Apr 5th, 8:00 AM

Apollo Exploration Shelter System

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APOLLO EXPLORATION SHELTER SYSTEM

by

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SUMMARY

This paper presents two unique personnel shelter systems. When functioning either alone or with MOLAB, they will provide the capability for maintaining 2 or 3 astronauts on the lunar surface for a duration of 30 to 44 Earth days with a stay-time growth potential of 90 days. These shelters offer the United States Lunar Exploration Program the operational flexibility and number of man-days on the Moon required to accomplish a wide range of necessary exploration and scientific missions, including a capability to maintain and repair the LEM, MOLAB, and the shelters themselves. An additional feature of the system is that a Lunar Roving Vehicle or a Lunar Observatory as well as a Shelter can be transported on the LEM truck in a single flight to the lunar surface by the Saturn V transportation system. Further, the shelter system concept optimizes the systems approach to lunar exploration in terms of timeliness, operational flexibility, growth potential, and return on the Apollo investment.

POST-APOLLO LUNAR EXPLORATION BUILD-UP

In general, accepted planning for post-Apollo lunar base activities has followed the approach developed in the NASA CR-39 document titled, "Initial Concept of Lunar Exploration Systems for Apollo, (LESA)". The concepts developed in the referenced document were influenced by the guidelines established at a time when more complete knowledge was not available. However, since then, more information has been gained and a greater understanding of the total lunar exploration problem has evolved. For example, there is now a greater realization of the continuing increase in current lunar exploration cost; the physiological limitations of man in other than a terrestrial environment; the engineering requirements for a given time period, experiments, equipment, and the number of manhours required to perform each. There is also a realization of the need for considerable operational flexibility in lunar exploration capability prior to any attempt to establish a permanent or semi-permanent lunar base. In NASA CR-39, four LESA base concepts are given. The base build-up begins with a capability of 3 men for 3 months and continues through the fourth base which has 18 men for 24 months. This concept depends upon the capability to deliver a 25,000-pound payload to the Moon. These four bases were essentially programmed in two phases: Base I and II having non-nuclear power and Bases III and IV having primarily nuclear power sources. Assuming that the physiological needs of man can be provided during the projected LESA stay-times on the Moon, this division may still be valid: if a 25,000-pound payload delivery capability is developed, if effective utilization of substantial man-days on the lunar surface can be accomplished, and if large quantities of power are available to support the lunar activities.

Since Westinghouse has a vital interest in the total manned lunar exploration program, a detailed examination of payload capabilities and lunar exploration needs versus program costs and mission flexibility was made. The results show that a redefinition of post-Apollo lunar exploration and base build-up phases is in order. Table 1 summarizes these phases redefined.

Table 1. Apollo Lunar Exploration Program

BASIC CHARACTERISTICS	PHASE I	PHASE II	PHASE III
PAYLOAD	6500 to 10,000	25,000 to 30,000	40,000 to 60,000
POWER	NON-NUCLEAR	NUCLEAR	NUCLEAR
LOGISTICS SUPPORT	APOLLO ORBITAL FLIGHT	DIRECT EARTH LAUNCH	EARTH ORBITAL LAUNCH
TRANSPORTATION	SATURN V LEM TRUCK	SATURN V LI & LII	IMPROVED SATURN
ASTRONAUTS	2 to 6	12 to 18	24 or more
DISPOSITION	EXPENDABLE	SEMI-PERM	PERMANENT

The basic three-phase breakdown shown in Table 1 is determined by the payload capability of the spacecraft used with the Saturn V in a given time period. In this approach, cost effectiveness is the vital issue -- maximum accomplishment for minimum cost.

In Phase I, the Apollo spacecraft with the LEM truck is the determining factor. It is during this phase that the greatest flexibility in exploration capability for the least cost is mandatory and the one in which shelter systems of the type discussed in this paper have the greatest impact. The next time period (Phase II) is determined by the lunar logistics vehicle (LLV) spacecraft with its L-I and L-II stages delivering a larger payload to the Moon. The advent of this phase is determined by the developing demand for heavy (nuclear) power on the Moon and the justification of the need for extensive man-days on the Moon at one location (approximately 4300 to 13,000 man-days).

The third time period (Phase III) will be determined by the development of an improved Saturn capable of delivering very heavy payloads to the Moon. The advent of this phase is determined by the decision to establish a long term or permanent lunar base. Here, Earth orbital logistic support and lunar shuttles will probably be employed.

In the earliest time period of Phase I, the Apollo spacecraft is the determining factor. Several programs are underway, based upon the payload capability and the NASA-stated need to stay within the Apollo spacecraft configuration. Briefly, these programs involve the following: the Lunar Excursion Module (LEM) is the first planned payload with a stay-time of 1 day. A stay-time-extended LEM (STEM) to extend stay-time to 3 to 14 days for 2-man crews is also under consideration. It is recognized, however, that extensive lunar exploration requires mobility and conceptual studies, and prototype designs for a Mobile Laboratory (MOLAB) have therefore been funded by NASA. It is postulated that further division and study in this area will occur. The MOLAB provides several hundred miles of mobility and has a stay-time of 14 days with the 2-man crew, (or 28 man-days to accomplish its lunar exploration mission). The MOLAB can be resupplied in several ways, one of which is to deliver expendables in a saddlebag mode on a LEM delivering a second crew. Thus, the MOLAB would be capable of a 56-man-day mission, provided it can continue to function reliably for this period of time without maintenance.

