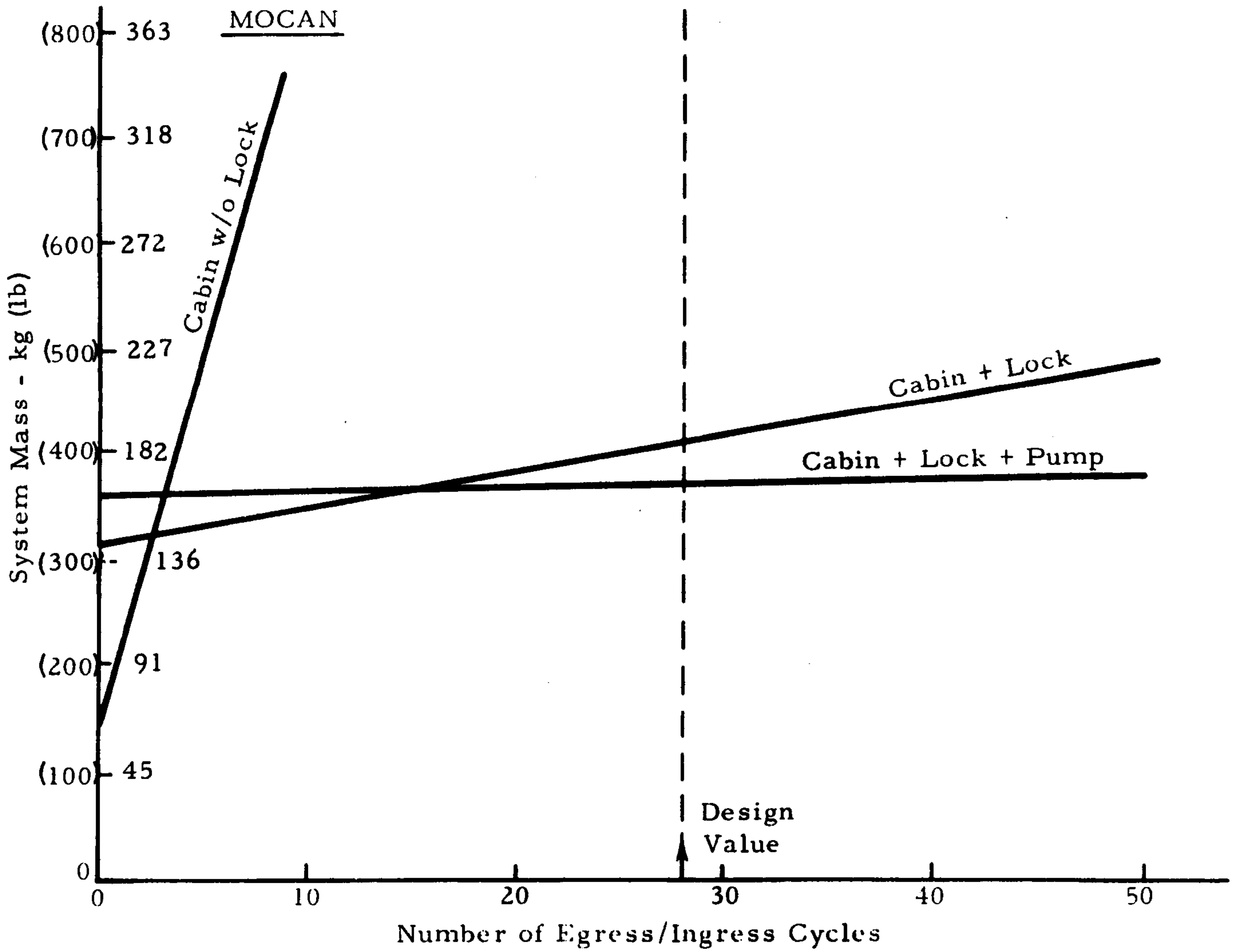


Figure 4-12 MOCAN Ingress/Egress Trade-Off

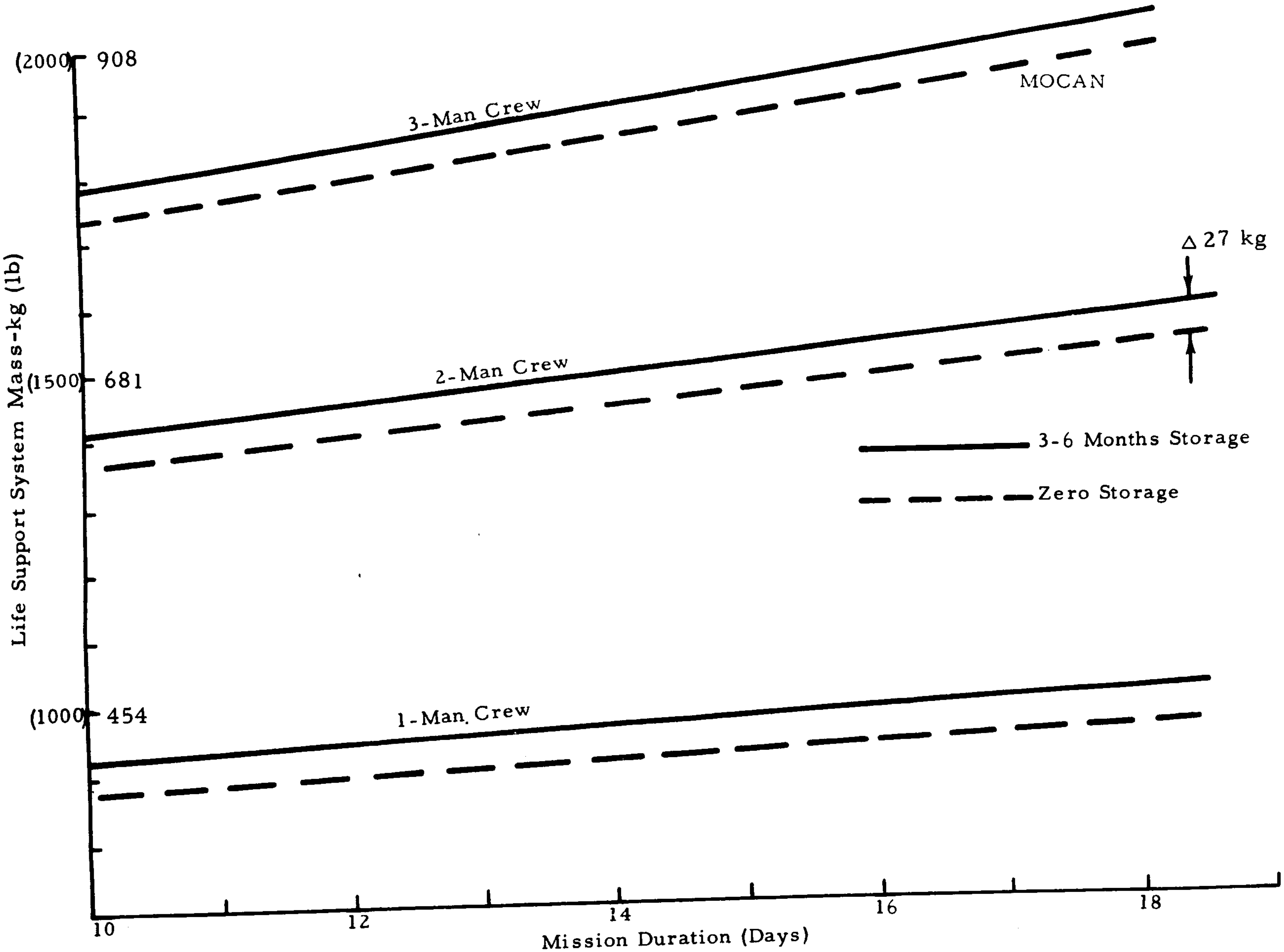


Figure 4-13 MOCAN Life Support System Sensitivity Data

SECTION 5

HUMAN FACTORS HABITABILITY, CREW SAFETY, and MISSION SUCCESS (MOLEM, MOCOM, MOCAN)

