



10TH

ANNUAL
MEETING

MAY 4-7, 1964

TECHNICAL PROGRESS ON
LUNAR FLIGHT PROGRAMS



III
K
SATURN HISTORY DOCUMENT
University of Alabama Research Institute
History of Science & Technology Group
Date _____ Doc. No. _____

APOLLO LOGISTIC SUPPORT SYSTEMS

by

Herbert Schaefer, Group Chief

and

Leonard Yarbrough, Group Chief

Aero-Astrodynamic Laboratory

NASA MARSHALL SPACE FLIGHT CENTER

PREPRINT 64-21

L52

APOLLO LOGISTIC SUPPORT SYSTEM*

+
Herbert Schaefer + and Leonard S. Yarbrough +

One possible conceptual definition of an early Apollo Logistics Support System (ALSS) is presented and various payloads for the System are briefly discussed. A more detailed discussion of one payload, a Lunar Mobile Laboratory (MOLAB), is given, including a summary discussion of the major sub-systems and critical features. Some of the considerations for planning a lunar scientific mission are discussed. A hypothetical traverse and general operations plan for the MOLAB are defined in a manner suitable for mission optimization, once valid design data becomes available. Some aspects of the MOLAB testing program are presented. It is concluded that this System appears feasible and the problems which presently confront its design and development do not seem insurmountable.

The ideas expressed herein are those of the authors and should not be construed as being official NASA policy.

* Prepared for Presentation at the Tenth Annual Meeting of the American Astronautical Society on May 7, 1964.

+ Chief, Payloads Group

‡ Operations Analysis Group

Systems Concepts Planning Office, Aero-Astrodynamic Laboratory, George C. Marshall Space Flight Center, Huntsville, Alabama

APOLLO LOGISTIC SUPPORT SYSTEM

INTRODUCTION

The Apollo Logistic Support System (ALSS) has been conceived to augment Project Apollo in support of scientific exploration of the Moon. This System would do so by providing increased stay-time, additional surface mobility and more equipment. Since the lunar surface cannot be economically covered in its entirety by surface exploration, such a System must be carefully planned if maximum possible return of data is to be obtained. It will be shown that ALSS takes full advantage of Project Apollo development. A hypothetical mission operations plan is developed to illustrate how ALSS can be used for a lunar scientific mission.

OBJECTIVES

Exploration of the Moon affords a unique opportunity to advance knowledge of the universe beyond terrestrial bounds. Further knowledge of lunar history is expected to provide answers concerning the origin of both the Moon and the Earth.. Ranger and Surveyor type missions hopefully will provide more knowledge of the Moon than is available now. Apollo and Post-Apollo missions will provide additional knowledge and will verify earlier data. The basic experiments and observations to be performed should be carefully chosen so as to provide the most useful data returned from surface mission.

Scientific missions will require many observations in order to provide valid data. This requires increased stay-time beyond that of the present Apollo. The basic functions of eating, sleeping, rest and housekeeping are time consuming, as are orderly data exchange and conference with Earth. Time is needed to allow the scientific instrumentation to stabilize; it is needed also to detect cyclical forces at work; for example, thermal changes between lunar day and lunar night. Should there be an anomaly on the surface, time is needed to determine which is the exception and which is the normal condition. Present space-suit designs probably will afford only very limited mobility on the lunar surface; traveling short distances will require appreciable time, even in the lesser gravity of the Moon.

This means that increased crew mobility is needed. A local environment for life support cannot be provided by a space-suit for very long periods without incurring extreme weight penalties. These penalties, of course, exceed the physical capabilities of man. A wealth of data can be obtained at a fixed site, but it is believed that by providing increased mobility, very much more (and more meaningful) data can be obtained. This assumes that mobility is one excellent way to benefit from man's unique abilities in remote area exploration.

Increased stay-time and mobility require more equipment than Project Apollo presently provides. While more scientific instrumentation would be required, the major increased equipment requirements are for sustaining operations beyond Apollo capabilities. One means by which these requirements can be met

(and, at the same time, make full use of Apollo elements) is by providing a Lunar Mobile Laboratory (MOLAB) which can sustain a two-man crew for extended periods and which can provide enough scientific apparatus to obtain basic and reliable selenologic and selenophysical data about the Moon.

SYSTEM DEFINITION

Launch Vehicle and Spacecraft

The Apollo Logistic Support System (ALSS) is defined as being the launch vehicles, spacecraft, flight crew, Earth-based support systems, and the functional payload which is delivered and

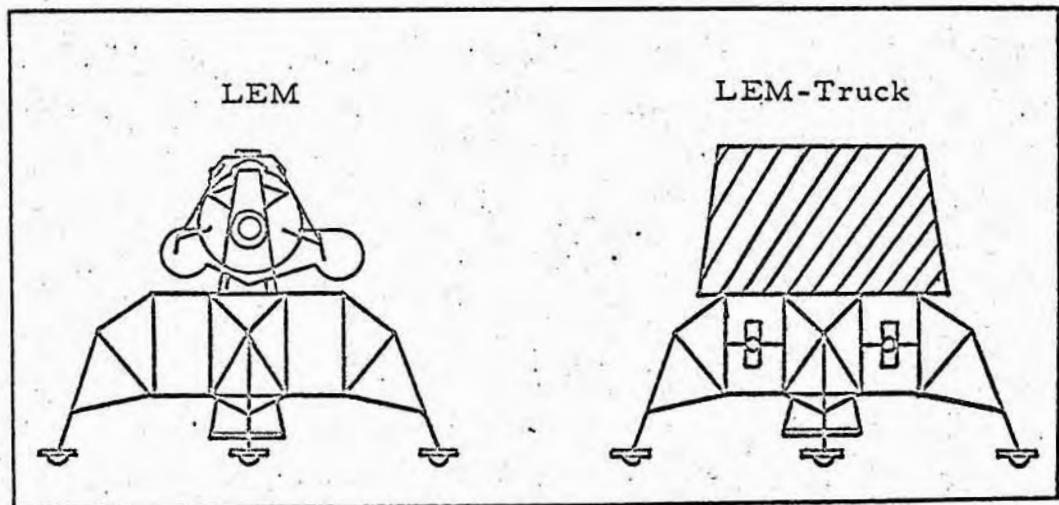


Fig 1 Conversion of LEM Into LEM-Truck

operated on the lunar surface. Two space vehicles are required for each ALSS mission. One is for delivering the functional payload; the other delivers the astronaut crew. The major difference

between the two is that the LEM-Truck has the Lunar Excursion Module (LEM) replaced by a modified LEM descent stage and payload. This is illustrated in Fig. 1. Other elements of the two vehicles are identical; Saturn launch vehicles, Apollo Command

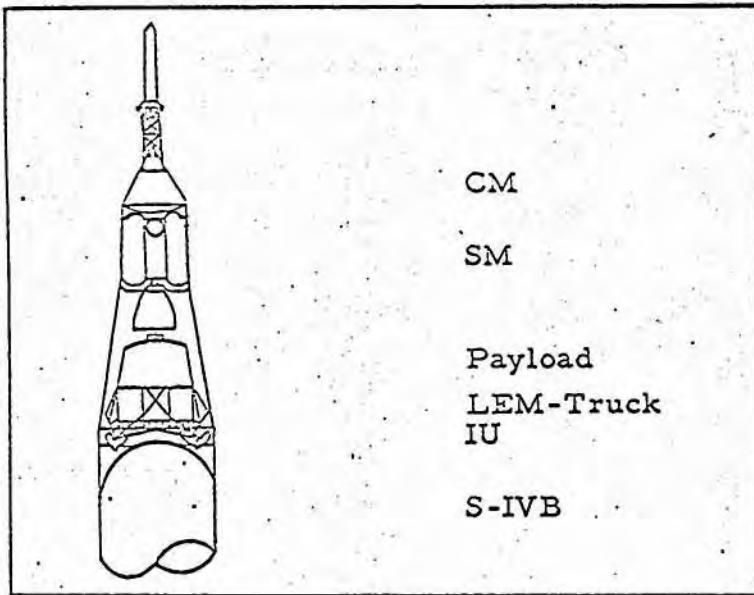


Fig 2 Saturn-Apollo Spacecraft With LEM-Truck/Payload

Module and Service Module. The upper part of the cargo version of an Apollo Space Vehicle is shown in Fig. 2.