The Westinghouse shelter concept, which is capable of being landed on the Moon by the Saturn V and LEM truck system, not only reduces the high costs of lunar exploration but extends the operational life of MOLAB from 336 to approximately 2000 hours or more. More important, it provides continual incremental increases in man-days on the Moon up to as many as 1080 man-days. It also provides flexibility in astronaut stay-time and can be redirected at anytime in mission scope and location. The shelter concept also takes advantage of the decreasing unit cost, increasing reliability, significant growth potential and learning curves and training factors inherent in the extended use of the basic Apollo spacecraft. Further, it provides an early capability to conduct studies on the Moon in the astrophysical, and selecological and other scientific areas wherein extended stay-time is mandatory and rotation of scientists of several specialties is required. As an added feature, the concept provides the capability for extensive early lunar satellite reconnaissance, in that Apollo Command and Service Modules (which deliver into lunar orbit the LEM trucks carrying the MOLAB, or the Westinghouse shelter) can be extensively instrumented for manned lunar reconnaissance. The cost of the reconnaissance operation can be shared with the lunar surface operation, since the same Saturn V booster system is used. There are also other areas of flexibility. The same basic shelter can be used as a maintenance facility for MOLAB by including the expandable section. By leaving off this section, the shelter can carry a Westinghouse lunar vehicle on the same payload which can support a crew of 2 and complete a number of essential missions planned for MOLAB at a substantial reduction in cost and weight. Another option available is to carry a large astrophysical device such as the beryllium lens telescope developed for the Orbiting Astronomical Observatory. This would provide at an early time unprecedented scientific research capabilities for a minimum investment. Finally, through the full exercise of the described capability, the requirements and engineering specifications for the larger semi-permanent base of Phase II and the permanent base of Phase III will be well-defined and tested prior to risking the very large investment required for such bases.

POST-APOLLO EXPLORATION PROGRAMS

The objectives of the post-Apollo Exploration Program are to conduct comprehensive exploration of the Moon, to carry out experiments in the space sciences, and to exploit the Moon and its resources if practicable to do so. Experiments carried out on the Moon will have to provide unique

and significant contributions, not achievable by Earth-based or space-laboratory-based experiments. The scope of these experiments will cover the broad spectrum of the traditional disciplines of physics, chemistry, and astronomy, joined by the biological sciences and selenology.

Although the information gained from unmanned lunar probes such as the Ranger, Surveyor, and the Lunar Orbiter, and the subsequent manned landing of LEM and STEM, will be extremely important; the opportunity for scientific exploration to determine the nature of the Moon, the development of the solar system, and the nature of the universe beyond it, will, of necessity, be far too limited. Also, the projected MOLAB mission, which is to explore the lunar terrain up to about 300 miles from base with a lunar roving vehicle is inadequate. Although much useful data on specific features of the lunar terrain could be obtained during the fourteen-day journey, the prime purpose will be to demonstrate, in a manner similar to famous exploration feats on earth, that certain planned objectives can be reached and that the lunar surface can be traversed with a roving vehicle. Any detailed examination of the lunar surface and underlying strata may be only marginally feasible in view of the limited time available at any one location. Furthermore, several significant experiments in the different disciplines may require the emplacing of delicate equipment, adjustment or observation by the experimenter, data collection techniques and experimental test duration inconsistent with the capabilities of the roving laboratory.

As an example, consider the geophysical investigation of a limited area around a lunar shelter. Lunar photographs, such as the Ranger photographs, will provide detailed topographical maps; therefore, the shelter could be landed in a region which is considered to be most interesting. The area to be explored (about 1 KM square) in detail would be within easy access of the shelter. The first step would consist of the set-up and calibration of equipment such as a magnetometer, which would be placed about 100 meters from the shelter area to obviate the possibility of interference from fields set up by the shelter. This set-up and calibration would take from five days to one week (Earth days). The second task would be to carry out a topographic survey to determine grid lines at 100-meter intervals, using techniques similar to those used on Earth. Identifying marks will be needed at each of the grid line intersection points. In areas of particular interest, such as around a crater, a much closer view would be necessary. In this area, the first drilling and logging of a hole would take place. This same drill hole would be used later to place heat-flow instruments after the hole has returned to temperature equilibrium. Gravitational and magnetic traverses would be made over the lines which had been previously identified so that a measure of the sub-area substructure could be determined. Detailed geological gravitational traverses and magnetic surveys would be made and samples taken from some of these interesting areas. These samples would be analyzed; and, on the basis of the analysis, specific areas would be selected for minimum shallow seismic surveys; these surveys would indicate where additional holes should be drilled.

It has been shown that the minimum possible time needed to drill a hole of the necessary depth is about one day. To accomplish this, completely new drills would need to be developed. After each hole has been drilled, the core would be analyzed by the various techniques known today. Shallow seismic surveys would also be carried out in other areas which are interesting and additional gravitational surveys would be conducted in these areas. The last item of business would be to emplace a heat-flow measurement in one or more drill holes and to make heat-flow measurements.

The effort described above requires approximately 60 Earth days (as a minimum) to complete the essential work. This, and similar experiments, will have to be repeated in a number of different locations on the Moon before sufficient information can be obtained to enable adequate determination of the composition of the Moon, and whether or not its resources can be beneficially exploited.

Therefore, a fixed installation, such as the lunar shelter, would provide (in addition to the necessary stay-times or man-days) a scientific base camp from which an area can be thoroughly explored. Because the experimenter will be in a fixed location, with no immediate and unknown hazards facing him while traversing an uncharted terrain, he will be psychologically more attuned to devote his attention to the gathering of data rather than to anxiety of assuring his survival.

SHELTER DESIGN CONCEPTS

It is pertinent here to discuss the structural design of a basic lunar shelter which can meet the specified volume, configuration, and environmental requirements within a total system weight of 5612 to 9725 lbs for a specified lunar mission. Two basic shelter design concepts are presented. They are: a Rigid Shelter (Model A)(figure 1) and a combined Rigid/Expandable Shelter (Models B and C) (figures 2 and 3).
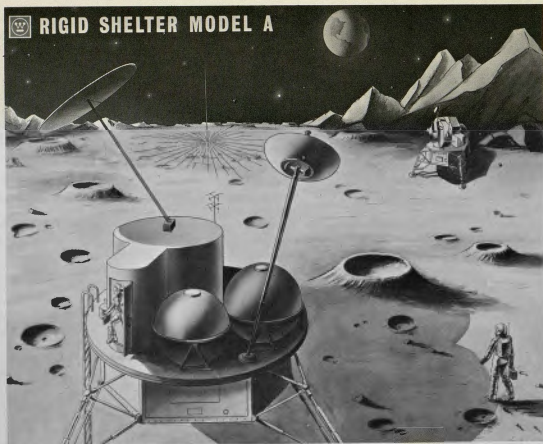
Figure 1. Rigid Shelter, Model A