5.1 HUMAN FACTORS

Summary rankings of the MOLEM. MOCOM and MOCAN with respect to human factors considerations are provided in Table 5-1. From this comparison, it is evident that the MOLEM concept has the least to offer in terms of operator efficiency comfort and safety. The MOCAN concept at the other extreme offers the greatest design flexibility because of its large available volume. The MOCOM concept lies intermediate between the MOLEM and MOCAN concepts. It should be noted that the numbers indicate only relative ranking and not that MOCOM is twice as good as MOLEM etc.

In addition to these comparative judgments, certain conclusions can be drawn regarding the adequacy of each concept on an individual basis. The MOLEM concept does not appear to be practical in terms of human factors and habitabilitycriteria. In every respect considered, the MOLEM proved marginal.

The MOCOM concept offers promise for a two-man crew. Sufficient free volume is available to include the specified crew safety and habitability provisions. However, with a three-man crew the MOCOM concept appears marginal.

The MOCAN concept has the most to offer with respect to usable volume, crew size flexibility, and mission duration. Without question, the MOCAN concept can meet all human factors crew safety and habitability criteria.

It should be noted that a two-dimensional analysis of a concept such as MOLEM which appears marginal at best cannot be entirely conclusive. Human factors design verification studies with realistic mockups would represent the next logical step in exploring the feasibility of the MOLEM or MOCOM concepts.

TABLE 5-1

HUMAN FACTORS CONCEPT COMPARISON SUMMARY*

	MOLEM	MOCOM	MOCAN		MOLEM	MOCOM	MOCAN
Volumetrics	3	2	1	Suit/PLSS Storage	3	2	1
Ingress/Egress	3	2	1	Suit Drying Space	3	2	1
External Visibility	3	1.5	1.5	Sleeping Arrangements	3	1.5	1.5
Work Stations	3	1.5	1.5	Habitability	3	2	1
Seating/Restraint	3	1.5	1.5	Crew Safety	3	2	1
Redundant Compartments	3	1.5	1.5	Crew Size	3	2	1
Solar Flare Protection	3	2	1				

Summary Rank: Molem 39 Mocom 23.5 Mocan 15.5

*Note: In order of decreasing merit (1 to 3 points)

5.1.1 Volumetrics

The available volume encompassed by the three concepts under consideration is a major factor in providing for a habitable living and working environment. Over-restrictiveness adversely affects mans' ability, his flexibility of performance, and his ability to adapt to his environment. The accompanying chart lists total volume within the MOLEM, MOCOM, and MOCAN cabins (see Table 5-2)

In considering volumetric requirements, a distinction is made between total volume and free volume. Free volume refers to that space not taken up by instrumentation, crew provisions, and other hardware subsystems. Available free volume must be converted to maximally useful volume. One index of the available useful volume is the available floor space within the three vehicles.

Comparisons of the MOLEM, MOCOM, and MOCAN in terms of free and useable volume are provided in the illustration. In connection with the MOLAB study, NASA has specified a minimum free volume of 175 ft^3 for a two-man crew for a two-week mission. Applying these criteria to the volume available in the concepts under consideration, it is noted that the MOLEM does not meet the specified minimum.

The free volume for MOCOM exceeds the NASA specification while the MOCAN free volume is sufficient to accommodate at least a four-man crew.

5.1.2 Ingress/Egress Ease

The ease with which the astronaut can enter or depart from the lunar vehicle has important implications for operational efficiency and crew safety. Ingress/egress provisions for MOLEM were reviewed for both normal and emergency modes of operation.

Two modes of vehicle ingress/egress were provided for each of the concepts studied. In each case, the emergency mode of egress is through an overhead hatch which is associated with the docking adapter. These hatches already exist in the three structures being considered.

TABLE 5-2

VOLUMETRICS

	MOLEM	MOCOM	MOCAN
Total Volume	250 cu ft	365 cu ft	1350 cu ft
Free Volume	150 cu ft	219 cu ft	810 cu ft
Floor Space	16 ft^2 (83 in. high) 10 ft^2 (61 in. high)	44.5 ft^2 (73 in. high)	185 ft^2 (78 in. high)
Rank	3	2	1

The normal ingress/egress hatch developed for each concept was predicted on the requirement to make minimum modification to existing structures while attempting to optimize ingress/egress maneuvers from the human factors standpoint. In the case of the MOLEM, the existing LM forward hatch was preserved with the addition of an expandable/collapsible airlock. This hatch requires a crawl-through mode of ingress/egress as opposed to a preferred walk-through provision. This arrangement is decidely inferior to those of the MOCOM and MOCAN. Aside from the awkwardness of this mode of vehicle entry and departure, the astronaut will have difficulty in manipulating packages through the hatch. More important, in the event that an astronaut is injured or incapacitated on the lunar surface, the remaining astronaut will have extreme difficulty in maneuvering an immobilized astronaut into the vehicle.

The hatch provided by the CM was found to be unacceptable for normal vehicle ingress/egress in that the astronaut would have to crawl over the control station. For this reason, the existing hatch was enlarged and placed in the aft portion of the MOCOM. This rectangular hatch (which measures 30 x 40 in.) when augmented by stairs and appropriate handholds on both sides of the hatch permits a walk-through ingress/egress maneuver. Manipulation of an injured astronaut with this arrangement represents an improvement over the MOLEM. An overhead hatch 34 in. in diameter is available for emergency egress.

The MOCAN offers the best ingress/egress provisions of the three concepts explored. A rectangular hatch measuring 30 x 60 in. permits walk through ingress without the necessity of supplementary stairs to go through the hatch. This arrangement permits the greatest flexibility in terms of manipulating packages through the hatch or an injured astronaut during a rescue operation.

5.1.3 External Visibility

The need for good driving visibility places considerable constraint on the location of windows and this has been considered first in view of potential impact on vehicle structures. An accommodation with the following ground rules has been sought:

1. Operability with one crewman disabled
2. Seated (and restrained) operation
3. Operation with a pressurized suit
4. Visibility of terrain directly ahead of each front wheel.

External visibility must also be considered with respect to the scientific, navigation, and safety requirements.

Ideally, the driven vehicle should have at least two observers with wide overlapping fields of view—one, the driver, directing the specific course of the vehicle, while the other navigates and assists in observing the overall scene. Of the three vehicles, both the MOCOM and the MOCAN satisfy this objective. However, the solution obtained in the MOLEM case is less than optimal, although it does not require major structural modificiations to alleviate the deficiency.