This approach appears very economical from funding and development time considerations. Changes to the launch vehicle proper would be minor, although some changes in the docking and thrust structure would be needed to accommodate the LEM-Truck with payload. Two major changes are required to convert the LEM descent stage to a LEM-Truck. One would be to relocate the descent

stage guidance and control systems normally placed in the LEM ascent stage. This would be required, since the LEM-Truck must land automatically after braking into lunar orbit and separation from the Apollo Command/Service Module. The other change would be provision of an unloading mechanism for the payload. This, too, would have to be automatic, since it is assumed that a landed crew would be physically incapable of unloading a payload. It is presently expected that a LEM-Truck could deliver 3,200 kg (7,000 lbs) to the lunar surface.

Accompanying the cargo spacecraft would be two or three crew members in the Command Module. They would not descend to the lunar surface but would remain in a lunar parking orbit until after the LEM-Truck has landed. A typical profile for this operation is shown in Fig. 3. The crew could verify the landing site prior to and after landing of the LEM-Truck. In addition, they could also conduct limited scientific observations while in parking orbit; this mission could be a training mission for at least one crew member. The manned spacecraft would follow a similar profile, except that the Command Module remains in lunar orbit until the landed crew members rendezvous after an extended mission.

Mission Control

It is assumed that mission control for ALSS will be provided by an Integrated Mission Control Center (IMCC) by means of the Deep Space Instrumentation Facility (DSIF) and Apollo tracking network. This control would also include remote payload unloading, monitoring and periodic check-out (in-flight and after landing), and Earth-controlled operation of the payload on the lunar surface.

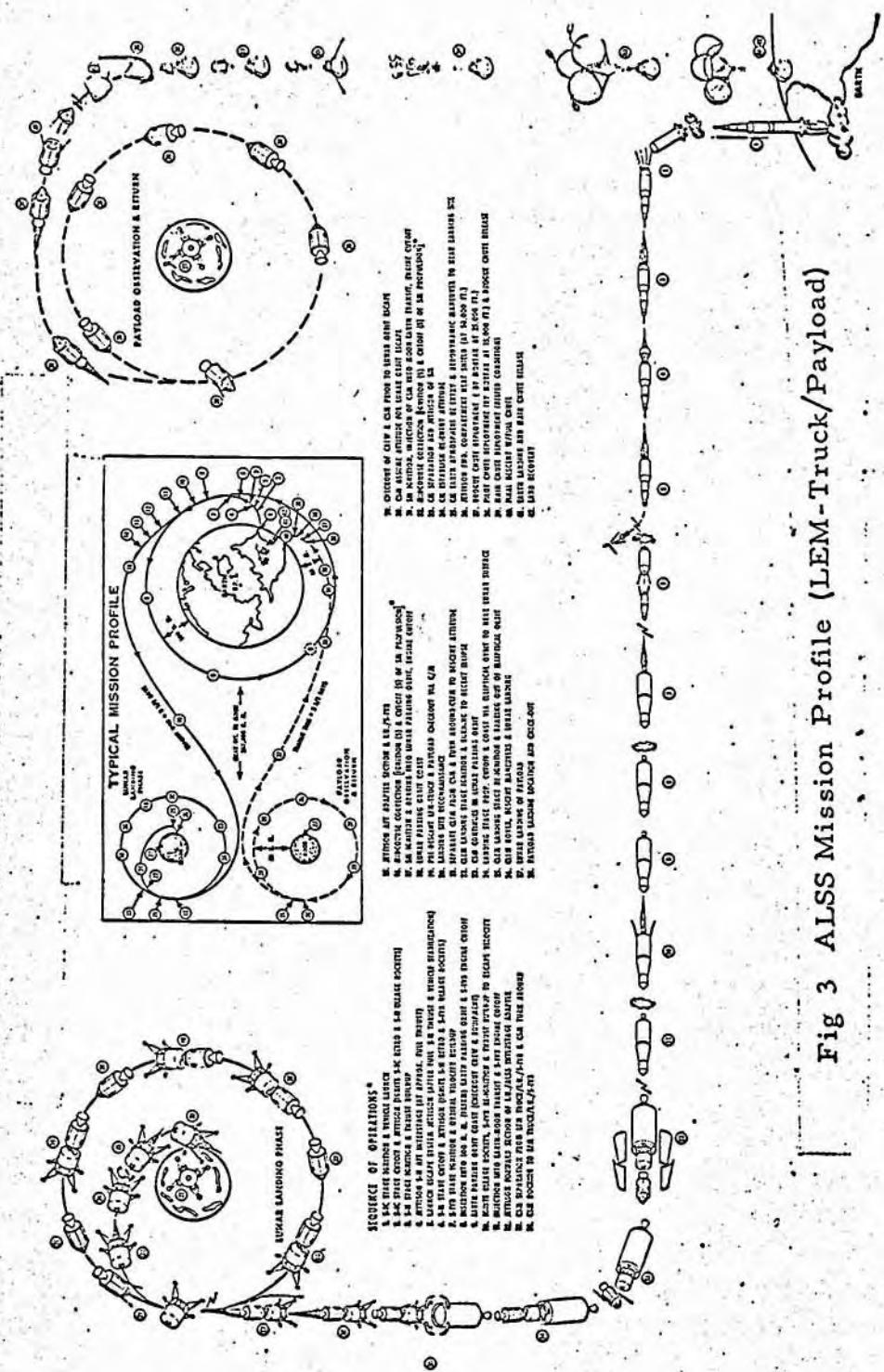


Fig 3 ALSS Mission Profile (LEM-Truck/Payload)

The last feature would be needed in the event the surface roving vehicle must be guided to the site of the landed crew.

Payloads

Various payload configurations for lunar exploration are possible. Although this paper is concerned primarily with one concept, the

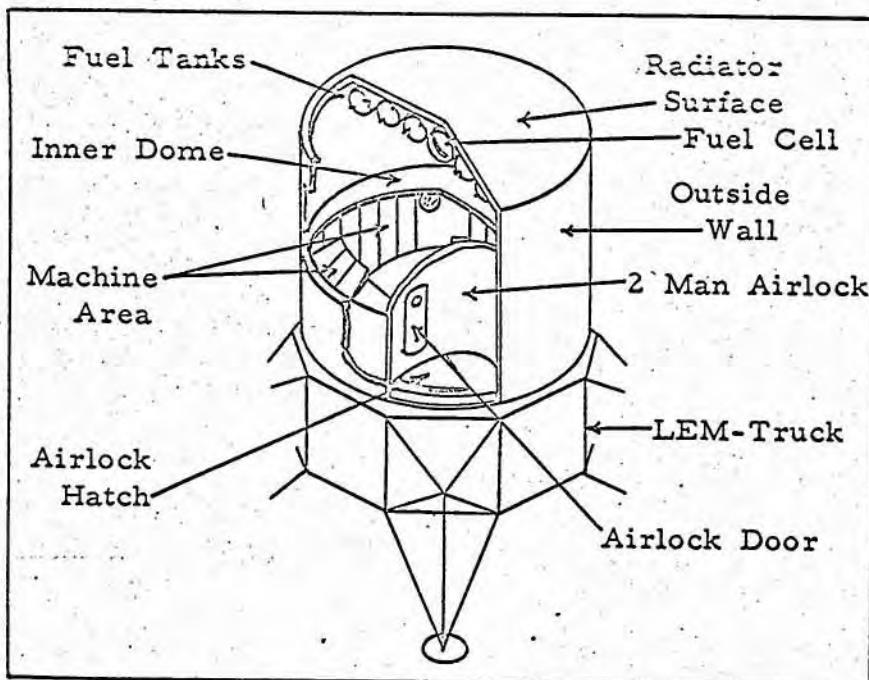


Fig 4 Artist's Concept of Two-Man Lunar Shelter

Lunar Mobile Laboratory (MOLAB), the payloads for ALSS are by no means limited to MOLAB. A two-man shelter concept weighing approximately 2300 kg (5,000 lbs) is shown in Fig. 4. No mobility is provided for crew members, but shelter and laboratory space are available.