RIGID EXPANDABLE SHELTER
MODEL B-2

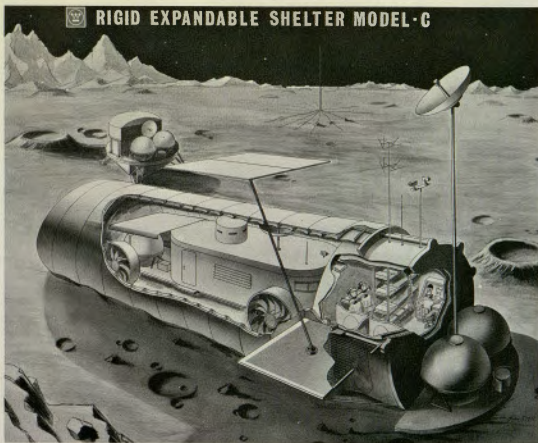Figure 2. Rigid Expandable Shelter, Model B

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Figure 3. Rigid/Expandable Shelter, Model C

The Rigid Shelter (Model A) system weight is in the range of 5612 to 5961 pounds, depending upon the material selected for the basic load carrying structure. This shelter, like Models B and C, is designed to be contained wholly within the prescribed limits of the conical shroud for the LEM payload. Shelter Model A is designed to withstand loads induced from pre-launch, launch, Earth-to-Moon transit, and landing on the lunar surface. The shelter is designed to have a 0.99 probability of 0 penetrations from meteoroids for a period of 1 year unattended lunar storage, plus an additional 30 or 44 days, during which time the shelter is occupied by astronauts. The shelter is therefore designed against meteoroids for a total period of 395+ days, within which time six or more 30 or 44-day operational cycles can occur, depending upon the selected mission option. Maximum use is made of double wall construction with filler material (thermal insulation) to provide maximum protection for the least weight. The basic design provides radiation protection sufficient to insure a probability of 0.99 that the astronauts will not receive a dose in excess of 200 rads for a period of 30 to 44 earth days. The allowable exposure is dependent upon the radiation background used for design (refer. fig. 5). Additional radiation protection is provided in the airlock during occurrence of major solar flares. At the end of this time period, a new crew of astronauts will occupy the shelter and replenish the expendables, in order to repeat the cycle of operation. The radiation shielding provided in the design takes advantage of the biological recovery factors from radiation exposure. [1] In addition, the design utilizes various combinations of metals and non-metals to obtain maximum protection from radiation with a minimum of weight within practical limits.

The problem of providing a minimum amount of leakage around such items as the airlock-door is solved by a unique multipoint contact seal that permits easy opening and closing action. [2] The total leakage from the proposed seal is at a rate of approximately 3.0 lb/yr. The solution to lubrication problems appears feasible based upon test data on self-lubricating materials containing metal based composites of various percentages of polytetrafluorethylene and tungsten diselenide. [3]

Shelter Model A makes maximum use of the available volume and configuration prescribed by the LEM shroud. This permits the other parts of the system such as life support equipment, thermal-electric generator, antennas, thermal radiators, sunshade, cryogenic tanks, etc., to fit within the shroud limits and in the desired location. This shelter can easily be fabricated from conventional materials.

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The rigid-expandable shelters (Models B and C, figures 2 and 3) with system weights of 7055 to 7759 pounds and 8684 to 9725 pounds, respectively, are designed to be transported on the LEM truck within the prescribed limits of the conical shroud. However, the system weights are higher than for Model A because of the expandable section which will provide additional volume on the lunar surface. The rigid segment of these shelters is designed to meet the same environmental requirements as Model A. The expandable segment, because of its large exposed volume, weight limitations, and material problem in a space environment is currently designed to provide protection when expanded, from the lunar environment (meteoroids and radiation) for a period of 15 days of continuous occupancy by the astronauts. However, the expanded portion of these shelters have the capability of being retracted into their original configuration (as landed). This permits the life of the expanded section to be distributed over a long period of time, depending upon the number of days and cycles required for various maintenance, calibration or laboratory activities. Shelter Models B and C, in their retracted position are integral with the rigid shelter. When expanded, the shelter is capable of being pressurized to provide an area of controlled environment.

The design of the expandable section Shelter Models B and C includes an integral bladder to contain the pressure loads. This bladder consists of Dacron which supports the stresses induced by the internal pressure, and Mylar to reduce gas leakage. Surrounding the bladder are two rows of telescoping metal shields spaced approximately one inch apart. These shields provide the required protection against the meteoroid and radiation environment. Structural arches are spaced at given intervals and support the pressure loads acting on the bladder. Each arch is fastened at six (6) places to a tube which is a structural element of a telescoping mast. These tubes provide lateral support to the arches and carry a portion of the pressure acting on the end door which is an integral welded structure of stringers and skin. A multipoint contact inflatable seal is used around the large end door to provide a minimum amount of leakage.[2] It is calculated that the total leakage rate from a seal configuration of this type is 18.40 lb/yr. However, venting or leakage rates of 0.2 lbs/hour for each shelter are necessary to avoid toxic gas contamination.

The expandable portions of Shelter Models B and C are similar. The rigid portion of Model B is similar to the rigid shelter, Model A. Model B is mounted in its normal operating position on the LEM truck but must be removed for operation. However, the configuration of the rigid portion of shelter Model C is different because of the packaging requirements. The shelter Model C is placed on the LEM truck with its longitudinal axis (axis parallel to lunar surface) in the vertical plane. This requires that the shelter be removed from the LEM truck and then rotated 90° for operation. The expandable portions of Models B and C are both capable of being retracted against the rigid portions of the shelter. To expand the shelters it is only necessary to apply a force on the large end door.

Wherever possible, the design of the shelters utilizes the construction material for more than one function. For example, the thermal insulation also provides a percentage of the required radiation protection, the sunshades (for Models A and B) are located in their 1 year storage position so that they add to both meteoroid and radiation protection for the upper portion of the shelters and the inner pressure shell serves as a main load carrying structure and as both a radiation and meteoroid shield.

