The One-Way Manned Space Mission

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The United States has embarked on the Apollo Lunar Program which will send two men to the surface of the Moon and return them to Earth. The Russians are undoubtedly concentrating on a manned lunar program of similar type, although the details of their approach are not currently known. There are more expedient ways of sending men to the Moon than the one the United States has chosen. It has been suggested that the Russians are planning to send a man to the Moon without provisions to return him to Earth. This is the concept of the One-Way Manned Space Mission. The concept can be applied to the Moon, to Mars, to Venus, or to other planets.

The advantages of the One-Way Manned Space Mission for early lunar exploration are significant both politically and scientifically. It is possible to keep the lunar explorer alive and doing valuable scientific work for extended periods of time. Further, it is possible to provide a means of returning the man to Earth at a later date. During his stay on the Moon, the lunar explorer or "One-Way Space Man" would be supplied with food, water, oxygen, medical supplies, etc. This would be accomplished by a logistics system consisting of unmanned cargo vehicles boosted from the Earth and retrolanded on the lunar surface, convenient to the manned landing site. The One-Way Manned Space Mission might be expanded into a two or more man mission by sending companion explorers in separate capsules.

The mission briefly described above is an extremely hazardous one since a majority of the problems are unknown and we possess no capability whatsoever to recover the man from his lunar trajectory once he escapes from the Earth's gravitational field. Such a concept is truly a one-way space mission until the point in time when the necessary return capability is developed. Because of the extreme hazards involved in this mission, we recognize the moral and ethical implications. It must be emphasized that we are not proposing that such a mission be accomplished, but rather we are discussing it technically from the point of view of a pertinent concept.

Mission Description

The One-Way Manned Space Mission is a broad based operation which could be integrated with existing and planned space programs. A summary schedule depicting a representative temporal relationship of the One-Way Manned Mission with

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The One-Way Manned Space Mission consists of sending a man to the Moon or a planet without propulsion to return him to Earth. The concept can be extended to keeping the man alive and doing valuable scientific work for extended periods of time. The paper presents a scientific and technical evaluation of a One-Way Manned Lunar Mission including a summary of lunar environments, life support requirements, propulsion, vehicle design, and weights, base and logistics requirements.

other events and missions is presented in Fig. 1. The relationships are typical whether the mission is applied to the Moon, Mars, or Venus.

The figure shows the major steps leading to the one-way mission and carrying it through until the one-way spaceman can be returned to Earth. These steps include unmanned probes and landings, unmanned explorations, development of the systems for the one-way mission, accomplishment of the one-way mission itself, lunar base establishment, logistics and supply, exploration and scientific investigations, and finally, landing of a vehicle or system capable of returning the man to Earth.

Manned Lunar Capsule

A preliminary study has been made of a minimum manned lunar capsule. The resulting configuration and weight summary are shown in Fig. 2. This concept represents a realistic minimum size and weight based on landing one man at a selected site on the surface of the Moon. Food, water, and breathing oxygen for 12 days are provided, plus an 18-day emergency-contingency supply of oxygen. The normal supply provides for two and one-half days in transit and nine and one-half days on the Moon. After the lunar landing, the man proceeds to establish his permanent living quarters and lunar base from material and supplies in the previously landed cargo vehicles. It is possible for the man to live in the capsule until the breathing oxygen is expended. In an extended emergency, he can continue living in the capsule beyond this period by replenishing supplies from the cargo vehicles.

The gross internal volume is 345 cu ft. The base diameter of 120 in. has been selected as a compromise between booster compatibility, size layout and volume, and stability. The capsule structure is based on a shell weight of 2 lb/sq ft plus an insulation weight of 0.5 lb/sq ft. The capsule environmental control system provides a shirt-sleeve environment at a pressure of 7 psi. Breathing air is pure oxygen stored cryogenically; a LiOH system is provided for CO_2 removal. Radiation protection provisions are not included.