On MOLEM, a standing driving position located off the vehicle centerline has been recommended to take maximum advantage of the present LM configuration. The principal disadvantage associated with the standing position is the anticipated difficulty of providing an adequate restraint system for rough driving conditions (fatigue is also a factor to be considered, but it is not known whether, or how much, fatigue will be increased or decreased as compared to the seated position at 1/6 g). The off-center driving position (in addition to utilizing the present windows) permits the bunks to be arranged to one side so that an incapacitated crewman can be carried when the vehicle is being driven. Given the MOLEM configuration and size, a standing position is also considered desirable from the standpoint of driving with an inflated pressure suit if cabin pressurization is lost.

The MOLEM driver's field of view (see Table 5-3) from the left window is less than optimum when looked at from the LM design eye reference point (which, though adequate to the left, yields only about a 13° field to the right of the centerline). However, in the recommended MOLEM, this is partially compensated for by use of a periscopic device which extends his field to the right window and a TV viewer which also provides supplementary coverage. (It should be borne in mind that it is unlikely that the MOLEM driver will be as constrained in locating his eye position as will the LM pilot who must use the window reticles for sighting. In addition, the other crew member will be available to observe the right-hand field).

TABLE 5-3

EXTERNAL VISIBILITY—DRIVER'S VISIBILITY

	MOLEM	MOCOM	MOCAN	MOLAB Criteria
Left	78°	35°	22°	20°
Right	13°	30°	20°	20°
Up	10°	15°	10°	5°
Down	65°	30°	30°	20°
Visibility Air Required	Yes	No	No	
Driving Visibility Rating	3	1	2	
Nondriving Visibility Rating	3	2	1	

The external visibility requirements were more readily fulfilled with the MOCOM concept, since greater latitude existed in locating windows with respect to the vehicle structure. The characteristics are given in Table 5-3. The angular values indicate the driver's viewing angle as measured at the design eye reference point and are considered conservative. With some head and body movement, a greater field is afforded through the forward windows and, on MOCOM and MOCAN, through the side windows. The "Other Visibility Requirements" rating refers to nondriving functions such as navigational sightings, scientific observations, and monitoring the EVA. This rating includes an estimate of the ease of using the side and forward windows for these functions.

Since no windows exist in the CAN structure, wider latitude is permitted in the design and location of windows for the MOCAN. Table 5-3 provides the driver's viewing angles permitted by MOCAN windows. In addition to two forward windows (each measuring 20 x 22 in.), two side windows (10 x 15 in.) are provided to facilitate monitoring of EVA operations and terrain observations while driving.

5.1.4 Work Stations

Based on an analysis of crew functions, work station requirements for the three concepts investigated fell into three categories: driving functions, navigation and system monitoring, and scientific analyses activities. Each concept was reviewed in terms of the most feasible integration of these three work stations with available external visibility and visual requirements during driving and for monitoring EVA activities.

A two-man integrated work station concept was established for each vehicle with a driver's station on the left and the navigator's station on the right. Integration of these stations faciltates a one-man vehicle operation in the event that one of the crew members is incapacitated. This side-by-side arrangement also facilitates sharing of control functions by placing panels of common interest, e.g., TV and communications, between the driver and the navigator.

During travel periods, the driver is primarily occupied with visibility of terrain directly ahead of the wheels and manipulation of the control stick. The navigator shares responsibility for external viewing, but is free to monitor navigation and other subsystem equipment. The navigator has a control stick at his location and can function as copilot when necessary.

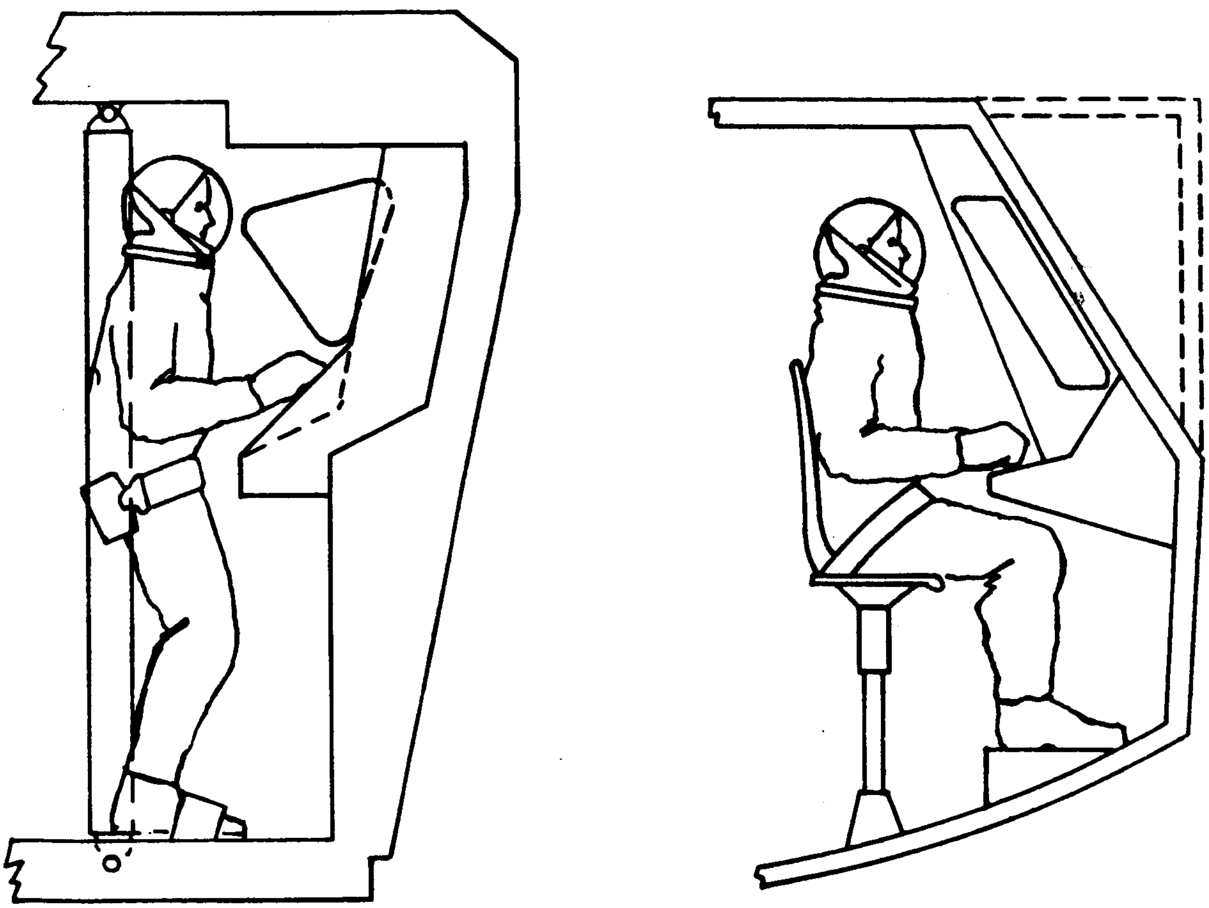
The scientific work station is required to permit analysis of lunar samples. These samples must be studied in their natural environment to prevent cabin atmosphere from contaminating the samples. This means that the samples must be manipulated external to the vehicle or in an unpressurized vehicle. Since it is desirable to permit the astronauts to perform scientific analysis activities in a shirtsleeve mode, a glove-box concept developed for MOLAB was incorporated into the MOCAN and MOCOM. This box accepts lunar samples inserted by the surface astronaut. The vehicle operator manipulates these samples by means of a remote manipulation device associated with the glove box.