A combination payload is shown in Fig. 5. This also is a two-man shelter, but it has a "garage" housing a small two-man lunar surface vehicle. This payload is estimated to weigh around 3000 kg (6500 lbs).

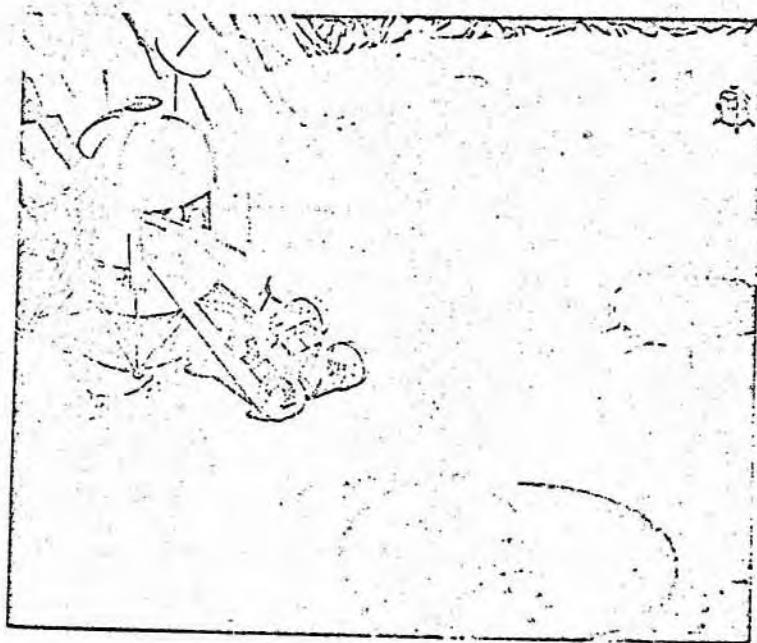


Fig 5 Artist's Concept of Lunar Shelter With Surface Vehitle

The next concept is the Lunar Mobile Laboratory (MOLAB) which would weigh about 3,000 kg (6500 lbs). This MOLAB would provide locomotion and shelter. An artist's depiction of a MOLAB is shown in Fig. 6. Since this concept appears to be the most promising, a more detailed description will be given later.

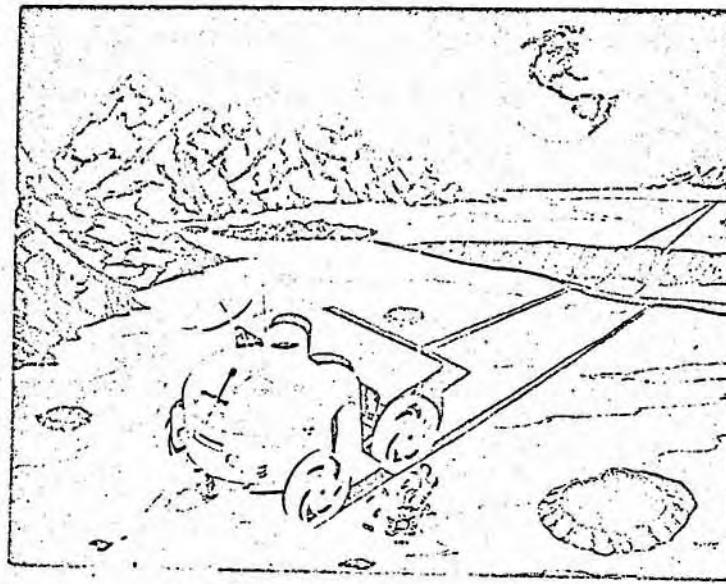


Fig 6 Artist's Concept of a Lunar Mobile Laboratory (MOLAB)

A quite useful payload is shown in Fig. 7. This is a Lunar Hopper. This device would be a useful adjunct to any of the payloads just presented. It would augment an astronaut's mobility by permitting

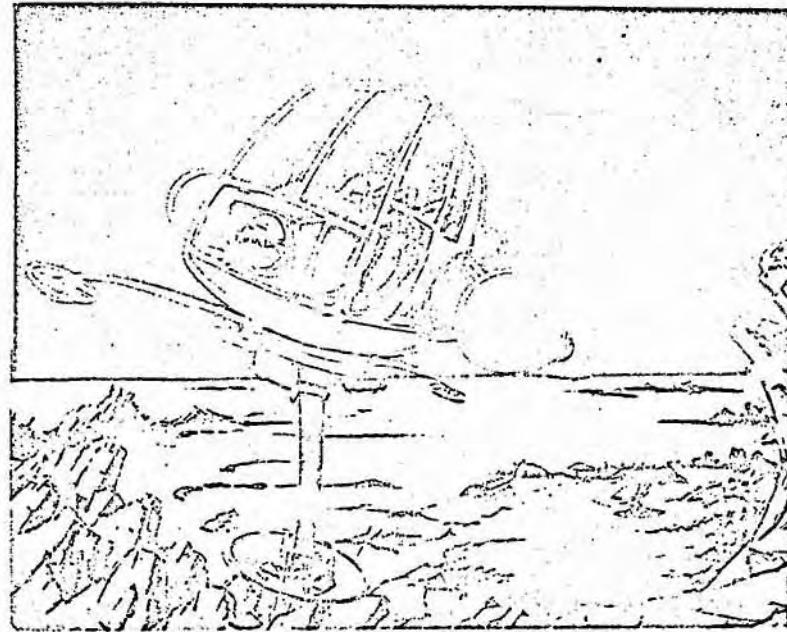


Fig 7 Artist's Concept of a Lunar Hopper

him to cross areas that cannot be negotiated by either a man afoot or by a surface vehicle. Even where surrounding terrain is readily negotiable, local conditions may be such that it is not advisable to risk being on foot or to use the surface vehicle. Since surface travel on foot is expected to be a major task for an astronaut in a space-suit, from both energy and time demands, a Hopper would increase the capability of the astronaut for satisfying mission requirements. Crew survivability would be greatly enhanced, since the Hopper could serve as an emergency escape device to return the astronauts to the LEM landing site. As a result, more flexibility could be allowed in planning lunar surface missions.

LUNAR MOBILE LABORATORY (MOLAB)

General Description

The payload for an Apollo Logistic Support System that appears most satisfactory is the MOLAB. This project is presently in the preliminary design study phase, but it is based on studies conducted during the last year and a half by NASA and industry. These studies indicate that the MOLAB should satisfy the following requirements:

1. Should provide shelter and mobility for two crew members.
2. Should carry an array of scientific instrumentation.
3. Should operate during lunar day or lunar night (or both) for a nominal two week period without resupply of expendables.
4. Should be capable of remaining in a dormant or stand-by mode on the lunar surface, for a minimum of six months. (This doesn't imply that it might not be brought up to an operational status several times during this period).

5. Should be capable of negotiating moderately rough terrain over a range of several hundred kilometers.
6. Would be transportable by the LEM-Truck. This includes tie-down and unloading mechanisms.
7. Should be capable of automatic check-out and operation from Earth.

It should be noted that the MOLAB as described here is not a recommended design or a preferred concept, but is simply presented as a typical example. A typical weight breakdown of the major subsystems and the expendables for a representative MOLAB is shown in Table I.

Cabin

Besides being the control and command center for the MOLAB, the cabin provides laboratory space and shelter for the crew during the entire ALSS surface mission. As shown in Fig. 6, the basic cabin structure is a section of a right circular cylinder. The top and bottom are convex bulkheads; all exterior surface would be covered with superinsulation for thermal protection. Particular care must be given to this structure, for it must provide protection from vacuum, temperature extremes, and particle bombardment (radiation and micrometeorites). The cabin includes an airlock capable of accommodating two men in space-suits. Present indications are that the airlock must be pumped in order to conserve gas, although this will probably be a time consuming operation. The airlock could also serve as a "storm cellar" during solar flares. The cabin should allow access to all equipments; it must, by its very nature, contain provision for sleeping, eating, personal hygiene, communications and control.