DESIGN CONDITIONS

Meteoroids

The meteoroid environment of project Apollo is used as a structural design criteria.[4, 5] The meteoroid flux used in this analysis is expressed as follows:

$$F = \alpha \; m^{-B}$$

F =   particle flux having a mass (m) or greater, number of particles per unit area per unit time

α =   a meteoroid environment parameter with units of mass per unit area per unit time = $10^{-12.955}$

B =   a dimensionless meteoroid environment parameter, $B = 1.0$

m =   meteoroid mass

F = $10^{-12.955} \, m^{-1}$

Application of the hypervelocity penetration theory results in the following relationships:

$$t = 10^{-2.005} (AT)^{1/3}$$

t = required thickness of a single-sheet meteoroid protection, inches

A = square feet, T = days.

The above equation was developed for aluminum and probability of 0 penetration of 0.99. Values of (t) are shown in figure 4 for an exposure range of 100,000 to 200,000 ft^2 -days. For example, if we assume that the Rigid Shelter Model A has an exposed surface area of 348 ft^2 and that the exposure time on the lunar surface is 395 days (1 year standby plus 30 days operational) the following single sheet thickness of aluminum is required.

$$t = 0.516 \text{ in. for } AT = 13.75 \times 10^4 \text{ } ft^2 \text{ -days.}$$

A double wall construction with intermediate filler material, such as thermal insulation, has a greater efficiency in stopping meteoroids than a single thickness.[6] When an outer shell, which is the meteoroid bumper, and an inner shell, which is the shelter wall, are spaced a minimum of 1 in. apart and the space filled with insulation, the following relationship applies: $t_B + t_S = 0.16t$, t_B = bumper thickness, t_S = shelter thickness. The bumper thickness, t_B, is dependent upon the expected meteoroid diameter which is related to the exposed area by the following relationship.

$$d = 10^{-2.562}(AT)^{1/3}$$

For $AT = 13.75 \times 10^4 \text{ } ft^2$ - Days

$$d = 0.140 \text{ in.}$$

Let t_B (min) = 0.5 d

$$t_B = 0.070 \text{ in. (min.)}$$

Therefore, the shelter skin thickness required for meteoroid protection, with a probability of zero penetrations over 395 days exposure equal to 0.99,

$$t_S = 0.16 (0.516) - 0.070$$

$$t_S = 0.013$$

Because of other environmental factors, a much larger value of t_S is required in the actual shelter design.

Radiation

Reports prior to Westinghouse Research Laboratory's study[1] did not take into account any biological recovery factor. The Westinghouse study demonstrates substantial reduction in radiation shielding requirements for the astronauts if the biological recovery factor is considered. This concept is used as the basic reference for the design of the shelters.

This shelter is designed to have a probability value of 0.99 that the astronauts will not receive a radiation dose in excess of 200-rad for a period of 30 days of exposure. From figure 5 it is determined that 3.62 pounds per square foot of aluminum bulk material or equivalent is required.

To establish values for equivalent weights and thickness for materials other than aluminum the following table was developed[1]. This data is based on the material being subjected to one NASA model solar flare and is used for material comparison only.

	Polyethylene (CH₂)	Aluminum	Thermal Insulation (NRC-2)
Equivalent unit weight (lb/ft^2)	4.40	6.12	4.97
Equivalent thickness (inches)	0.93	0.426	42.60
Density (lb/ft^2)	56.80	173.0	1.40

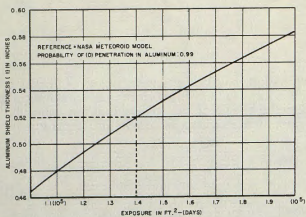$$\text{Thickness} = \frac{\text{Unit weight}}{\text{Density}}$$

Figure 4. Aluminum Single Wall Thickness for 0.99 Probability of No Penetration Versus Exposure in ft² Days
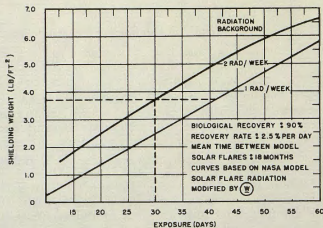
Figure 5. Shielding Thickness Versus Exposure for 0.99 Probability of Not Exceeding 200 RAD (skin dose) (Westinghouse Data)

The relationships in the preceding table indicate that a lighter design can be developed by using either NRC-2 or CH_2 as compared to aluminum to obtain the same amount of protection from the radiation environment. However, the required thickness is much larger and in many cases would not be practical for design. The shelter designs proposed in this paper makes use of these relationships to establish the required amount of radiation shielding. The actual values of unit weight shown in the table are used only to establish equivalent ratio's between the various materials. The actual design value for the radiation sheilding requirement is 3.62 pounds per square foot of aluminum or equivalent. For example, preliminary analysis established the following design characteristics for the cylindrical wall of the Model A shelter to be:

Outer meteoroid bumper shield, 0.070 aluminum,   1.006 lb/ft²
Inner monocoque structure, 0.125 aluminum,   1.802
Thermal insulation, 5.5 inches,   0.792
                                                     ‾‾‾‾‾‾‾‾‾‾‾‾
                                                     3.600 lb/ft²

Equivalent aluminum thickness of insulation

$$t_e = 5.5 \left(\frac{0.426}{42.6}\right), \quad t_e = 0.055 \text{ in.}$$

Unit Weight, $W = \left(\frac{0.055}{12}\right)$ (173), $W = 0.792$ lb/ft²

In the event of a major solar flare occurance during the 30-day exposure period, additional shielding material must be added to the shelter. The Airlock appears to be a logical area in which to provide this additional shield material. The astronauts would take shelter in the airlock upon receiving a warning from the Earth that a major solar flare has occurred. For purposes of a weight analysis, a shield weight of 5.5 gm/cm² (11.25 lb/ft²) is used for the airlock walls and roof. This amount of shielding will limit the dose inside the airlock to 115 rads when subjected to one major solar flare.[1] The astronauts would only be required to stay in the airlock for a few hours.

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The increase in the airlock weight to provide protection from one major solar flare is as follows:

Model	Weight Increase (Earth weight, lbs)
A	603
B	535
C	434

The above weights are not included in the summary weight table.