The scientific glove box was not incorporated into the MOLEM because of the requirement for making minimum penetrations into the structure, thereby eliminating the necessity for requalifying the LM structure. Therefore, with the MOLEM concept, scientific sample analysis must be conducted by the astronaut in the suited/pressurized condition. Scientific measurement equipment is associated with the navigator's station.

5.1.5 Seating/Restraints

In the three vehicles, all significant interior activity is expected to be performed by the crew while seated with the exception of driving in the MOLEM case (Figure 5-1). Furthermore, driving activity in the case of the MOLEM will be performed by a suited astronaut for safety reasons, although the suits will normally be vented. In addition, whenever one astronaut is engaged in extravehicular activity, the inside astronaut will be wearing his pressure suit, vented, to be prepared for an emergency rescue. For driving, restraint systems must be provided which will accommodate pressure-suited astronauts with suits vented for normal operations or pressurized for emergency operations. Figure 5-1 shows the restraint systems intended for astronauts wearing softsuits which are vented. These systems will also serve with the suits pressurized. If hardsuits are used, similar systems will be provided although the dimensions will vary. An integral seat-suit combination for the hardsuit case would not be adopted, because the seat would not serve comfortably when the pressure suits were not being worn. It is not considered feasible at this time to provide a restraint system which will accommodate both hardsuits and softsuits.

For MOLEM, an attempt has been made to provide some flexibility to allow for the unknown fatigue effects of prolonged standing in a 1/6-g



MOLEM
Ratings: 3

MOCOM/MOCAN
Ratings: 2/1

Figure 5-1 Seating and Restraint

environment. Thus, the astronaut can brace himself using the foot-anchoring straps and seat rest or he may assume a semiseated posture by positioning the seat rest more horizontally. The entire apparatus will be of soft materials and can be stowed against the overhead bulkhead when not in use.

MOCOM seating will be the MOLAB type illustrated in Figure 5-1. In contrast to the MOLEM, the MOCOM provides ample room for seating at the MOCOM work stations. Simple fabric seats on a tubular aluminum framework appropriate for a 1/6-g environment are provided. A lap belt restraint system is associated with the seats. These seats, ordinarily located at the driver and navigator stations, can be moved and readily mounted at the scientific work station or the solar flare shelter positions.

MOCAN seating and restraint will be comparable to MOCOM.

5.1.6 Redundant Compartments

A redundant compartment or the ability to segment total vehicle volume into a dual rather than a single compartment crew cabin has important safety and habitability implications. For a second compartment to be most useful, it must be at least large enough to accommodate the entire crew, permit suit donning in the event of main compartment meteorite puncture, permit isolation of the crew during sleep periods for safety reasons, and at the same time serve as an airlock. Because of limited internal volume coupled with LM configurational factors, a useful segmentation of the LM cabin into two compartments is not possible.

An expandable airlock has been provided in association with the forward hatch. While this airlock is useful in conserving O_2 and permitting intracabin vented suit operations during EVA periods, it does not provide the other safety and habitability features of a redundant compartment.

The MOCOM is large enough to permit an airlock compartment of 60 ft^3 free volume with 160 ft^3 of free volume remaining in the main compartment. An airlock or second compartment of this size permits separate sleeping provisions so that the entire crew is not jeopardized in the event of a meteoroid puncture during simultaneous sleep periods. This airlock is marginal in terms of available space for suit donning with two men in the compartment, and there is limited capability for increasing the size of the airlock.

The availability of a relatively large redundant safe compartment permits a true shirtsleeve environment. since in the event of a cabin failure the crew can enter the safe compartment and don suits. The MOLEM concept does not provide this feature and thus requires vented suit operation for safety reasons.

The larger volume MOCAN offers the greates flexibility in terms of a second compartment airlock size. The airlock shown in Figure 4-4 contains 95 ft^3 of free volume. This volume is sufficient to be comfortable for suit don/doff requirements. It is also possible to enlarge the redundant compartment in the event that a larger crew size is contemplated. This redundant compartment permits a true shirtsleeve environment.

5.1.7 Solar Flare Protection

The solar flare shelter depicted in Figure 5-2 is the type developed during ~~the MOLAB Study.~~ The shelter is basically a tapered box surrounding the head, arms, and torsos of the crew. This approach to radiation shielding maximizes the use of inherent protection provided by hardware subsystems, e.g., environmental control equipment. The seating for the shelter is available by utilizing removable work station seats. The additional protection required is provided by polyethylene pads which are readily assembled to form the configuration shown in the illustration. The astronauts will have at least 15 minutes available subsequent to a warning to assemble the shelter.

The shelter will provide minimum habitability essentials. A source of light will be provided. Food and water will be stored within the shelter. The portable waste disposal unit will be located outside the shelter within easy reach of the astronauts. In the event of a vehicle system malfunction, the astronaut is free to leave the shelter for short periods to attend the malfunction.

The polyethylene pads which form the shelter may be integrated into the cabin flooring to eliminate a storage problem. The recommended location for the solar flare shelter in each of the three concepts is indicated in Figure 5-2.

5.1.8 Suit and PLSS Storage and Suit Drying Provisions

Four pressure suits and PLSSs will be required for the two-man MOBEV missions. These will be stowed as indicated below. Provisions for hardsuits will be essentially the same in all three cases.