Table 1
TYPICAL WEIGHT BREAKDOWN[#]
FOR VEHICLE CLASS 5000-6000[#]

ITEM	WEIGHT (#)	% OF TOTAL
Locomotion Reactants	330	
ECS Reactants	680	
Scientific Reactants	260	
Life Support Reactants	350	
Communications Reactants	50	
Fuel Cell	700	12
O ₂ Tank	250	4
H ₂ Tank	400	7
Scientific Equipment	250	4
ECS System		
Life Support System	1150	19
Wheels and Motors	240	4
Control System	100	2
Radiators	200	3
Structure	1000	17
	5960	100

A combination docking adaptor/observation tower is located on top of the cabin. To the rear of the cabin are spherical LH₂ and LO₂ tanks and the cryogenic fuel cells. The entire aft section would be covered by radiators for rejecting excess heat. Antennas and an instrument and tool compartment are located on the starboard side. At the top front is a periscope and a range finder. Locomotion is provided by four individually driven semi-rigid wheels.

Environmental Control System (ECS)

Previously, it was shown in Table 1 that the greater portion of reactants carried by MOLAB is for ECS. The weight required for operation of the ECS is in itself sufficient to consider this system as critical. This, with the fact that failure of the ECS almost certainly means failure of the mission, identifies this as a key system. Since Apollo uses a single gas system (pure oxygen), it is logical to consider the same system for MOLAB. At this time, it appears that a nominal two weeks mission in a pure oxygen atmosphere would not be detrimental to the crew. This system also avoids certain regulation problems associated with a two-gas system and possible problems of decompression encountered when changing from one atmosphere to another.

A typical ECS is shown in Fig. 12 as it would operate under "closed face plate" conditions. The major elements are the purifiers, blowers, water evaporator, heat exchanger and supply reservoir. This is a semi-closed system; that is, one in which contaminated gas is purified and reused. Those losses from usage and leakage are replaced from the reservoir. A completely open system would be simpler, but the penalty from dumping contaminated

23 October

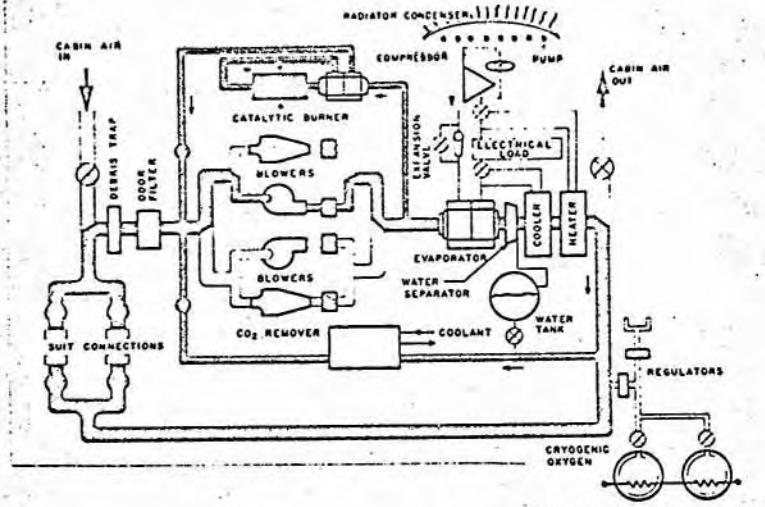
Proposed for AIAA
Meeting on Oct 1969.for the accompanying
instructions.1. Propulsion
2. FuelCircuit path is shown
in the drawing. Abstract is
shown.In space and a half
full space worthbe drawing, are rise
and inserted in theany prints or photos
copied.bit. Boxes and figures
used.

Fig 8 Basic Schematic of a Typical ECS

gas appears to be prohibitive under the weight limitations of the LEM-Truck and MOLAB. The design ambient pressure is 3.5 Newtons/square centimeter (5.0 psia).

Power Subsystem

Investigation of the power requirements for MOLAB indicate that electric power can be most feasibly provided by a cryogenic fuel cell primary system, a rechargeable silver - cadmium battery system for back-up, and an isotope auxiliary system for dormant storage periods. These are summarized in Table 2.

Table 2
POWER SYSTEM

	TYPE	FUNCTION
Primary Power	$H_2 O_2$ Fuel Cell	Locomotion Communication Experiments
Auxiliary Power	Isotope	Stand-by
Emergency Power	AG-CD Battery	Back-Up

The use of these power sources is based upon these considerations:

- a. The propellants for the fuel cell will be identical to that planned for the Apollo modules and, furthermore, the fuel cell will be the source of potable water for the crew.
- b. The battery system will be able to operate the MOLAB for a limited period (such as during an emergency) and will also be used as a "peak shaving" system for the cryogenic system.
- c. The isotope supply will handle all power requirements during dormant storage periods. In addition, this system may also power scientific apparatus integral to the MOLAB.

The cryogenic system offers the advantages that it is amenable to modular design and is capable of being adapted to a variety of conditions; there are few moving parts and the inherent reliability is high; reactant consumption is directly proportional to power

demand; idling situations require practically no reactants; and the system is noiseless and vibrationless, which minimizes the crew fatigue and interference with other systems.

The fuel cell is sensitive to current density, so it is desirable to have as nearly a constant load as possible. This necessitates some means of avoiding wide fluctuations in power demand from the fuel cell. Survivability requirements necessitate a secondary power system. Adopting a rechargeable battery system and using it to handle peak power demands satisfies both of the foregoing requirements. In addition, for a given situation, use of a rechargeable system with a fuel cell system allows a smaller fuel cell system to be used than if no battery were used.

Even though fuel cell efficiency increases with decreasing power demands, the expected low current drain during the storage period (six months or longer) can be more economically supplied by an isotope supply. It will not be necessary to bring the fuel cell up to its operating condition until large amounts of power are required, either for check-out or activation of the MOLAB. Further, if some malfunction or other adverse event occurs to compromise the power sources, the monitoring equipment aboard will not be disabled and some knowledge of the event will be obtained. After the MOLAB is activated on the surface, this supply can possibly be used as a power source for the scientific apparatus, as has been stated previously.

Present indications are that the primary system must be capable of providing around 6000 watts. The secondary system depends on the peak power demands anticipated and must be carefully considered for optimum design. The isotope supply will be

probably required to provide approximately one hundred watts power, according to present indications.

Communications Subsystems

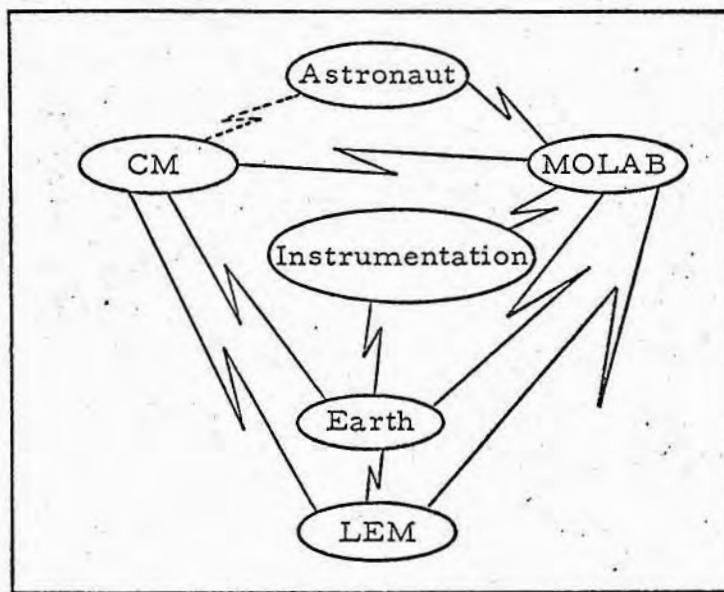


Fig 9 Basic Communications Links for ALSS (MOLAB)

The communications system is to be completely compatible with the LEM and Command Module and will be comprised of interchangeable units as much as possible. It is envisioned that there will be provision for complete Earth monitoring and control of the MOLAB. The basic communications links are shown in Fig. 9. These links include voice, video, telemetry and control channels (each named channel will not necessarily be in each link) and are to be carefully considered for proper optimization and utilization of the equipment and channels required. The communications subsystems must be capable of operation over a broad radio

frequency range; in addition, the telemetry subsystems must accommodate the scientific equipment as well as operational equipment of the MOLAB. Capability for data storage and read-out is implicit in the requirements of the systems. Sufficient video capability and resolution is needed to permit Earth control of the MOLAB prior to the landed crew's assumption of control.