Thermal

To prevent degradation of equipment during the one year storage, it is necessary to provide protection from the temperature extremes occuring on the lunar surface. The proposed design provides for the passive technique of employing sufficient super thermal insulation, a minimum of heat leaks or thermal conducting paths between interior and exterior of the shelters, and an active power source to generate heat during the critical night-time unattended storage. One means of providing this power is to use the waste heat from a SNAP 9A thermal-electric generator (approximately 250 watts). This may be accomplished by the use of conducting rods or a circulating fluid.

A complete, active thermal control system utilizing coolant flow and a sunshade is necessary during occupancy of the shelter by the astronauts. The sunshade prevents direct insolation on the radiator and the sum of radiation from the sunshade and reflected lunar radiation are much less than the absorbed solar energy would be without it. Before habitation, the sunshade in its retracted position would protect the horizontal thermal radiator from erosion and offer some measure of meteoroid penetration protection. Another advantage is that the radiator sunshade combination is relatively immune to changes in solar absorptivities, whereas, uncovered radiators are very vulnerable to those changes. It is, of course, dependent upon retention of a fairly high emissivity. Disadvantages are that it must be sun tracking and kept approximately one diameter or more away from the radiator to be effective. It is assumed that approximately half the heat generated in the shelter could be removed by coolant flow through the equipment generating the heat (a high temperature loop), the other half being first transferred to the cabin atmosphere and then to a heat exchanger (a low temperature loop). Heat loads included in the second category would be astronaut metabolic heat, lights, and circulating blowers.

Lunar Landing

A limit vertical landing load factor of 6 (9 ultimate) is used as a structural design criteria.[7] These load factors are used with Earth weights.

Pressure

A maximum internal pressure of 14.7 psi is possible within the shelter when the payload leaves the atmosphere, assuming a pre-launch internal pressure equal to the normal ground atmosphere pressure (i.e., zero pressure differential). To eliminate the 14.7 psi differential a pressure relief valve would be provided. Both the rigid and expandable shelter sections are designed to withstand an internal pressure of 5 ± 0.5 psi during occupancy on the lunar surface. A safety factor of 2 is used in the structural analysis.

Vibration, Shock, Acceleration, Thermal

These environments induced during pre-launch, launch and Earth-to-Moon transit are not considered critical design conditions as compared to the more stringent requirements imposed by the radiation, meteoroid, and the thermal environment that exists on the lunar surface. The thermal environment, natural and induced, that exists before landing on the lunar surface, (i.e., aerodynamic heating) are considered not to be critical for design.

Material

The basic load carrying structure is aluminum. However, a new and promising material which can be made available in the required quantity and shape is "LOCKALLOY"[8].

In the expandable portion of the Rigid-Expandable Shelter, the problems of supporting the pressure load and containing the pressure were solved by using DACRON and MYLAR materials. Dacron is selected as the material to provide strength and flexibility and a three layer laminate of approximately one mil mylar is used as a seal. Mylar has been used at cryogenic temperatures for diaphragms, expulsion bladders and tank liners. This material in lighter gages remains flexible at -320°F. Published information on the mechanical properties of dacron polyester fibers and mylar at low temperatures conclude that these materials are satisfactory for the low temperatures expected on the lunar surface. [9, 10] The material selected for the seals for the airlock doors and the large door on the expandable shelter is a combination of Silicone rubber and Dacron fabric. [2]

The thermal insulation material is the super insulation NRC-2 supplied by the National Research Corporation. [11] To prevent "cold-welding" of metal parts subjected to a hard vacuum environment a self-lubricating material containing polytetrafluorethylene and tungsten diselenide is being considered. [2]

The detail design of the shelters are shown in figures 6, 7, and 8. Included are typical structural cross sections that show the required meteoroid, radiation, and thermal protection. In addition, the various substructures are shown. These are; Antenna S-Band, sunshade, TV-cameras, cryogenic tanks, ladder, dipole antenna, vertical and horizontal thermal radiators and a SNAP-9A thermal-electric generator.

Table 2 shows the system weights of the three shelter designs.

TABLE 2. SYSTEM WEIGHT (lbs)

SHELTER MODEL	A		B		C	
Basic Structural Material	Aluminum	Lockalloy	Aluminum	Lockalloy	Aluminum	Lockalloy
Rigid Shelter	2423	2074	2423	2074	2994	2518
Expandable Shelter	0	0	1300	1005	2230	1725
Expendable Weights (38-Day Supply)	509	509	509	509	509	509
System Weights	1165	1165	1177	1177	1212	1212
Deployment Equipment	0	0	260	200	260	200
Subtotal Excluding Cryogenics	4097	3748	5609	4965	7205	6164
Cryogenic Oxygen (6-months Storage time + 10% contingency)	1420	1420	1640	1640	2050	2050
Cryogenic Hydrogen (6-months Storage time + 10% contingency)	444	444	450	450	470	470
Total System Weight (lbs)	5961	5612	7759	7055	9725	8684