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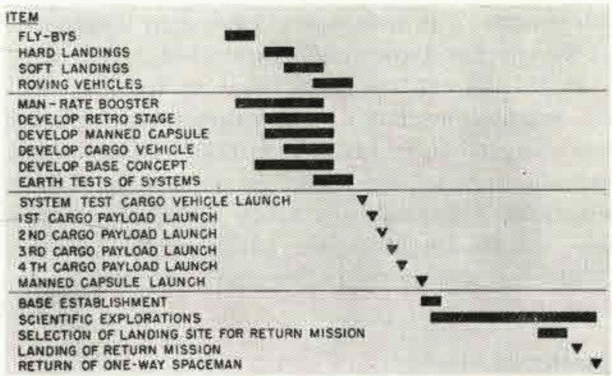

Fig. 1. Implementation plan.

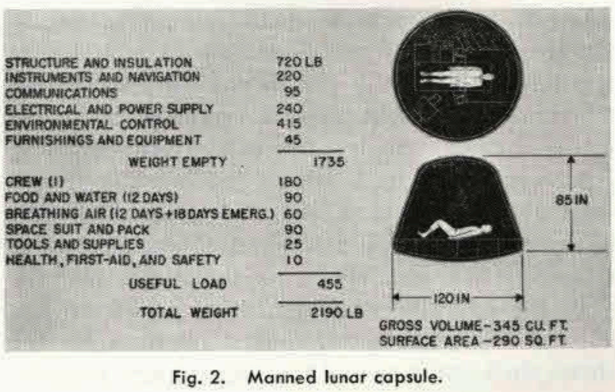

Fig. 2. Manned lunar capsule.

well understood for these substances. This often requires the definition of potential service profiles and the use of simulation tests to assess and guide the materials development.

In summary, a new discipline—materials—has evolved. It faces unique challenges if it is to make its most effective contribution to aerospace technology. It must develop both *horizontal* and *vertical* interdisciplinary competence and approaches in individuals, as well as in groups.

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One-Way Manned Space Mission

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Since there is no air lock, the environmental control system must be capable of pressurizing the capsule to a habitable environment each time the spaceman enters and seals the hatch. When the habitable level is reached, the spaceman can remove his space suit. The emergency contingency supply of breathing air will provide for losses due to use of the hatches.

The capsule also has provisions for an Earth abort-escape system which is jettisoned after the boost phase of launch. The capsule is retrolanded by a propulsion stage consisting of retroengines, tanks, controls, adapter sections, and retractable alighting gear. The retropropulsion stage also contains the reaction control system.

The capsule includes two-way voice communications provisions through an S-band data link. This link also serves as a tracking and lunar landing radar. An emergency back-up landing radar capability is provided by a Ku-band landing radar, and back-up communications are provided by a spare data link. In the near-Earth region, a VHF voice link is provided for communication with a UHF transmitter-receiver as back-up.

An Earth-to-Moon homing type navigation system is provided in the capsule. It is assumed that a beacon transponder has been previously placed on the Moon by one of the unmanned lunar systems at a suitable landing site. The navigation system consists of a platform, computer, and flight control system.

The power supply system provides electric power for all electronic components, instruments, and environmental control systems, and other miscellaneous components. The normal power load for the manned capsule is 600 watts with a mission duration of 12 days. The most practical system appears to be a liquid oxygen-liquid hydrogen fuel cell. The power required is relatively high, and the mission time is too long for batteries, and too short for nuclear power.

The Manned Lunar Capsule concept described is based on current state-of-the-art capabilities. Its design does not require technological advances. The capsule depicted is a realistic minimum system consistent with a high, but reasonable, risk. The gross volume and the 12-day cycle are as low as practical. The capsule systems are simple with no sophisticated back-up capability. The weights are realistic and not based on any technological breakthroughs. The concept relies on mission support beyond the 12 days from the lunar cargoes which have been previously landed nearby. This entire philosophy has resulted in a minimum weight capsule of 2,190 lb.