Navigation

There is a close interdependence between the communications and navigation subsystems. This is because prior to actual landing of the astronauts, the communications subsystem is one means by which location of the LEM-Truck/MOLAB is determined. Even though large scale maps should be available for locating features and sites more accurately than is possible now, another means should be available. In addition, it is desirable to utilize the MOLAB guidance system for mapping during the geological traverse. The drift rates of inertial systems and the relatively small distances traveled make this method undesirable unless some means of accurately correcting errors is available. The accuracies desired, too, present some problems, particularly where change in elevation is needed. One scheme that has been suggested is through the use of an optical range-finder system which, by the use of conventional stadiametric processes, can precisely establish the location of the MOLAB in relation to known features. Once this is done, a local reference is available for mapping and navigation. Another possibility is a celestial navigation system which requires a star-tracker and an accurate star map for the lunar perspective.

The final design will probably be composite, using the best features of several methods, since each suggested method has so far at least one drawback. For example, the inertial method is too inaccurate; or, the optical method is limited if out-of-sight targets are needed. This would be the case if the LEM and LEM-Truck are not in line-of-sight after both have landed.

Locomotion

Lack of knowledge of the precise nature of the lunar surface presents certain problems in defining quantitatively and ideal locomotion system for a lunar surface vehicle. Obviously, any locomotion system must be reliable, mechanically stable, easily controllable, economical (from both power and mass considerations), and buildable. Various types of locomotive methods have been investigated (some of which are shown in Fig. 10). It appears that for crossing the Moon's surface, either a tracked or wheeled vehicle would be the best choice. At this time (and making certain assumptions about typical surface conditions), the best type of locomotion appears to be that provided by the use of a semi-rigid non-inflatable wheel. Again, it must be remarked that data from Ranger and Surveyor will either confirm or deny this choice.

This note of caution bears repeating in regard to the use of four wheels for this concept of MOLAB. It is the present belief that a four-wheeled non-articulated vehicle is more desirable; certainly an articulated vehicle is more complex. There is also much knowledge available about the design of four-wheel systems. This applies also to the choice of the conventional automotive suspension, which also provides very good vehicular control. Hence, Ackermann steering appears to be the logical choice, with each

wheel driven by its own direct current motor for propulsion purposes. However, it should be noted that preference for this locomotive system is not yet a resolved matter; future studies may provide entirely different results. Regardless of the final design, steering will most likely be accomplished by a closed-loop servo-mechanism system.

The lower gravity of the Moon may present some problem in regard to vehicle dynamics. Certainly there will be problems of sealing and lubrication, because of a large ambient thermal range and the extremely low pressure. Possible sintering effects

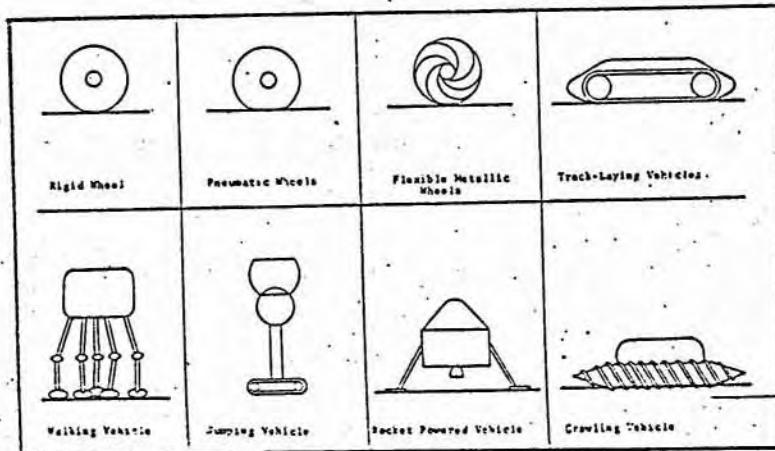


Fig 10 Representative Types of Locomotion

present an additional problem which must not be overlooked.

Tie-Down and Unloading

Earlier, it was mentioned that unloading of an ALSS payload must be done upon command. Fortunately, this does not necessarily mean that a pre-programmed sequence must be developed; it does mean that provision should be made for unloading the payload by

extra-human means. It is safe to assume that the LEM will not land within walking distance of the LEM-Truck (although this is a point which definitely requires clarifying). This means that Earth-controlled unloading, at least, is necessary. Present uncertainties of surface conditions dictate that the LEM-Truck be capable of unloading its payload in any azimuth. Certainly, the possibility of the LEM-Truck landing in a near horizontal position is small, because of local terrain conditions or because blast effect from touchdown. Finally, it appears at this time that it is logical to transmit through the tie-down mechanism docking loads between the LEM-Truck and Command Module.

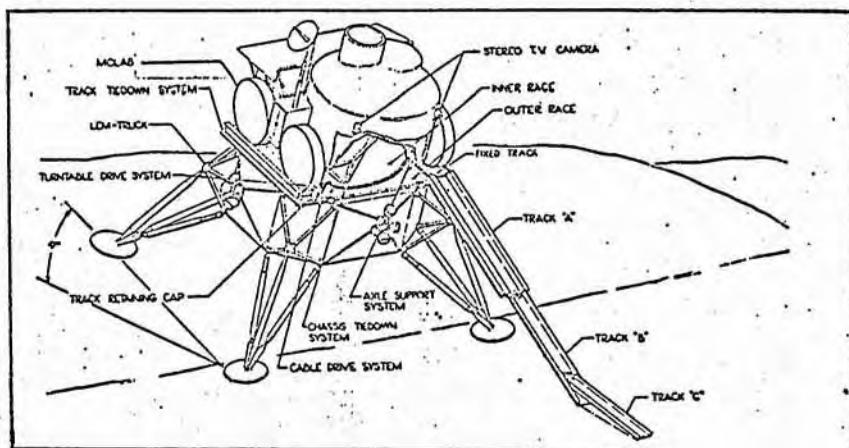


Fig 11 MOLAB Tie-Down and Unloading Concept

One concept of a tie-down and unloading system for MOLAB is shown in Fig. 11. The identifying features are a rotating turntable to facilitate unloading in any azimuth, the composite unloading track and a stereo TV camera for control purposes.

TYPICAL MISSION FOR MOLAB

Purpose of Mission Analysis

In order to properly assess the value of MOLAB, it is desirable to consider a possible surface traverse mission. This type mission is chosen because investigations to date suggest that it might be a typical ALSS mission. The duration is assumed to be a nominal fourteen Earth days and is planned so that eleven days, more or less, are in lunar day and the remaining time is in lunar night. Obviously, any plan, hypothetical or otherwise, must be incomplete at this time; however, the analysis should provide, at any point in the mission, answers to certain fundamental questions, such as:

1. What has been accomplished?
2. What remains to be done?
3. What does return to LEM site involve?
4. How long does it take to rendezvous with the CM?

The list of questions, of course, could be continued further, but the point is that a great deal of thought must be given to establishing the proper order of events for any lunar mission. The assumed criterion of effectiveness is satisfaction of the requirement that at any time during the mission, maximum possible return of useful data has been realized.