Test, maintenance and scientific equipment are purposely excluded. They will be transported in LEM saddlebags or with a logistic payload depending upon the option selected.
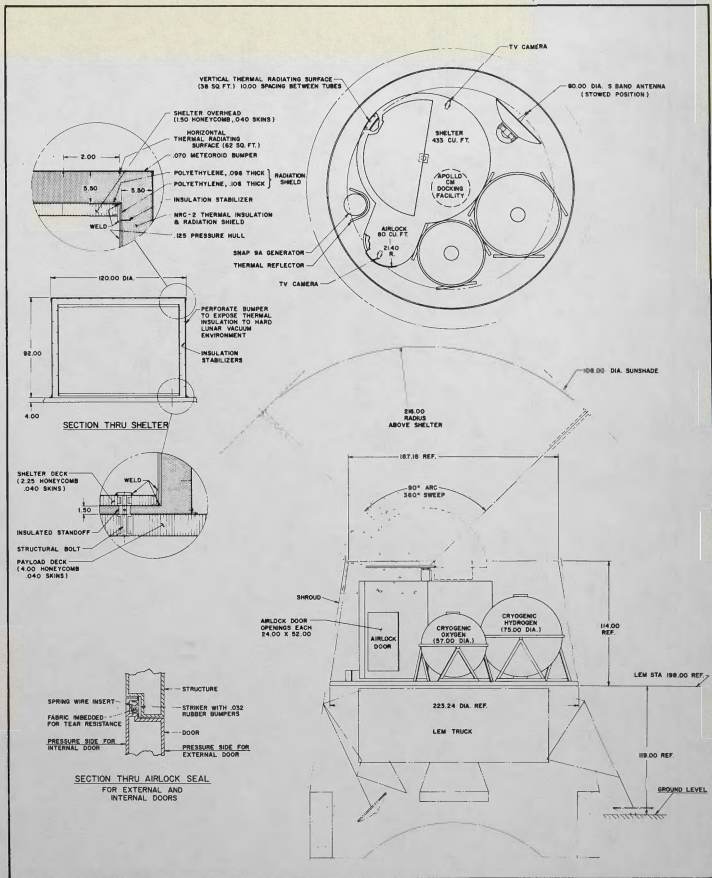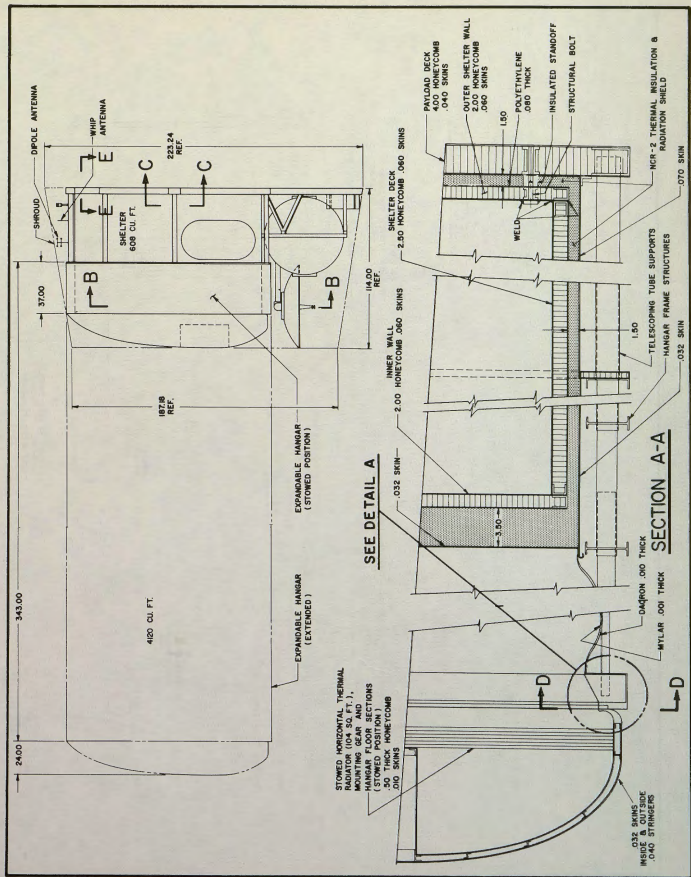
Figure 6.   Westinghouse Rigid Shelter, Model A

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Figure 7.   Westinghouse Rigid/Expandable Shelter, Model B

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Figure 8. Westinghouse Rigid/Expandable Shelter, Model C

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SECTION D-D

CONTINUOUS SEAL

INFLATABLE SILICONE RUBBER
DACRON FABRIC SEAL. INTERIOR
INFLATION SURFACE CONTAINS
A THIN FILM BARRIER MATERIAL

LIP SEAL TRICOT WEAVE DACRON

DETAIL A

BONDED STRIKER
BONDED & WELDED
TO HANGAR DOOR

HANGAR DOOR

SILICONE RUBBER BUMPER
MATERIAL .070 THICK
VULCANIZED TO HANGAR

STRUCTURE

TELESCOPING
TV CAMERAS

APOLLO
CM
DOCKING
FACILITIES

CRYOGENIC HYDROGEN
60.00 DIA.

TELESCOPING
60.00 DIA. S BAND ANTENNA
(STOWED POSITION)

A

A

SNAP 9A GENERATOR

THERMAL REFLECTOR

CRYOGENIC OXYGEN
53.00 DIA.

TELESCOPING
TUBE SUPPORT

SECTION C-C

TYPICAL 5 PLACES

Figure 8-A. Westinghouse Rigid/Expandable Shelter, Model C

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SECTION E – E

VERTICAL THERMAL RADIATING SURFACE (50 SQ FT)
.38 O.D TUBING

OUTER SHELTER WALL 2.00 HONEYCOMB .060 SKINS
NRC-2 THERMAL INSULATION & RADIATION SHIELD
POLYETHYLENE .080 THICK
MODIFIED PAYLOAD DECK 3.58 HONEYCOMB .040 SKINS

SECTION THRU AIRLOCK SEAL

FABRIC IMBEDDED FOR TEAR RESISTANCE
SPRING WIRE INSERT
STRUCTURE
PRESSURE SIDE FOR INTERNAL DOOR
PRESSURE SIDE FOR EXTERNAL DOOR
STRIKER WITH .032 RUBBER BUMPERS

METEOROID SHIELDS .032 SKIN TELESCOPING
NRC-2 THERMAL INSULATION & RADIATION SHIELD
.032 SKIN
.025 PRESSURE HULL
DACRON .010 THICK (OUTSIDE)
MYLAR .001 THICK (INSIDE)
.032 METEOROID BUMPER

SHELTER DECK (2.50 HONEYCOMB .060 SKINS)
LIGHTENING HOLES

DOUBLE CELL AIRLOCK DOOR ARRANGEMENT

SHELTER AREA
AIRLOCK DOOR OPENINGS EACH 24.00 X 51.00
SHELTER DOOR 1
SHELTER DOOR 2
PARTITION
EXTERNAL DOOR
80 CU. FT.
80 CU FT.
HANGAR AREA
HANGAR DOOR
40.83
37.75
37.75