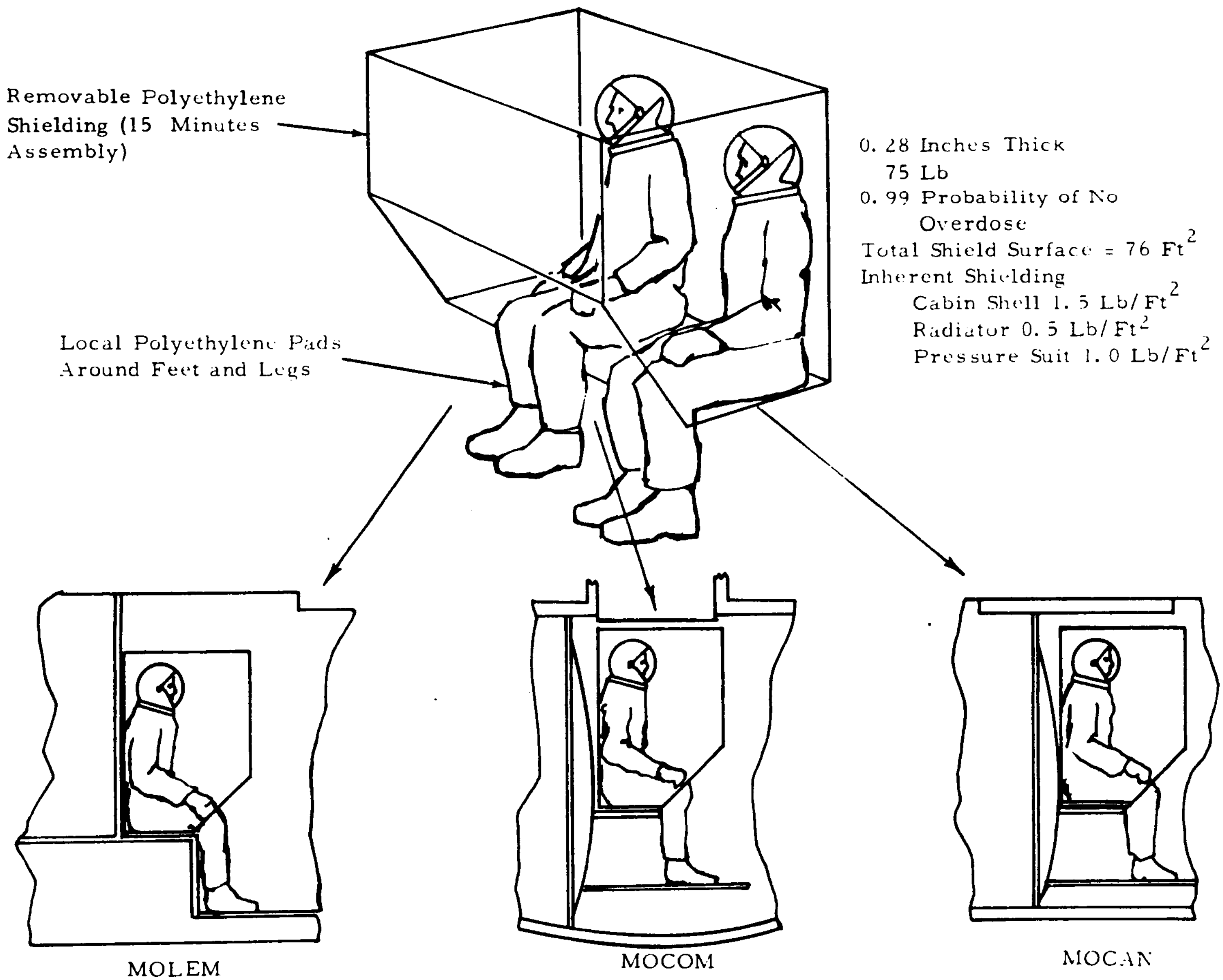


Figure 5-2 Solar Flare Shelter

On MOLEM, the bunks are used as the principal suit stowage area. The suits will be placed on the floor in the forward cabin section when the bunks are used for sleeping. A suit being dried will be suspended in the aft cabin section of the bulkhead opposite the bunks, connected to the ECS suit loop, and vented. PLSS stowage is provided on the inner face of the forward hatch, on the aft bulkhead and on the side bulkhead of the aft cabin section.

The requirement to move suits in order to use the bunks is a major disadvantage for the MOLEM. Considerable time will be wasted in rearranging bunks and suits. In addition, the suits will represent an impediment to emergency responses made by the crew to malfunctions or dangers which arise during sleep periods.

The four suits will be stored and dried after EVA operations on the left-hand side of the main cabin in the MOCOM. As shown in Figure 2-4, the PLSS storage will consist of two units on the cabin side of the airlock bulkhead with two units on the airlock side of the bulkhead.

In MOCAN, one suit is stowed at each end of the airlock and one suit is stowed in each of the two storage compartments in the main compartments. A suit being dried subsequent to EVA activity wouid be suspended on the cabin side of the airlock bulkhead. The four PLSSs are all stowed against the right-hand side cabin bulkhead. The MOCAN offers better than adequate suit/PLSS storage capability.

5.1.9 Sleeping Arrangements

Provisions for simultaneous sleep of crew members was a ground rule in developing the three concepts under consideration. Where possible, bunks were placed in separate compartments for crew safety reasons. Placement of bunks was also considered in terms of provisions for accommodating an injured or temporarily incapacitated crew member while still permitting the remaining crew member/s to perform station management functions. A third consideration which entered into the design and evaluation of sleeping arrangements was the ability of the astronaut to respond to an emergency occurring during sleep periods.

Bunk size in each case was 30 x 78 in. The bunks are constructed of a lightweight tubular frame with a nylon net or webbing covering. The bunks are readily collapsible and stowable.

In the MOLEM concept, the two bunks are suspended one above the other. This bunk arrangement does not readily permit accommodation of an injured astronaut. When either bunk is erected, it interferes with movements of the remaining astronaut within the cabin. In addition, access to the bunks during emergency suited/pressurized operations is limited.

The MOCOM configuration lends itself to separate sleeping arrangements, with one man in the airlock and the other in the main compartment (see Figure 3-4). This arrangement satisfies the requirement for isolating an injured astronaut so that the remaining astronaut can attend to station-keeping tasks unhampered by the injured astronaut. Separate compartments for sleeping purposes also provide the safety advantage of not risking the entire crew in the event of a major meteoroid penetration.

As in the case of the MOCOM, the MOCAN offers separate sleeping quarters for the crew. If a crew larger than two men is required, two men can sleep in the airlock and two in the main cabin.

5.2 HABITABILITY

The term habitability encompasses a wide variety of environmental, psychological, and cabin design factors which add up to a comfortable, life-sustaining work and living environment. As in the case of crew safety, many aspects of habitability are dependent on available volume within the concepts being developed. Table 5-4 shows comparative evaluations of the various habitability features for each concept under investigation.

The design goal associated with each of these factors is as follows:

1. Usable Volume: Arrangement of space available for normal and emergency crew activities taking into consideration hardware subsystems volume requirements.

2. Traffic Flow: Capability of two or more crew members to move about the cabin without interfering with each other's activities. Both normal and emergency traffic patterns are of concern here.

3. Privacy: Where possible, a provision for privacy is a plus factor in terms of habitability. Dual compartment vehicles offer a degree of privacy.

TABLE 5-4

HABITABILITY RANKING

	MOLEM	MOCOM	MOCAN
Usable Volume	3	2	1
Traffic Flow	3	1. 5	1. 5
Privacy	3	1. 5	1. 5
Confinement	3	2	3
Eating Provisions	2. 5	2. 5	1
Waste Management	2. 5	2. 5	1
Personal Hygiene	2	2	2
Recreation Provisions	3	2	1
Temperature/Humidity	2	2	2
Airflow	2	2	2
Illumination	3	1. 5	1. 5
Sleeping Provisions	3	2	1
	32	23. 5	18. 5

4. Confinement: Since EVA activities offer a means for escaping the confines of the vehicle, confinement is not a serious problem in terms of vehicle habitability. In general, the smaller the vehicle in terms of volume, the greater the subjective sense of confinement.

5. Eating Provisions: Freeze-dried dehydrated foods will be utilized in all three concepts. The MOLEM will utilize control console work shelves for eating surfaces.

6. Waste Management: A portable toilet with chemically treated wastes and storage will be provided.

7. Personal Hygiene: Cleansing deodorant pads, a vacuum razor, and dentrifice will be supplied for personal hygiene.

8. Recreation Provisions: Crew activity schedules will include at least two hours per day for relaxation. The larger the crew cabin, the more room available for recreational equipment, e. g. , reading material, personal cameras, games, etc

9. Temperature/Humidity: Temperature will be adjustable within 65^{o} - 85^{o}, 5^{o} plus individual suit temperature adjustment.

10. Airflow: Airflow velocity will be 20-60 ft/min for each concept.

11. Illumination: Illumination will be variable from 5 to 50 ft-candles with separate control for each cabin compartment.

12. Sleeping: Where possible, a provision for separate sleeping quarters is desirable. There are times when sleep periods must be staggered to some extent to complete unfinished work or attend to an urgent maintenance task. The activities of the astronaut who is working should not interrupt the sleep of a second astronaut. Dual-compartment vehicles offer a separate sleeping arrangement. The MOLEM does not provide this option.

5.3 CREW SAFETY

Each of the factors discussed above has some bearing on the problem of crew safety. However, when examining the vehicle from a safety standpoint, it is improtant to look at the effects on the crew which these factors produce.