Lunar Cargo Vehicle

The unmanned lunar cargo vehicle is required to transport supplies from the Earth to the Moon. A representative cargo vehicle configuration has been established. The configuration and weight summary are shown in Fig. 3. For purposes of illustration, the total weight and diameter of the cargo vehicle have been made equal to that of the manned capsule. In this manner, both can be landed by the same retropropulsion stage. Actually, it might be worthwhile to investigate designing the cargo vehicle to sustain a harder landing requiring less retropropulsion. The basic vehicle is a utility concept that can be adapted to serve as permanent living modules, supply and equipment storage cells, or merely expendable cargo carriers. Its size and volume have been optimized towards the requirements of a shelter module. The basic structure is strong and air tight. The ten foot diameter permits laying the cylinder on its side and installing a floor which will provide a large flat area with adequate head room. In this manner, cargo vehicles can be adapted to lunar living shelters in single or multiple units.

The cargo vehicle requires communication and navigation provisions to guide it to the lunar landing site. The vehicle will carry an S-band data link and a Ku-band landing radar. The homing navigation system is basically the same as in the manned capsule. Instrument, telemetry, and communication requirements are less. The power supply system has a normal load requirement of 150 watts with a mission duration of two to three days. The relatively low load is due to the absence of any environmental control system. This, combined with the relatively short mission duration, makes a good application for batteries.

STRUCTURE	1050 LB	
INSTRUMENTS AND NAVIGATION	120	
COMMUNICATIONS	25	
ELECTRICAL AND POWER SUPPLY	85	
WEIGHT EMPTY		1280
CARGO PAYLOAD	910	
TOTAL WEIGHT		2190 LB

GROSS VOLUME–980 CU. FT.
SURFACE AREA–575 SQ. FT.

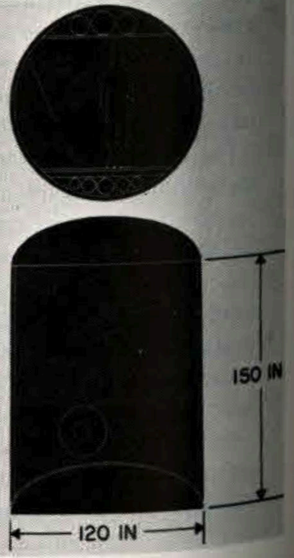

Fig. 3. Lunar cargo vehicle.

The cargo vehicle weight empty shown is 1,280 lb. Based on using the same landing retropropulsion system as the manned capsule, the cargo payload is established as 910 lb.

Lunar Landing Requirements

The manned lunar capsule and the unmanned lunar cargo vehicles will be landed at the preselected lunar site by a standardized retrolanding propulsion system. The propulsion system will be packaged in a stage which will include controls, subsystems, and alighting gear. The propulsion system will provide thrust to cancel the lunar approach velocity over a reasonable time duration, and will provide lateral traverse, with hovering if required to accurately set down at the desired location.

Preliminary design studies of several lunar landing propulsion stages have been made. Basically, the design of such a stage is straightforward and within the current state-of-the-art. The weight of such stages is dependent on the lunar payload to be landed (in this case, the manned lunar capsule or the cargo vehicle but not including the propulsion stage). It also depends on the landing requirements, and performance. In Fig. 4, the required Earth escape payload is shown for landing different lunar payloads. The Earth escape payload consists of the lunar payload plus the retropropulsion stage. Also shown on the same plot is a curve of the Earth escape payload required to accomplish a lunar landing and a return launch to Earth, as a function of lunar payload.

The curves are shown as bands to account for the variance in requirements, performance, and other characteristics. The plots are based on a nominal 9,000 ft/sec velocity increment, which approximately corresponds to a two and one-half day transit time. The curves include an allowance for mid-course corrections both going and return. The structural efficiencies reflect a reasonable range of achievable mass fractions, and include landing and launching structure. The upper portions of the curves represent storable propellants, while the lower portions represent high energy propellant systems. The slight flattening of the curves with increasing payload is due to the achievement of higher mass fractions as the stage size

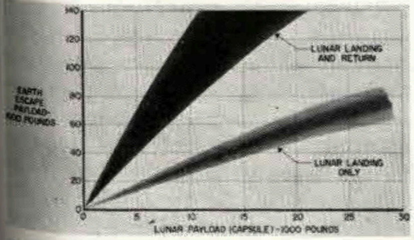

Fig. 4. Lunar landing and lunar launch requirements.

increases. For lunar landing only, the lunar landing retrostage may be more than half of the escape payload.