Selection of Landing Site

Many features can be distinguished on the lunar surface and a preliminary summary of some of these is given in Table 3. It is believed that a mission which can visit as many of the unique

lunar features as practicable will be more useful than one which visits only a few features. Therefore, the landing site for a MOLAB mission should be located in an area which has as many of the features as possible within a reasonable radius of operations.

Table 3
LUNAR MORPHOLOGICAL FEATURES OF INTEREST

Maria	Rays
Craters	*Highlands
*Pre-Imbrian Age	Rills
Imbrian Age	Wrinkle Ridges
Procellarian Age	Fault Scarps
Eratosthenian Age	Lineaments
Copernican Age	Ejecta
	Mare Scarp
*Maar (Volcanic) Craters	*Bright Hills With Ray Material
Chain Craters	Contacts
Satellitic Craters	*Other Phenomena
Domes	(Alphonsus, Linne, Etc)

*Features Not Found In The Kepler Region.

At this time, available geologic maps of the surface indicate that many features can be found within a small area in the Kepler region. Thus, this mission assumes a proposed landing site of $39^{\circ} 25' W$ and $4^{\circ} 40' N$. Twelve features of interest can be identified on the Kepler map within an eighty kilometer radius of this site.

During the traverse, a variety of geological, geophysical and geochemical studies will be made. Analysis of possible ALSS scientific programs is in progress to define the most useful investigations and instrumentation for MOLAB missions.

Traverse

Preliminary design data indicates that a total distance of several hundred kilometers might be the range of the MOLAB. A range of 400 kilometers has been used as a reference for the traverse developed here. Notwithstanding the possible availability of high resolution surface maps, the nature of the surface cannot be assumed known until the MOLAB physically travels over it. For this reason, it appears desirable that the MOLAB have the capability to retrace its path to the point of origin. This provides for the situation where the MOLAB may encounter a cul-de-sac near the end of the traverse and from which return to the origin is possible only by retracing the original path.

If on arriving back at the landing site, no retrace of any part of the traverse were required, enough propellant would be available for a second shorter traverse. If the second traverse be completed successfully, enough capability might remain to undertake optional experiments or observations near the LEM site. These factors indicate a "figure-of-eight" traverse according to the methodology shown in Fig. 12. In this traverse, a 30% margin was arbitrarily selected for contingency and local maneuvers. The daylight loop then was chosen as 185 kilometers distance and the night loop was taken to be 95 kilometers distance. A possible traverse is shown in Fig. 13.

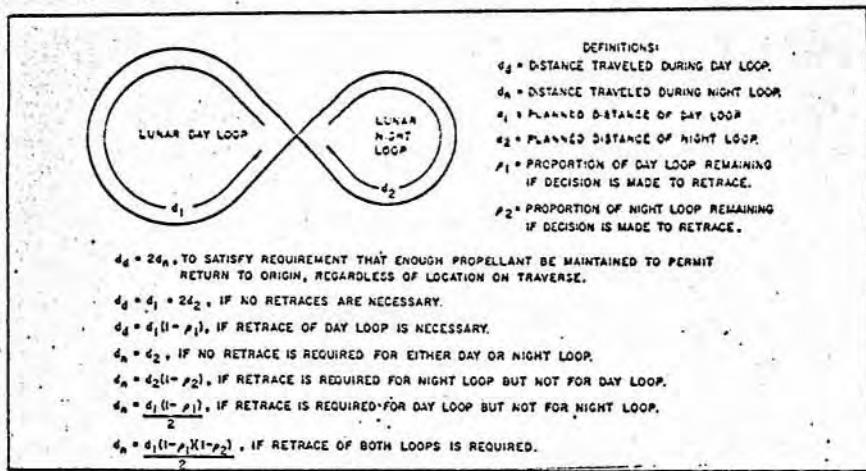


Fig 12 Methodology Used in Planning Lunar Surface Traverse

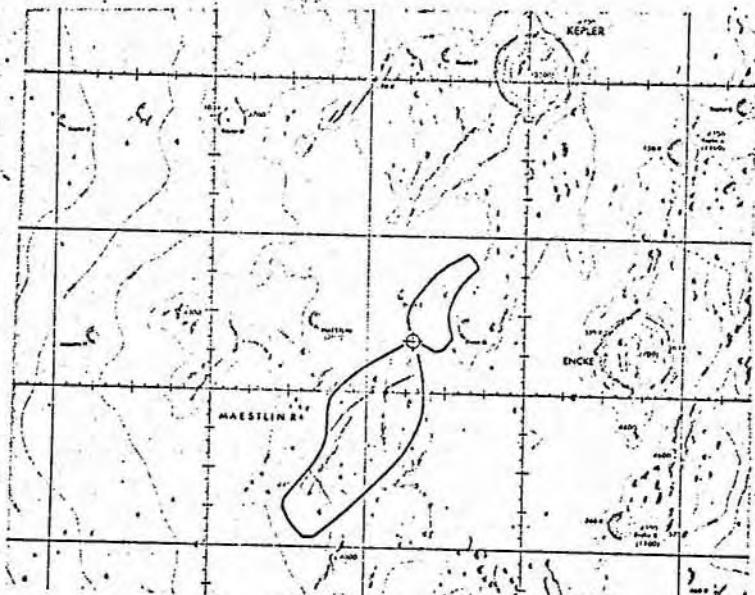


Fig 13 "Figure-Of-Eight" Traverse in The Kepler Region

* From Kepler, LAC 57, Aeronautical Chart and Information Center, USAF, St. Louis, Mo. July, 1961 ed. (Scale 1:1,000,000).

Indications are that it may be desirable to have the crew near the LEM site during the passage of the terminator. Regardless of any scientific advantage offered by this, it should be psychologically advantageous for the crew. Travel over unfamiliar terrain on Earth is more difficult at night than during the day, so it is reasonable to expect this to be true on the lunar surface as well. From an operations stand-point, it is desirable to have the crew on familiar ground during the transition from day to night. One reason is that if conditions are not satisfactory for travel during lunar night, the mission can be ended without undue risk.

Mission Elements

The elements of this - and probably any other - hypothetical mission may be described by two criteria. One is in terms of the mass allowances required. The other is in terms of time required. The former has been described under Systems Definition. Time requirements are determined more or less by the mission; therefore, time is the criterion for describing the major elements of the mission. These elements are engineering tests, data exchange, travel time, housekeeping (including eating, sleeping and resting), and scientific experiments and observations. Design of MOLAB subsystems and preparation of operations plans require valid data about times needed for each of these activities. Investigations to date, which must still be regarded as preliminary, have provided some data; the pertinent totals are shown in Table 4 and Fig. 14 as they might appear for a nominal 14 day mission.

Table 4
TRAVERSE TIME ALLOCATION

WHERE WHAT	DAY LOOP	NIGHT LOOP	LEM /LEM-T	TOTAL
ENGINEERING TESTS	---	---	30	30
DATA EXCHANGE**	12	7	12	31
TRAVEL TIME	40	22	3	65
EAT, SLEEP, HOUSEKEEPING	42	24	24	90
EXPERIMENTS /OBSERVATIONS	56	26	38	120
TOTAL	150	79	107	336

* INCLUDING CHECKOUT OF LEM AND MOLAB

** REQUIRING PERSONAL TIME OF CREW

(The time allocated for experiments and observations refer to occasions that MOLAB is at rest, as it would be at a scientific station. Although it is tacitly assumed that various measurements and recordings would be made while MOLAB is in motion, these properly should be identified as part of the scientific instrumentation studies now under way. For this reason, they are excluded from consideration here; however, provisions for them should be made during design).