The MOLEM suffers in each of these areas primarily because of the limited volume available in the vehicle, volume which should properly be apportioned to provide a multicompartment vehicle, freedom of astronaut movement in response to an emergency, adequate space for rapidly donning pressure suits, etc. A comparison of these factors for the three vehicles under consideration is presented in Table 5-5.

TABLE 5-5

CREW SAFETY RANKING

	MOLEM	MOCOM	MOCAN
Freedom of Movement—Emergency Responses	3	2	1
Space Suit Accessibility	3	2	1
Suit Donning Provisions	3	2	1
Separate Sleeping Quarters	3	1. 5	1. 5
Redundant Safe Compartment	3	1. 5	1. 5
Ingress/Egress Safety	3	2	1
Manipulation of Injured Astronaut	3	2	1
Minimum EVA Operations	3	1. 5	1. 5
Solar Flare Provisions	2	2	2
	26	16. 5	11. 5

Once it is occupied, operational safety of the three concepts mainly depends upon the ability of the vehicle to remain mobile, provide life support, and maintain the cryogenics and power necessary to these functions. As long as rated mission capabilities are maintained, the vehicle itself represents no hazard to crew safety or safe return of the astronauts. In the event of subsystem or equipment failures, the degree of performance which remains is of vital importance to crew safety.

With four independently powered/controlled wheel drive units, the three concepts have the capability of sustaining mission operations with one wheel unpowered; it has additional backup for emergency return (up to 80-km radius) in the very unlikely event that two wheels become unpowered. The loss of one steering drive mechanism (or control) will allow mission continuation, and emergency return in the scuff-steering mode is possible in the very unlikely situation where two steering drive mechanisms fail to function. Mobility suspension and wheel structures for MOLEM are integrated design concepts where the wheel or support arm suspension mechanisms may degrade, but still provide capabilities for safe emergency return.

Power system components of major concern to crew safety are the fuel cells, the associated cryogenics, and the power conditioning/distribution equipment. The MOLEM vehicle has two fuel cells; in the event of a failure, the remaining fuel cell is adequate to return the vehicle to the base. MOCOM and MOCAN have two fuel cells providing sufficient backup for emergency return. Subsequent mission operations could be limited to less than 80-km range to ensure crew safety. The power conditioning and distribution components have not been defined in detail; however, no serious design penalties would result if redundant components were used for all functions needed to maintain a mobile vehicle, or for life support.

The cryogenic supplies are sized to furnish life support and fuel cell operation for the 14-day manned mission and seven days of extended life support. In MOLEM the supply is stored in one hydrogen tank and two oxygen tanks. The loss of the single hydrogen tank is a hazard to crew safety, because the fuel cells cannot function without hydrogen; therefore, failure will immobilize the vehicle and reduce life support power to the capability of secondary power sources. The possible loss of an oxygen tank is less serious (if both tanks are simultaneously used), since the failure of one can allow the remaining tank to provide both power and life support for emergency return and stay time extension. MOCOM and MOCAN contain two hydrogen tanks and two oxygen tanks, thus the failure of any tank will still allow for emergency return.

Although the MOLEM cabin is a single compartment design. emergency return can be accomplished in spacesuits in the event the cabin is punctured beyond repair. The environmental control system includes a water-boiling heat exchanger to compensate for a thermal control loop failure.

Isolated failures of communications and navigation equipment items on the vehicles are not considered crew safety critical problems. since several degrees of backup exist. The use of multiple equipment items for operational flexibility generally provides for more than one remaining alternate mode for use in emergencies.

Communications equipment failures considered likely are expected to reduce the amount of scientific data that may be handled. but not to cause failure of earth-link voice and biomed communications capabilities.

Navigation equipment failures considered likely may reduce the ability of any of the concepts to continue operations at a safe radius of 80-km from the base. Failure of the inertial measuring unit (IMU) represents the most serious condition. since this would result in the loss of the position-fix function. and the dead-reckoning function would have to be accomplished using the S-band antenna or other means for azimuth determination during an emergency return. Other navigation components can fail with no serious effect on the capability for emergency return, the vehicle may still operate out to 80 km, but mission effectiveness can be reduced by the time required for position fixing.

Micrometeoroid protection of the cabin is designed for 99% probability of no penetrations (75% confidence level).

MOCOM suffers less from volume constraints than does MOLEM, although it does not provide the space available in MOCAN. It is clear that MOCOM is superior to MOLEM in each of the factors enumerated. In particular. the MOCOM vehicle offers separate sleeping quarters a redundant safe compartment and, because of the remote lunar sample handling apparatus, less extensive EVA requirements.

5.4 MISSION SUCCESS

Mission success considerations encompass prelaunch checkout, launch, flight, lunar landing, lunar storage, and the 14-day manned mission on the lunar surface.

Assuming that structure design safety margins and development testing can virtually eliminate launch and landing risk factors, vehicle equipment reliability for six-month lunar storage, unloading, and the 14-day manned mission phase is of greater concern in this analysis.

During lunar storage, the MOLEM, MOCOM, and MOCAN dependency on RTG auxiliary power and related thermal control equipment is the outstanding critical problem. The RTG electrical functions and/or the thermal fluid loop functions have no redundancy or other effective backup to prevent the possible loss of the vehicle during lunar storage. The failure of one (of two) oxygen tank or its controls would reduce, but not eliminate, a potential mission. The loss of the single hydrogen supply would prevent the manned mission.

During the unloading phase, the probability of successfully deploying all three vehicles is enhanced by: the all-azimuth capability of the design concepts, by the availability of three external TV cameras (any one of which could serve the unloading sequence), and/or by the manual unloading features of the concept which allows for deployment in the event of power distribution, TV, or other unloading device malfunctions.

During the 14-day manned mission mode, the lack of a backup cabin compartment (large rigid airlock), dependency on a single hydrogen tank, and the high degree of dependency on the inertial measurement unit represent equipment items considered most critical from the mission continuation standpoint for the MOLEM. Other potential failure modes discussed under crew safety are either much less likely to occur or do not seriously impair mission continuation effectiveness.

The capability of remaining mobile in degraded modes as previously mentioned under crew safety ensures a good probability of completing a planned mission.

Loss of cabin pressure would cause mission termination unless satisfactory repairs could be made; the degraded-mode success of the communication depends on the amount of scientific data required.

SECTION 6

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APPENDIX A

GUIDELINES

A. 1 MOLEM, MOCOM, AND MOCAN DESIGN GUIDELINES

General guidelines and restraints have been developed for the MOLEM, MOCAN and MOCOM vehicles using MOLAB as a basis. These are detailed below.

A. 1. 1 General Restraints

A. 1. 1. 1 Operating Period

The operating period shall be for the lunar equatorial regions as follows during lunar day, lunar night, or any combination of these conditions.

A. 1. 1. 2 Standby Period

Provisions have to be made so that the payload can be in a standby mode of at least sixmonths duration during which period it may be activated remotely to operational status several times and deactivated again to the standby mode.

A. 1. 1. 3 Compatibility With Spacesuit and LM

All payload systems shall be compatible with the capabilities and limitations of the man/suit combination—particularly with respect to dexterity, time, human factors, and handling limitations such as size, weight, volume, and shape.