In the case of lunar landing and Earth return, the total weight of the landing retro and return launch stages may be 80 to 85 percent of the escape payload. This leaves only 15 to 20 percent for lunar payload or manned capsule. This emphatically points out the advantage of the One-Way Space Mission. The Earth escape payload requirements for missions with return capabilities are increased three to four times over those for one-way missions. For example, in the case of the 2,190 lb manned lunar capsule or unmanned cargo vehicle shown earlier, the Earth escape payload for lunar landing only is 6,000 to 9,000 lb. If a return to Earth capability is provided, the Earth escape payload becomes 17,000 to 30,000 lb. These are basic relationships that influence the design of any manned lunar system. Improvements in performance and design efficiency will reduce corresponding escape payload requirements. However, for the next several years, these relationships illustrated cannot be improved significantly. The same general type of relationship applies to Mars and Venus missions.

Booster Capabilities

The Earth escape payload requirements of the previous section can be translated into booster requirements by plotting the Earth escape payload capability as a function of booster thrust (Fig. 5). The booster thrust indicated is that of the first or bottom stage. Since the thrust-to-weight for most known boosters ranges only from 1.2 to 1.5, the correlation could also be made on the basis of booster gross weight.

A band is shown, rather than a line curve. This is done to indicate the variance due to staging, performance, mass fraction, etc. The lower limits of the band are based on more conventional booster systems. The upper limits are based on more sophisticated multistage boosters using high energy propellants. The correlation is good. Almost all of the known existing and planned booster systems fall within the band. This includes Thor, Atlas, Saturn, and Nova with various upper stages. It also includes many booster systems which were conceived but never reached program status. Boosters which fall significantly outside of the band usually fall into one of two categories. The first is represented by extremely sophisticated systems beyond the state-of-the-art. The other is comprised of systems which as a result of abnormal cost, schedule, or other requirements are based on grossly inefficient concepts.

Along the right hand side a scale of

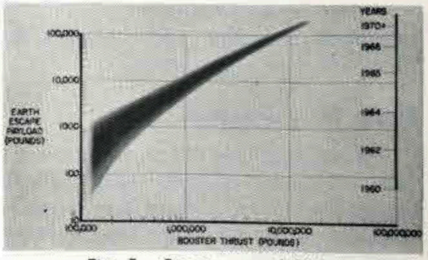

Fig. 5. Booster capabilities.

operational dates is plotted, representing United States capabilities. The 1960 date represents the 60-lb Thor-Delta capability. From this point on, the operational date scale becomes more and more approximate. This is due to having a range of capabilities in some of the earlier years, and due to the grossness of the estimates for some of the future stages. Nevertheless, the plot indicates roughly the trend in capability with respect to time.

The system weights developed for the One-Way Lunar Mission can be applied to the escape payload-booster thrust-time curve. The lunar payload of 2,190 lb was shown in the previous section to require a minimum Earth escape payload of 6,000 lb. From Fig. 5, this requires a booster thrust of 450,000 to 1,100,000 lb which could be achieved some time between 1964 and 1965. It is interesting to note how the booster requirements increase if the 2,190-lb lunar payload must also be returned to the Earth. In the previous section, this required an Earth escape payload of 17,000 to 30,000 lb. From Fig. 5, this requires a booster thrust of 1,100,000 to 3,500,000 lb. This threefold increase in booster thrust could not be achieved until approximately 1965 to 1967. This time differential of approximately one and one-half to two years in booster capability shows the timewise advantage of the One-Way Space Mission over missions with return capabilities.