SECTION B – B

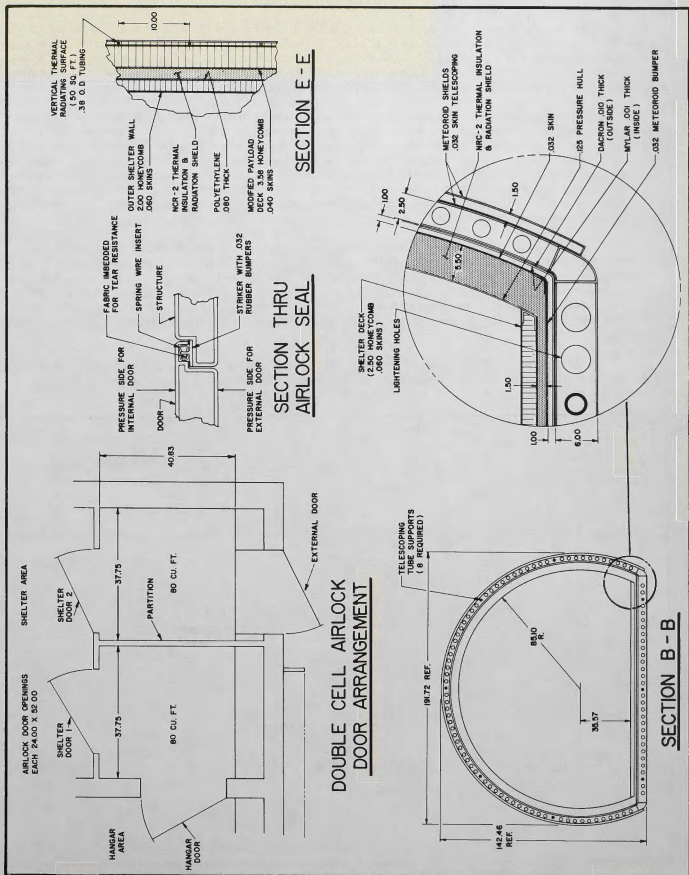TELESCOPING TUBE SUPPORTS (8 REQUIRED)
85.10 R.
119.72 REF.
35.57
142.46 REF.

Figure 8-B.   Westinghouse Rigid/Expandable Shelter, Model C

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Since Shelter Model A remains on the LEM truck throughout its storage and operating life, the task of deployment applies only to Models B and C. Analyses have been made to determine the sequence of events, the conditions imposed from launch through deployment on the lunar surface, and the performance and design characteristics of the equipment. While the details of these analyses have not been included, the results are reflected in the design concept outlined herein.

The principal elements of the concept (shown in figure 9) are the deployment rails, mechanisms, cable, control panel, winch, power unit, and leveling devices, all of which are packaged with the shelter, thereby giving the system self-sufficiency. Deployment and leveling are semi-automatic processes which are manually-controlled with electrical and mechanical interlocks to assure proper sequencing of operations. Each operating mechanism and interlock will have an override and disconnect so that in the event of a malfunction, an auxiliary means may be used to perform the function. Extensive Westinghouse laboratory tests indicate that the selected devices and mechanisms can meet lunar storage and operating conditions.

Two sets of telescoping box section deployment rails are packaged within and beneath the shelter floor. These rails are extended horizontally by the cables attached to either the winch or to other telescoping members. The winch is fixed to the shelter base on the side opposite the unloading and consists of a reversible gear motor drive with a provision for free-wheeling play-off when rotating in the over-run direction. As the deployment cable is played-off its drum, the other drum extends the two deployment rails. The winch motor extends the deployment rails until telescoping sections lock to each other.

The shelter is pulled off the deployment rails by the shelter winch. During shelter deployment, the winch rotates in the opposite direction from rail extension and winds the deployment cable on that drum. Shelter motion is guided by channels in the shelter base.
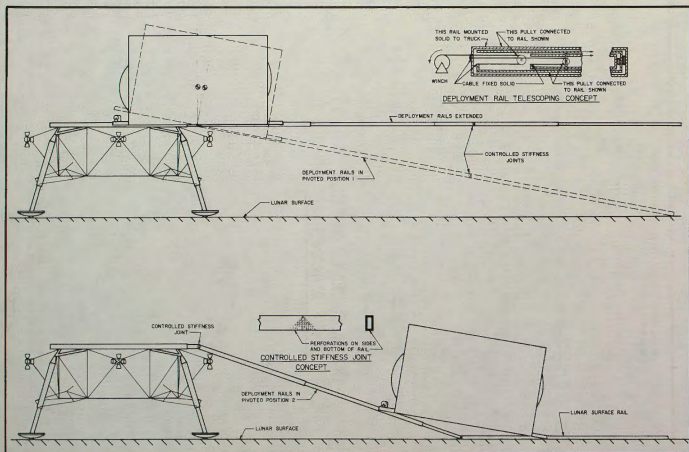

Figure 9. Shelter Deployment, Controlled Stiffness Joints,
Plan View, Elevation

The shelter moves horizontally along the rails on the LEM truck until its center-of-gravity passes the upper controlled-stiffness joint. Passing this joint causes the rails to bend at the joint until the extended end contacts the lunar surface.

The shelter is winched down the rails until the shelter center-of-gravity is above the lower controlled stiffness joint, which then bends as shown in figure 9.

Shelter Model C is deployed from the LEM truck in the same manner as Model B. However, because of the slope limitations imposed by the conical shroud of the LEM it is necessary to place the longitudinal axis of shelter C (axis parallel to lunar surface) in the vertical plane when placed on the LEM truck. Therefore, after deployment of the shelter, Model C, on the lunar surface, the following sequence must be followed before the shelter can be expanded.

The payload support deck must be separated into two segments, one containing the major substructures and one containing the basic shelter structure. This is accomplished by removing two structural shear pins (piano hinge shear pin concept) that hold the two segments of the payload deck together. The segment containing the shelter structure is then rotated 90° so that its longitudinal axis is transferred from the vertical plane into the horizontal plane (parallel to lunar surface). The expandable portion of the shelter can now be extended to its operation position on the lunar surface.

Although the shelter-site will be selected on the basis of its smoothness, the best available site may not be level enough to be completely suitable. Therefore, three leveling legs located near the edge of the base and 120° apart provide leveling.

The total shelter deployment system weighs approximately 200 pounds. The power source for the deployment is the shelter SNAP 9A power supply and batteries, or as a back-up, the astronaut can activate the shelter fuel cell.