A. 1. 1. 4 MOLEM, MOCOM, and MOCAN Guidelines

1. Design and operation must be fully compatible with the equipment and operation of the LM-Truck, the Apollo CM and SM, the Apollo and Saturn V Ground Support

Equipment (GSE), the Apollo Integrated Mission Control Center (IMCC), and the Apollo LM. The interface requirements of the payloads upon the Apollo system must be minimized, especially those which might dictate modifications to the standard LM-Truck. The capability for alignment of the LM-Truck's Inertial Measurement Unit (IMU) shall not be compromised. The MOLEM, MOCOM, or MOCAN will be mounted on the LM-Truck.

2. Monitoring of payload status during transit to the lunar surface and during standby prior to or between Apollo missions must be provided.

3. All payloads shall have the capability of being unloaded on more than one azimuth. As a guideline, payloads shall be capable of being unloaded on any azimuth.

4. Off-loading must be accomplished under surface conditions at least as severe as specified in the ELMS (Engineering Lunar Model Surface).

5. It shall be possible for an astronaut to effect off-loading manually without benefit of power devices in the event of automated system failure.

6. A single crew member shall be able to perform all essential functions associated with unloading, startup, traveling, and maneuvering. The same functions shall be possible to be performed by remote control from earth.

7. The MOLEM, MOCON and MOCAN shall be designed to permit one crewman to effect an unassisted rescue of another on the lunar surface including ingress and egress operations.

8. The crew size shall be two astronauts.

9. Provisions shall be made and definitions shall be given for special tools, equipment, and repair kits necessary to provide rudimentary maintenance and repair operations.

A. 1. 1. 5 Apollo Environment

Equipment and instruments must be capable of withstanding the Apollo Launch, transit, docking, and LM-Truck landing acceleration loads, shocks, and vibrations.

A. 1. 1. 6 Weight and Volume and cg

The envelope for the MOLEM, MOCOM, MOCAN shall be between Sta. 200 and Sta. 316. 9 on the Saturn V (diameter at Sta. 200 is 219. 1 in.; diameter at Sta. 316. 9 is 182. 2 in.). See Figure 2-1 of Vol. II, Book I, of MOLAB Final Report (ALSS Payloads Final Report Vol II, Book I June 1965 ALSS-TR-013; BSR-1119; BSC 45336)

The cg envelope is: (1) horizontal: within 2. 5 in. of LM-Truck vertical centerline, and (2) vertical: between 32 and 46 in. above Sta. 200.

The total weight for MOLEM, MOCOM, or MOCAN shall not exceed 8500 lb.

A. 1. 2 Specific MOLEM, MOCOM, MOCAN Restraints

In addition to the general restraints listed above, the following special restraints are applicable to the MOLEM, MOCOM, and MOCAN systems:

1. These systems shall be designed for easy adaptability to changes in the exploration missions (varying duration and range, and varying scientifc instrument packages).

2. These systems shall have mobility over as wide a range of lunar surface conditions as possible (MOBEV Statement of Work, Annex A, Engineering Lunar Model Surface - ELMS).

3. These systems shall be designed to accommodate adequately a crew of two astronauts with standing room and adequate sleeping facilities.

4. These systems shall be designed for easy crew egress and ingress under lunar operating conditions.

5. These systems shall fully satisfy life support and communications requirements of the crew using onboard equipment and power supplies for mission duration.
6. These systems shall be equipped with a nonregenerative Life Support System, including food and water, adequate for a 28 man-day operation without resupply. For emergency conditions, the vehicle shall provide a life support safety contingency of 50%.
7. These systems shall provide adequate electrical power to permit reasonable surface illumination.
8. These systems shall have the ability to navigate, maintaining the pre-arranged general course, while performing continuous small-scale corrections at the operator's discretion. It must also have the ability to adopt remote control operation during a manned mission at the request of the crew or by command from a lunar surface, lunar orbit, and earth control center.
9. These systems shall have the ability to perform certain unmanned missions by remote control from lunar surface, lunar orbit, and earth control centers.
10. The cabin for these systems shall include a support and restraint system to:
    a. Provide adequate protection against all anticipated acceleration vectors.
    b. Provide suitable restraints for the crew functioning in a lunar-gravity environment.
    c. Be adjustable for comfort, visibility, and accessibility to control.
    d. Accommodate the crew wearing pressurized spacesuits.
    e. Provide sleeping facilities such that one astronaut may sleep while the system is in motion.
11. There shall be no requirements for sterilization, i.e., no requirements for sterile assembly of subsystems, no requirements for resistance to ethylene oxide, heat cycles, or other common techniques for reducing the number of viable microorganisms.

12. The systems shall be equipped with first aid equipment, drugs, and medical supplies.

13. Provisions shall be made to allow remote checkout, testing, and conditioning at Cape Kennedy.

14. These systems shall be capable of being loaded with propellants or expendables, conditioned and checked out in eight hours on the launch pad, and shall be capable of being launched in 24 hours after a delay that required the draining of propellants or removing of expendables from the system while on the launch pad.

15. These systems shall be capable of a 12-hour prelaunch standing time in the propellant-loaded condition. This period includes continuous propellant topping on the pad up to launch time.

16. These systems shall be adaptable to both intermittent and continuous use.

17. The power subsystem for MOLEM, MOCOM, or MOCAN shall furnish all power required during the mission, and must possess a sufficient degree of reliability and redundancy to ensure complete mission safety and success. The power requirements for scientific equipment will be considered as 75 kwh.

18. Each system and its scientific instrumentation payload shall have the capability of being resupplied with expendables and spare parts on the lunar surface. This is applicable to both the vehicle system and its scientific instrumentation payload.

19. Each system shall be readily adaptable to the addition of a variety of appendages for making measurements, lifting, drilling, etc.

20. Each system shall have the capability of operating with a circular area of at least 80-km radius measured from the LM-Truck landing point. Total travel distance within this area shall consider 400 km as a design goal.

21. The cabin for each system shall be designed according to the "Space Environment Criteria Guidelines for Use in Space Vehicle Development: (1965 Revision)," for radiation protection criteria.

22. Each system shall contain viewing ports which provide the crew maximum visibility of the lunar surface without imposing severe penalties to design or manufacturing considerations.

23. Each system shall have a design goal of traveling at least 6 km/hr in soft soil ($K_\phi = 0.5$, $n = 0.5$), and up to 16 km/hr on level compacted soils ($K_\phi = 6$, $n = 1.25$) if found to be safe and desirable during manned operations.

24. The checkout system for each system shall be capable of operation throughout the mission to assure and increase the probability of mission success. The checkout system shall provide information to assist in assessing the capability of the landing stage vehicle combination to initiate unloading of the vehicle to continue a normal mission. Specific objectives of checkout shall include the following:

    a. To provide assurance of readiness of the MOLEM, MOCOM, MOCAN systems and earth-based systems before launch.

    b. To provide assurance of readiness of the lunar system for initiation of the mission phase from landing until mission completion.

    c. To provide diagnostic assistance for fault isolation and possible correction.

    d. To perform evaluation of critical systems.

    e. To evaluate trends.

    f. To provide research and development information.

25. The ground system shall be designed to be compatible with an integrated checkout concept covering prelaunch, launch, inflight and lunar operation phases of the mission.

26. The checkout system shall incorporate provisions for monitoring and analysis of critical system functions in such a manner that out-of-tolerance performance can be recognized and assessed in time for remedial action when on the ground, in flight, and on the lunar surface using onboard equipment. No equipment used solely for prelaunch testing shall be installed aboard the spacecraft as fly-away hardware unless an overall program savings can be demonstrated. Test equipment installed aboard the MOLEM, MOCOM, or MOCAN as fly-away hardware shall be compatible with all equipment used in the other phases of checkout.