The entire discussion thus far has been based on the direct ascent approach to the One-Way Manned Space Mission. The direct ascent approach is straightforward and within the projected state-of-the-art. Comprehensive studies are currently being made of various rendezvous approaches to lunar missions and the Gemini Program will demonstrate the rendezvous capability within the next few years. The rendezvous approach naturally reduces booster requirements for space missions. However, the escape payload must still be placed on an escape trajectory to or from the rendezvous orbit. The less the escape payload, the less sophisticated the propulsion requirements and the earlier the mission can be undertaken. The One-Way Space Mission results in reduced escape payload requirements for either the rendezvous or direct ascent approach, and the timewise advantage is pertinent (although not necessarily the same) for both approaches.

Lunar Environments

For the purposes of this paper, only a brief summary of lunar environments relative to their effects on long duration missions is presented. The environmental parameters which appear to be most significant, relative to the One-Way Space Mission are: surface and terrain characteristics; electromagnetic radiation; particulate radiation; micrometeorites; and vacuum.

Lunar Surface

The most obvious characteristic of the lunar surface is the large number and relative immensity of the lunar rock formations and craters. The lunar craters are the dominant topographic forms and range in size from a few hundred miles diameter, to less than one-eighth of a mile diameter. The entire lunar surface is covered with thousands of such craters. Regardless of the landing place, we may expect that the presence of smooth uninterrupted plains on the lunar surface is not very likely. The average slope of the crater walls has been estimated to vary from three to forty degrees, whereas the lunar angle of repose has been estimated to be approximately 52 degrees.[1, 2] Consequently, the lunar explorer will consume considerable energy as he attempts to move from point to point on the lunar surface.

Detailed information on the fine structure of the lunar surface is difficult to evaluate because of the poor resolution of current viewing techniques. Photometric measurements, however, indicate clearly that the lunar surface must be covered with a relatively porous and fine particle dust layer. The density of this surface material is approximately 2.0 grams/cm^2, whereas the average density of the Moon has been estimated[1] to be 3.34 grams/cm^2. Recognizing that the Moon has been exposed to approximately the same micrometeorite flux density as has the space immediately surrounding the Earth, we should expect that the lunar surface will be covered by a layer of micrometeorite dust. Furthermore, since the lunar surface has been exposed, unprotected, to extremely wide variations in temperature and radiation levels, we may predict that the lunar rock is continually being broken and the crystal structure changed as a consequence of these environments. Kopal[2] has estimated that, whatever the origin of the dust layer, the amount deposited over the lunar surface should not exceed one yard.

Regardless of the depth of the dust layer, the lunar explorer will undoubtedly stir up a dust cloud as he moves across the lunar surface. One would expect a ballistic trajectory of the particles without the influence of air drag based upon the small surface gravity of 0.17*g*. However, any time the particle hits surface material or any other objects, it will bounce into a new trajectory. This effect may result, because of the irregular lunar terrain, in a continuous flow of dust particles surrounding the man or his vehicle thereby obscuring vision. It is also possible that the impact of micrometeorites on the lunar surface will create a continuous movement of the surface dust particles.

Electromagnetic Radiation

The electromagnetic radiation which will confront the lunar explorer may be classified as visual and thermal. The lunar latitude of the explored area and the lunar diurnal cycle determine the intensity and duration. The maximum solar radiation appears at noon, 14 earth days after the lunar midnight and at the lunar equator.

The visual spectrum ($0.29\ \mu < \lambda < 1.0\ \mu$) to which the lunar explorer will be exposed will be more intense than that on the Earth's surface because of the lack of attenuation through an atmosphere. For example, the luminance of the Sun when viewed directly from the lunar surface will be approximately 700,000 Lamberts as opposed to 440,000 Lamberts when viewed from the Earth's surface. The resulting visual effects and potential physiological hazards may be adequately controlled, however, by filter techniques.