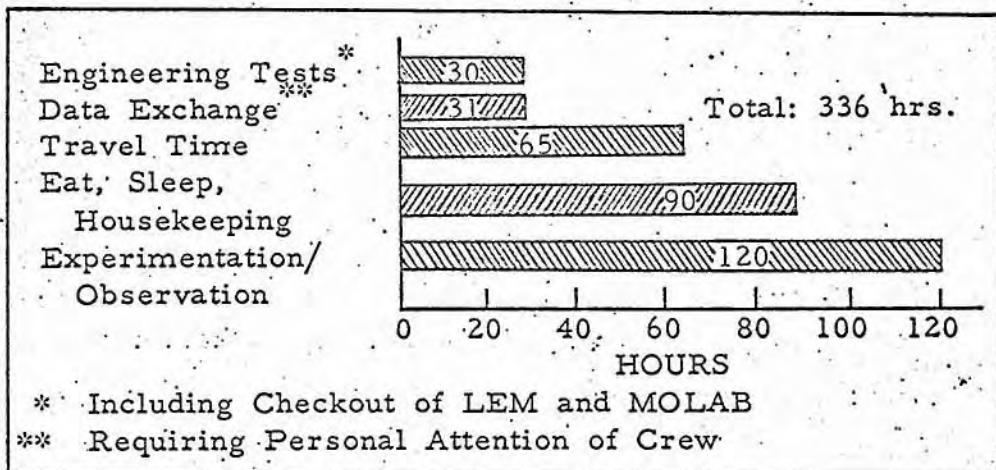


Fig. 14 Allocation of Activities (Typical)

For further insight into the activities to be accomplished, a typical (insofar as it can be described at this time) twenty-four hour period is graphically shown in Fig. 15. Specific activities associated with each station rely, naturally, upon the experiments and observations to be performed. It is probably safe to assume that there will be a basic set of measurements at each station, but the peculiarities of features and terrain most likely will dictate the activities to be performed.

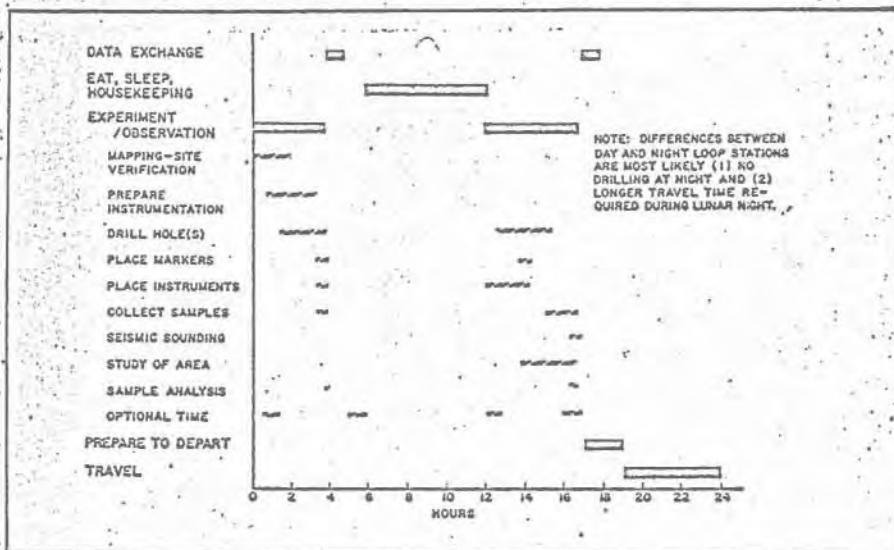


Fig 15 Activity Breakdown For Typical 24 Hour Period

Scientific Mission Considerations

The scientific objectives and instrumentation are beyond the scope of this paper; yet, there are two operations which merit short discussion. The first is mapping and the second is drill-hole logging. As indicated earlier, mapping will depend upon the navigation system and upon photographic methods (including both film and video techniques). The traverse so far described, when considered with the increased curvature of the Moon, will very

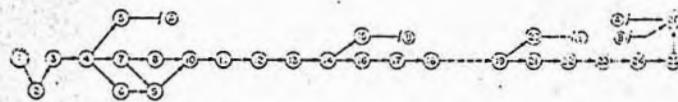
likely require many verifications of position. This could require a significant amount of time. Because of the obvious close inter-relationship between mapping for navigation purposes and mapping for scientific purposes, it is believed that mapping requirements require careful planning prior to equipment definition.

Drilling requires no such subtle interfaces as mapping; however, this operation will undoubtedly require a sizable amount of power in order to provide a hole suitable for logging and other purposes. Since it must be assumed that lunar rock is at least as hard as the hardest of Earth rock, it is reasonable also to assume that appreciable drilling is required. This means the MOLAB must be at a drill-hole site for some time. The extent to which this detracts from the overall mission must be carefully examined.

These two activities serve to illustrate the point that is not altogether practicable to design a surface vehicle and then define a mission for it. The expected close margins for each integrated functional subsystem therefore require that consideration be given the mission during design of the MOLAB, just as mission planning requires that thought be given to MOLAB design limitations.

Operations Plan

It is always helpful to present an overall view of a mission, particularly one so ambitious as the one under discussion. Consequently, a modified critical path network for the nominal fourteen day mission is shown in Fig. 16.



1. LEM/T LANDS; INSTRUMENTATION DEPLOYED AND OPERATED.
 2. MOLAB UNLOADED.
 3. PERIODIC CHECK-OUT.
 4. CM/LEM COMMITTED, CRIT achieved.
 5. CM CONTINUES ITS MISSION.
 6. MOLAB ACTIVATED.
 7. LEM/T AND LEM SITES VERIFICATION.
 8. LEM LANDS.
 9. MOLAB GUIDED TO LEM.
 10. LEM PLACED ON STAND-BY; MOLAB CHECK-OUT.
 11. TRANSFER TO MOLAB COMPLETED.
 NOTE: UNTIL THIS EVENT IS COMPLETED, THE MISSION MAY BE ADJUSTED ALMOST AT WILL, DEPENDING SOLELY UPON POSITION OF THE CM. FUTURE ASCENTS REQUIRE RETURN TO THE LEM AND ACTIVATION OF THE ASCENT STAGE.
 12. MOLAB ENGINEERING TESTS; MOVE TO LEM/T (STATION NO. II).
 13. RE-VERIFY LEM/T SITE; ENGINEERING EXAMINATION OF LEM/T.
 14. PERFORM PRESCRIBED EXPERIMENTS AND OBSERVATIONS. THIS IS THE START OF THE SCIENTIFIC MISSION PER SE.
 15. ABORT.
 16. PREPARE TO LEAPTOFF FROM STATION NO. 2.
 17. TRAVEL TO STATION NO. 2.
 18. ARRIVE AT STATION NO. 2; PERFORM PRESCRIBED DUTIES. AFTER THIS EVENT, STEPS 16, 17, AND 18 ARE REPEATED FOR SUCCESSIVE STATIONS ON THE TRAVERSE, UNTIL ARRIVAL AT STATION NO. I.
 19. ARRIVE AT STATION NO. I; ROUTINE MAINTENANCE, ETC. THIS IS THE END OF THE DAYLIGHT PORTION OF THE TRAVERSE.
 20. ABORT.
 21. PERFORM DUTIES ASSOCIATED WITH THE PASSAGE OF THE TERMINATOR.
 22. PERFORM DUTIES ASSOCIATED WITH LUNAR NIGHT.
 23. PREPARE TO DEPART FOR NEXT STATION.
 24. RETURN TO STATION NO. I; PERFORM PRESCRIBED DUTIES.
 25. TRANSFER TO LEM; PREPARE FOR RENDEZVOUS.
 26. RENDEZVOUS WITH CM; DEPART FOR EARTH.

Fig 16 Scientific Mission Sequence of Events for a Fourteen Day Mission (Typical)

As shown, the mission begins with the arrival of the Apollo Command-Module/LEM-Truck with MOLAB payload into lunar orbit. The mission terminates when the ascent stage achieves rendezvous at the end of the traverse. Two possible abort events are shown. Again, the events shown are based upon data presently available. As more knowledge is obtained, it hopefully will be possible to assign times to each event and a mathematical simulation model will be available for optimizing each mission according to its predetermined objectives.

The operation plan shown above provides the mechanism by which answers to the questions raised earlier can be obtained. A similar network can be prepared for each station along the traverse or for each day's activities.