27. Checkout facilities aboard the MOLEM, MOCOM, or MOCAN may be a combination of manual and automated systems. From launch to mission completion, this equipment shall provide information to allow independent go/no-go decisions.

28. The telemetry system for each system shall transmit at least as much data as are available to the onboard crew. Where applicable, earth-based facilities shall be capable of comparing mission data and prelaunch tests data to reveal trends and to develop confidence in the MOLAB equipment. Earth-based checkout facilities shall make maximum use of the facilities provided for the initial manned lunar landing.

29. Each system shall be compatible with the Apollo space vehicle in regard to mass distribution as it affects stability during launch and transit phases.

30. Cabin systems, subsystems, and components must be compatible with a pure O_2 atmosphere.

31. The Primary Structure of each system such as the environmental cabin, docking adapter, unloading structure, vehicle chassis, etc., and secondary structure shall have adequate strength for resisting various loads and combinations thereof, including vibration and acoustical effects during handling, transportation, launch, flight, staging, and operational use.

32. The pressurization limit load for the environmental cabin shall be compatible with the LM capsule cabin pressure. The pressure containers, including the cabin structure, shall have a safety factor of 1.5 based on the yield strength of the material for limit pressures and a safety factor of 2.0 based on ultimate strength for limit pressures. For nonpressurized structures, the yield and ultimate safety factors shall be 1.35 and 1.5, respectively, for limit load conditions.

A.1.3 Guidelines

A.1.3.1 General

1. Number of Astronauts on Lunar Surface

   In general, only one astronaut will be outside of the spacecraft shelter or roving vehicle and on the lunar surface at any given time (one astronaut remaining inside).

2. Apollo Development

   Wherever possible, maximum use is to be made of components, subsystems, and systems being developed for Project Apollo.

3. Interchangeability

   Subsystems and components which are common to several systems within the MOLEM, MOCOM, or MOCAN and the LM shall be as interchangeable as possible. This is of special concern for items such as communications equipment, thermal control elements, life support equipment, expendable supplies, scientific instruments, and tools.

4. Flexibility of Packaging

   The Mission Operational Plan will be modified as the manned lunar exploration program is formalized and as lunar surface operations are underway. Therefore, the design of each system should permit the introduction of design changes into individual payloads at as late a date prior to launch as possible. This is especially true for expendables, scientific instruments, tools, and spare parts.

5. Standardization

Small hardware, component parts, fittings, and containers should be standardized to the degree practicable.

6. Thermal Control

As a design objective, thermal control of external heat fluxes to the interiors of the environmentally controlled cabin shall be of a passive nature to the maximum extent possible, and a function of the structural design and surface finish. Where the passive system does not meet environmental requirements, an active system with arrangements for positive thermal control shall be provided as required.

A.1.3.2 Specific Guidelines

In addition to the general guidelines listed above, the following special guidelines are applicable to the MOLEM, MOCOM, and MOCAN systems:

1. Each system shall provide auxiliary devices to enable the crew to extract the system should it become immobile in difficult lunar terrain.

2. Each system design should consider the safety of the crew in the event a critical MOLEM, MOCOM, or MOCAN system becomes inoperable.

3. The Command Module will be oriented so that the docking adapter is in the vertical position.

4. The Command Module side hatch will be used for ingress/egress.

5. The "CAN" Pressure Shell will have to be modified to allow for the wheels to fold beneath the cabin. The cryogenics will be stored within the cabin.

A.2 SUBSYSTEM GUIDE FOR THE 8500-LB MOBILITY SYSTEMS (MOLEM, MOCAN, AND MOCOM)

The following information provides the mobility derivative model for comparison of spacecraft subsystems to allow determination of those subsystems which are functional in the mobility derivatives. This also provides the basis for defining the stripped spacecraft.

The mobility system against which existing subsystems are to be compared is described in the following paragraphs.

A.2.1 Mission Requirements

The requirements are specified in Bendix ALSS Payloads Final Report, BSR-1119, Volume II, Book 1, System Design (ALSS), Section 2.2.

A.2.2 Major Functional Subsystems

These are: cabin, mobility, power, and astrionics.

A.2.3 Envelope

The envelope is described in MOBEV Statement of Work, Annex "D", Carrier Vehicle Data," dated 24 November 1965.

A.2.4 Mobility Model Subsystem Performance Goals

1. Cabin

Environment	Shirtsleeve: $70^{\circ}F \pm 5^{\circ}F$; 5-10 mm Hg humidity
Atmosphere (cabin)	100% O_2 at 5 psia
Life Support for Operations External to Vehicle	PLSS
Atmosphere (spacesuit)	100% O_2 at 3.5 psia
Ingress/Egress Cycles	40

Radiation Protection	As specified in ALSS Payloads Final Report Section 2.21
Meteroid Protection	P = 0.99 of no punctures in 194 days with 80% confidence
Crew Number and Accommodation	2 (95th percentile airmen)
Life Support Expendables	Two men for 14 days plus 7-day emergency reserve (i.e., 42 man-days)
Sleeping Arrangement	Two separate bunks

2. Mobility System

Total Range Capability	400 km
Power Subsystem	Generally commensurate with MOLAB Power requirements. For reference, see ALSS Payloads Final Report, Figure 4-5.

3. Astrionics

Navigation System

Relative Position Accuracy	0.27 km
Absolute Position Accuracy (includes gravity anomalies)	0.9 km
Absolute Heading Accuracy	2 min.
Homing (10-km range assured, 80-km range possible)	$\pm 8.7^{\circ}$ (3σ) at 80 km $\pm 1.0^{\circ}$ (3σ) at 40 km

Television System

Cameras	Forward camera unit, two, in a stereo pair arrangement for remote control of vehicle system
	Rear camera unit, single camera for reverse driving and astronaut monitoring
	Interior cameras for astronaut monitoring
Camera Movement	Forward and rear camera units, $\pm 65^{\circ}$ azimuth, 0 to -70° elevation
	Internal cameras, fixed
Fields of View	
Forward and Rear Cameras	$50^{\circ} \times 37^{\circ}$ $30^{\circ} \times 22^{\circ}$ Selectable $5^{\circ} \times 4^{\circ}$
Internal Cameras	$50^{\circ} \times 37^{\circ}$, only
Data Format	Analog

4. Communications System

RF Link MOLAB to Earth via S-band	See ALSS Payloads Final Report, Table 4-6 Service Column Only
RF Link Earth to MOLAB via S-band	See ALSS Payloads Final Report Table 4-7
RF Link MOLAB to Communications via VHF-AM	ALSS Payloads Final Report Table 4-8
T/M System	Approx 400 T/M Points

Data Rate	Less than 1.6 kbits per sec for vehicle system data (actual rate, a function of mission phase) For scientific data, use 51.2 kbits/sec Vehicle data and scientific data are not both transmitted simultaneously
Data Processor	Stored program, general-purpose, serial, fixed-point, binary Storage: 8192, 26-bit words Input/Output: Serial digital bus
Command System	Approximately 150 commands
Command Rate	Less than 1000 sub-bits/sec, or less than six 30-bit command messages/sec

5. <u>Tiedown & Unloading Subsystem</u>

Debarkation Azimuth	360° (goal)
Remote Debarking with a manual debarking backup capability	