Because of the porous lunar surface, the light impinging on the surface will be reflected with probably only slight scattering. As a consequence, visual contrasts will be very high. A wide variation in brightness of the surrounding terrain under full solar illumination will also be apparent. The dark areas (Maria), which are generally accepted as areas of lava flow, have a visual albedo of approximately 0.05, whereas some of the brighter crater rims possess an albedo of 0.40. These characteristics of the visual scene, however, should not present problems to the lunar explorer. It is possible that conditions of depth preception may be temporarily affected. However, these effects, if they occur, should be cancelled relatively quickly through the relearning of perceptual cues.

The lunar surface temperature varies as a function of time within the lunar day and the lunar latitude of the object. At a subsolar point at the lunar tropics with the sun directly overhead, a surface temperature of +228°F has been predicted. During the afternoon, the temperature will decrease to freezing and at midnight reach a minimum temperature of approximately −292°F. Thus, at the lunar equator, we anticipate temperature ranges of approximately 520°F. Proceeding either south or north from the equator will decrease the temperature as a function of the solar incidence angle. At 55° north latitude, for example, in the Mare Imbrium area, a maximum temperature of approximately 90°F has been predicted. The diurnal temperature variations, while great, occur across the 656-hr lunar day and therefore represent a small mean temperature change. During the time of a lunar eclipse, however, the temperature range and gradient are very large. For example, when the shadow covering a point on the lunar surface at the equator passes, the temperature will increase by approximately 392°F within less than one hour. It is obvious that any lunar system must either be protected from such a rapid heating or cooling rate or be designed to accept these changes in full force.

Micrometeorites

The flux density of micrometeorites on the lunar surface may be less than that observed in the vicinity of the Earth because of the small (0.17 *g*) gravitational field of the Moon. However, since no experimental data are available on the lunar flux density, the conservative estimates of the flux density near the Earth shall be used. Unpublished data from NASA[3] indicate that the relationship between flux density (F) and meteorite mass (m) near the Earth may be stated as follows:

$$F = 10^{-12} m^{-10/9} m^2 \text{sec} \qquad (m > 10^{-8.5})(\text{grams})$$

$$F = 10^{-17} m^{-1.70} m^2 \text{sec} \qquad (10^{-10} < m < 10^{-8.5})(\text{grams})$$

Three general effects can result as a consequence of micrometeorite impact: sandblasting, spalling, and penetration. The sandblasting effect is small relative to erosion of material, approximately 0.0036 in. per year for an aluminum surface. This might require consideration in all cases where optical surfaces or corrosion-sensitive coatings are used. Spalling is defined as the breaking off of an inner wall surface part, when a meteorite impinges. Such an effect poses a serious problem when the spalled particle impacts an internal system or the human occupant.

The most critical problem occurs when a particle penetrates the protective structure of the manned capsule, lunar shelter or extravehicle protective system. Table 1 presents the number of penetrations predicted by unit times for each of these systems when exposed to the flux densities predicted for a near-Earth orbit. These estimates are conservative and therefore probably overestimate the actual lunar surface penetration probabilities. The data indi-

Table 1. Number of Penetrations Predicted for Five Unprotected Systems Located on the Lunar Surface (Based on 40 km/sec Particle Velocity)

Mission Time on Lunar Surface	Manned (1) Lunar Capsule	Lunar (2) Shelter	Full (3) Pressure Suit	Full (4) Pressure Suit	Full (5) Pressure Suit
4 Hr	0.0003	0.0006	1.3	0.007	0.002
1 Day	0.0019	0.0038			
10 Days	0.019	0.038			
30 Days	0.057	0.11			
180 Days	0.34	0.68			
365 Days	0.69	1.4			
730 Days	1.4	2.8			

cate a reasonably low number of penetrations for both the manned lunar capsule and the lunar shelter.

Particle Radiation

The particulate radiation to which the lunar explorer will be exposed may be classified as cosmic background radiation associated with the solar system or galaxy and solar flare radiation associated with high energy bursts of solar origin. We must consider the effects of this radiation on the lunar system components and the biological effects on the man himself.