It is worth noting, too, that once the MOLAB has started on the traverse, it is not a simple matter to abort the mission. Up until this time, it is necessary to wait until the CM is in the proper orbital position before initiating lift-off. This time is never longer than the period of the CM orbit (approximately 2 hours). This presupposes that events are such as to allow delay until lift-off. However, after the MOLAB leaves the LEM, time must be provided for return to the LEM. This time is a direct function of the distance to be traveled to the LEM.

More data and study are required before sequencing of activities and allocation of time can be optimized. Much cannot be done until a final design of the MOLAB is chosen; much must await the definition of a scientific mission and the development or adaptation of scientific instrumentation for lunar exploration. This plan has portrayed the general considerations in order to identify areas where further study is indicated.

ENVIRONMENTAL CONSIDERATIONS

Payloads for ALSS will be exposed to severe environmental conditions. These environmental conditions are expected to vary greatly during the life-time of the payloads as they go through various phases on Earth, during flight, and during their stand-by and operating modes on the lunar surface.

These conditions encountered by ALSS payloads will be, at first, essentially those encountered by any spacecraft or satellite. Later, during an actual mission on the lunar surface, new environmental conditions will be encountered which will require special attention. Some of these are peculiar only because of their severity; for

example, the extremely low temperatures which some components or parts of the payloads will be subjected to during the long lunar night. Others, like particle radiation, become more serious than they presently are for spacecraft and satellites because of the long-time exposure. The same is true of micrometeorites, but the severity is expected to be intensified by secondary ejecta caused by impact of micrometeorites on the lunar surface.

Environmental conditions which did not have to be considered until now, except for lunar soft-landing spacecraft, are: electromagnetic radiation emanating from and being reflected by the lunar surface (expected to be equivalent to approximately one solar constant); surface topography; sand and dust; lunar gravity; possible surface electric potential; possible radioactivity; and possible seismic activity.

The topography of the lunar surface in small detail is not known as yet because the resolution of observations and photographs is presently in the range of 150 m (450 ft) to 400 m (1,200 ft). Until information of the lunar surface structure from Ranger and Surveyor flights becomes available, a hypothetical Engineering Lunar Model Surface (ELMS)* will be used for further studies. This model has been prepared for the general area of exploration described above. It is based on the theory that the as yet unknown micro-structure profile of the lunar surface directly resembles its macro-structure. Conservative estimates of the various pertinent soil constants have been included in this model surface. The study considers maria and upland surfaces. Furthermore, "Standard Obstacles" have been postulated for evaluating obstacle negotiability for a lunar surface vehicle. Such model surfaces

*This is now in working paper form and is expected to be published as a NASA technical paper in the near future.

are particularly valuable in order to compare different locomotion designs and evaluate their performance.

MOLAB TESTING CONSIDERATIONS

Reliability

As in any manned mission, the reliability of all sub-systems and their integrated operation is of paramount importance. ALSS systems should be given an extensive program of development and quality assurance testing at all levels of assembly. A thorough training program of the astronauts and the ground crews on Earth should be provided to minimize human error.

Environmental Tests

Environmental tests, including combined environmental tests, will have to be conducted to the greatest extent possible on complete MOLAB prototypes, consistent with the relative yield of information from the specific tests, the practicability and cost of the test, and the cost of the required test facility.

Critical Tests

One of the critical problems is thermal testing of the MOLAB. It would be desirable to test full scale prototypes. The purpose would be to verify experimentally the proper thermal design of the MOLAB and subsystems for varying thermal conditions on the lunar surface. A realistic simulation of electromagnetic radiation in a lunar environmental chamber is complicated by the problems of simulating radiation emanating from and being reflected by the lunar surface, in addition to that of direct solar radiation.

Another critical area in testing of the MOLAB pertains to the realistic simulation on Earth of its dynamic and mobility characteristics under the influence of the lunar gravity. Considerations have been given to testing full scale vehicles with suspension systems equipped with special springs and damping devices, scaled down models, and other means. Much study on this subject is still required.

Extended lunar environment exposure tests for MOLAB may be considered critical from the point of view of the length of their duration, as they will be tying up costly major facilities for many months. A payload such as the MOLAB should undergo exposure tests under simulated lunar environmental conditions; that is, vacuum, simulated space heat sink, and solar and lunar electromagnetic radiation. The total test duration shoud, if possible, be equal to the useful life-time of the vehicle. During such a test, the MOLAB must be brought to operational status several times, checked out, possibly with active participation of astronauts where feasible, and returned to dormant status again.

Astronaut Training

In order to accomplish their mission, it is of the greatest importance that the astronauts be thoroughly acquainted with the equipment they must use on the lunar surface. They must know how to operate the equipment, check it out, trouble-shoot, and be able to accomplish simple adjustments and/or repairs under lunar environmental conditions, in many cases while wearing a space suit. Repeated operation of the various subsystems and systems by the astronauts seems desirable, first under Earth ambient conditions and later, if feasible, under simulated lunar

environmental conditions. In addition, training in simulators will be needed before mission testing is started.

Mission Testing

After the astronauts have been trained sufficiently in simulators and in the use and operation of all subsystems, including scientific instrumentation, they must participate in a series of simulated mission tests. Early tests of this nature will be performed under partial simulation of the lunar environment only. Ultimately, mission tests should be performed under conditions which approach those on the lunar surface as much as practical. This includes exposure of astronauts and equipment to vacuum conditions. Such tests would have to be conducted in a large lunar environmental chamber. Astronauts should remain in the chamber for the duration of the mission test. This test should be as long as the planned mission, while the astronauts are performing, to the maximum extent possible, all the various tasks and duty cycles described in the section on a typical mission for MOLAB above.

It would be desirable to simulate these conditions during a mission test:

- a. Vacuum ($< 10^{-4}$ torr)
- b. Simulated heat sink of space (black shrouds at LN₂ temperature).
- c. Solar simulation which also provides simulation of the rising and setting sun.
- d. Earth shine simulation which provides for changes in relative position of the Earth.

- e. Simulation of radiation emanating from and being reflected by the lunar surface.
- f. Simulation of the lunar surface, representing a typical landscape of the region of landing, including simulated lunar soil, if possible, and rocks, and with a topography simulating that resulting from the jet blast of the LEM-Truck.

CONCLUSIONS

The results of studies conducted during the last eighteen months indicate that it is feasible to provide an early Apollo Logistic Support System by using the payload carrying capability of a LEM-Truck. A payload delivered in this manner will be capable of extending stay-time of a LEM-landed astronaut team up to possibly two weeks duration. The Lunar Mobile Laboratory (MOLAB) is one such payload. It can provide a self-contained environmental control system, locomotion, power, communications, navigation, food and scientific equipment. A two-man astronaut team with MOLAB can perform a broad and informative scientific exploration mission.

The equipments and mission operations plan that have been described are admittedly general in nature. Hopefully, knowledge gained from such programs as Surveyor will permit the design of payloads which are based not on admittedly conservative estimates but on actual lunar conditions. The system which has been presented should be capable of performing general explorations or highly specialized missions, whichever may be desired. The operations plan which has been defined can be useful for mathematical simulation of missions in order that a more optimum ordering of events can be obtained.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the advice and assistance of their many colleagues and associates within the National Aeronautics and Space Administration. In particular, credit is given to the following:

Marshall Space Flight Center

Mr. P. J. de Fries	Aero-Astrodynamics Laboratory
Mr. James A. Downey, III	Research Projects Laboratory
Dr. Daniel P. Hale	Research Projects Laboratory
Mr. John Rains	Propulsion and Vehicle Engineering Laboratory
Mr. Stan Johns	Propulsion and Vehicle Engineering Laboratory
Mr. Edward Dungan	Astrionics Laboratory

Kennedy Space Center

Mr. Georg von Tiesenhausen	Future Studies Branch, Launch Support Equipment Engineering Division
Mr. David Cramblit	Future Studies Branch, Launch Support Equipment Engineering Division

Office of Manned Space Flight

Mr. Donald A. Beattie	Advanced Manned Missions Program
Maj. Edward Andrews	Advanced Manned Missions Program

Finally, especial thanks are due Miss Mildred Howard, who spent many hard and hectic hours typing and retyping the manuscript.