WESTINGHOUSE LUNAR ROVING VEHICLE CONCEPT

The Westinghouse lunar roving vehicle concept shown in figure 10 is not intended as a replacement or competitive design to the MOLAB. Rather, it is an optional capability which is provided with Westinghouse shelter system and which can provide a two-man crew with local transportation and assistance in exploration and experimentation. As each succeeding step in the National Lunar Exploration Program develops, the shelter system offers the capability to select a payload combination best suited to the particular need or phase of the lunar mission, e. g. , a shelter alone, a shelter with an observatory, a shelter with an expandable section for special experiments or maintenance, or a combination of a shelter and a roving lunar vehicle.

The Westinghouse vehicle, like the shelter, is designed to withstand the loads induced during ground handling, transportation, launch, Earth-to-Moon transit and lunar landing. In addition, the portions of the vehicle that are pressurized are designed to withstand an internal gas pressure of 5 (±0. 5) pounds per square inch with a factor of safety of 2 (e. g. , ultimate design condition is 11. 0 pounds per square inch). The vehicle has a lunar storage capability of one year in its compack package and provides for 0. 99 probability of no penetrations from meteoroids. When the vehicle is in its expanded or operating position, the metallic shields surrounding the basic structural shell provides radiation and meteoroid protection for a period of 15 days. The continuous stay-time of 15 days is a maximum for any individual crew member to prevent receiving a radiation dose in excess of 200 rads. To provide for the required environmental protection with the minimum weight, the vehicle design (like the expandable section of shelter Models B and C) utilizes various combinations of metals, (aluminum, lockalloy) and non-metals (polyethylene, dacron, mylar).

The vehicle rigid design includes a recessed floor which mates with the shelter and which provides the space for retracting the wheels during transit. Since all of the vehicle subsystems are attached to the floor, structural design dictated a honeycomb floor with NRC-2 for thermal insulation. The roof of the vehicle is also a rigid design consisting of a convex elliptical dome which can be retracted or compressed for transit and storage periods; the roof consists of a meteoroid bumber with NRC-2 super-insulation and is similar in construction to the expandable section of the shelter design. The wheels as currently configured are semi-rigid in that they can be compressed during storage and act as springs during vehicle motion; they are 60 inches in diameter and 15 inches wide, to maintain compatibility with ELMS[12] data.
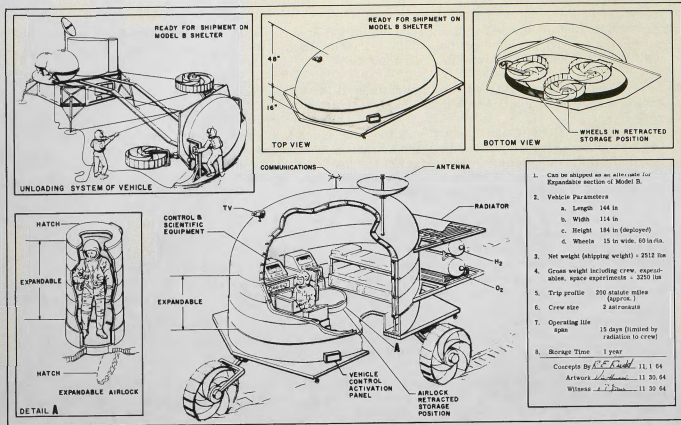
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Figure 10. Westinghouse Lunar Roving Vehicle

    The vehicle expandable design consists of a mid-section, 78 inches high, which makes up the vehicle walls and is retracted completely during transit and storage (see figure 10) causing the floor and roof to meet; after deployment from the LEM truck, the walls are expanded to give an additional 629 cu ft of volume for the crew. The design of the expandable section is nearly identical in basic construction (e. g. , self-locking telescoping tubes and I-beam structure) to the expandable shelter, Models B and C. When not in use, the vehicle walls can also be retracted, just as the shelter expandable section, into their original configuration. This allows the life of the vehicle to be distributed over several increments of time. While expanded, the vehicle is capable of providing a shirtsleeve environment to a two-man crew; this requirement (in the current concept) is waived during locomotion partly for astronaut safety reasons and partly to offset the total electric power load on the fuel cells, e. g. , the crew will wear their space suits.

    The vehicle design also includes an internal bladder to contain the cabin atmospheric pressure loads. Just as in the expandable shelter design, the bladder consists of dacron for structural strength and mylar for low leakage rates. An expandable airlock of similar structural design as the walls is provided in the center of the vehicle with ports for ingress-egress.

    During the conceptual design, the extreme soil conditions and obstacle negotiability requirement of the ELMS profile were used as a guide. The 3.5 mph soft soil condition and the 9.5 mph hard soil condition require nearly the same power delivered to the soil, e. g. , about 350 watts for the wheel power requirement results in an overall mobility power of about 700 watts. The total mobility power of 900 watts includes steering and instrumentation power. The three-wheeled approach, because of its low weight, large tread to wheel-base ratio, and unique front wheel suspension design, when optimized, can be made highly maneuverable.

    Leakage rates and seal technology are well within the environmental control subsystem requirements of 4.8 lbs of oxygen per day. The airlock port has a unique multi-point contact seal which facilitates opening and closing action. This seal is similar in design to that used in the shelter airlock.

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Finally, the design approach makes maximum use of compatibility with Apollo-LEM-MOLAB-Westinghouse shelter developed hardware, subsystems, and techniques. This requirement will not only reduce development costs but also provide the LEM or shelter systems with added astronaut safety by interchangeability of subsystem modules.

CONCLUSION

From the preliminary analysis and design work completed on the shelter program, it can be realistically concluded that within the 1965 - 1966 state of the art, it is possible to design and build personnel shelter systems which meet NASA's current lunar environmental models. It can also be concluded that these shelters and their subsystems can be built with sufficient inherent reliability, and contengencies, to meet the planned work and physiological needs of the astronaut crews who will inhabit them. However, to insure achievement of this, much work remains to be done. This work includes all aspects of lunar exploration from precisely what is to be done, to how and with what it is to be done with, including a re-definition of the lunar criteria models to more accurate and factual data.

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ACKNOWLEDGEMENTS