The computations of Table 1 were based on the following design parameters:

(1) Surface area, $26.9m^2$, double-wall structure with bumper equivalent to 0.75 cm solid wall thickness.

(2) Surface area, $53.4m^2$, double-wall structure with bumper equivalent to 0.75 cm solid wall thickness.

(3) Surface area, $2.0m^2$, 0.66 cm nylon equivalent to 0.035 cm aluminum.

(4) Surface area, $2.0m^2$, 0.066 cm nylon equivalent to 0.035 cm aluminum plus 0.10 cm woven aluminum cloth.

(5) Surface area, $2.0m^2$, 0.066 cm nylon equivalent to 0.035 cm aluminum plus 0.17 cm aluminum skin over all surface area.

The radiation tolerances of electronic components and the other electromagnetic equipments are relatively high when compared to the tolerances of humans. Cumulative exposure doses of between 10^5 and 10^9 roentgens are generally required to produce detrimental effects. Vitreous glasses, transparent plastics, and semiconductors usually show little or no degradation up to 10^5 roentgens. The preliminary calculations performed to date, therefore, indicate a high probability of continuous operation for equipment exposed to the expected particle radiation for periods of up to two years.

The radiation tolerances for humans (expressed in Rem, where Rem = roentgen x RBE) are difficult to define at the present time due to the lack of accurate data defining the RBE (Relative Biological Effectiveness) of particle radiation in the energy levels expected in the space environment. The conservative tolerance values are those published by the National Committee on Radiation Protection (NCRP) of the National Bureau of Standards. These are 0.3 Rem per week, 3 Rem per quarter, and 5 Rem per year for whole body radiation with a recommended 25 Rem limit for emergency exposure.[4] For space flight, the Air Force has suggested 25 Rem as a maximum dose with an additional 25 Rem reserved for emergencies.[5] It is important to note that while these radiation tolerance values are relatively conservative, the passage of low energy protons through especially sensitive portions of the human anatomy, such as the brain or heart, can cause death even though the integrated dose is quite small. Thus, any estimates of radiation tolerance must be open to question.

The lunar explorer, while located on the surface of the Moon, will be continuously exposed to the cosmic background radiation. This radiation consists of approximately 86 percent (H) protons, 13 percent (He) Alpha particles, and one percent light and medium nuclei particles, all of which appear to be omnidirectional. These particles show an extremely large energy range from 10^8 ev to 10^{18} ev. The average intensity is modulated during the eleven year solar cycle and, as the solar activity increases, the radiation intensity decreases. The average kinetic energy has been estimated by several authors to be between 3.6 bev and 4.0 bev per nucleon.[6] Recent measurements[7] of the Pioneer V space probe show a flux density in free space of $2.5/cm^2/sec$ and an ionization rate of 0.6 mr/hr inside a low number shielding material with surface density of 1 $gram/cm^2$. Extrapolating this internal radiation level to the lunar shelter with a structural skin thickness of approximately 0.25 cm, the radiation dosage to the occupant is approximately 5 to 7 Rem/year. This value, while not extremely high and only slightly above the recommended values published by the NCRP, is obviously a low estimate of the total integrated dose because it neglects the high energy radiation associated with solar flares.

The solar flare, a sudden short-lived energy discharge of the solar surface, generates an extremely high flux density of protons across a wide range of energy levels with the highest flux density occurring in the 100 Mev range. Robey[8] has estimated that the large flare of May 10, 1959, would have delivered a radiation dose of approximately 4,000 Rem to an unprotected man located on the Moon's surface. The radiation protection afforded by the lunar shelter would provide only a small, almost negligible, attenuation. Since more than 25 similar, but less intense, solar flares have occurred in the past three years, we must anticipate that the survival probability of the lunar explorer in an unprotected lunar shelter for a long duration is very small, if not zero. This becomes especially obvious when we note that the current period of the solar cycle is one of low activity. The next period of high solar activity is predicted to begin sometime in 1967.

Protection against solar flare radiation is especially difficult because no predicti n techniques are currently available which predict long enough in advance to enable the required protection. As a consequence, the lunar shelter must be shielded by a heavy shield of metal (such as lead) or be covered by a considerable thickness of lunar rubble. This latter approach can be accomplished by piling rubble directly on the shelter or surrounding the shelter with rubble after it has been inserted into a void on the side of a lunar mountain or crater.

The Earth's atmosphere provides us with approximately 1,023 grams/cm² shielding against the constant particle radiation which reaches the fringes of the Earth's atmosphere. To provide the same protection on the lunar surface, approximately 34 ft of lunar rubble is required to cover all living quarters.[9] With such a protective shield, the lunar explorer would be safe from even the most severe solar flares and would accumulate a yearly radiation dose very much less than the accepted NCRP tolerance values, disregarding the radiation dose he accumulates when outside the shelter. Other estimates of the amount of lunar rubble required to provide a satisfactory level of radiation protection from solar flares have indicated that as little as 6 ft of material is necessary. It must be recognized, however, that the accomplishment of burying the lunar shelter under almost any depth of rubble requires considerable time, effort, and support systems.

Other Environmental Parameters

In addition to those previously described, the following environmental parameters must be considered: The very small magnetic field (1.4×10^{-6}), the reduced gravitational field, and the hard vacuum environment. Some experimental investigations of the effects of low magnetic fields have been conducted.[10] The results to date indicate no significant physiological or psychological effects. Hence we have no basis, at the present time, either experimental or theoretical, for predicting adverse effects from this environmental parameter. The hard vacuum effects expected are not different from those found in deep space with other systems and should not require special attention in consideration of the one-way mission.

The reduced gravitational field, however, may result in some locomotion problems due to modified functioning of the semicircular canals and otolith organs, and the increased strength of the man relative to his reduced weight. The lunar explorer may literally not "know his own strength" and may consequently find himself stumbling or falling more often than can be tolerated. The results of a fall against a sharp piece of lunar rock could be disastrous. Thus, extreme caution must be exercised during all movements across the lunar surface during the entire mission, but especially during the initial period when the lunar explorer is learning what may be new techniques of walking.

Table 2. Environmental Control System Requirements

Lunar shelter volume (including air lock)	980 ft³
Mission time	3 years
Shelter temperature	70°F ±5°
Shelter pressure	362 mm Hg, 7.0 psia
O_2 partial pressure	160 mm Hg
N_2 partial pressure	192 mm Hg
CO_2 partial pressure	<5 mm Hg
H_2O partial pressure	5 mm Hg
Maximum CO_2	<1 percent by volume
Number of men (Maximum)	2
Occupant heat rejection	
Latent	460 BTU/hr/man
Sensible	200 BTU/hr/man
Occupant water rejection	2.8 lb/day
Occupant CO_2 production	3.3 lb/day
Occupant O_2 requirement	2.6 lb/day
Shelter leak rate	2.4 lb/day
Circulation	9–12 cfm

Environmental Control System

The environmental control system in the lunar shelter must provide the following:

(1) Atmospheric Supply—The required total pressure and partial pressures of O_2, N_2, CO_2, H_2O and control of noxious odor and particulate matter.

(2) Temperature Control—Maintenance of the temperature at required values.

It is difficult, without considering in detail the metabolic levels of each shelter occupant, to precisely define the environmental control system requirements. However, as a preliminary estimate, the values given in Table 2 are provided.

The final decision as to how these environmental parameters should be met will be the object of a detailed system design and trade-off study directed specifically toward the operational requirements of the lunar shelter system. The factors which have primary influence on the final system choice and configuration are: reliability, weight, installation limitations, power requirements, production or absorption of heat, oxygen supply, and contaminant production.

Oxygen Supply System

There are three major methods which can be used for supply of oxygen to the lunar shelter:

(1) Storage of molecular oxygen by either high pressure or cryogenic storage techniques

(2) Chemical means

(3) Derivation from waste products

Several studies have been made of these alternative approaches indicating that at the present, a definite decision as to which of these alternative approaches should be taken cannot be made. Table 3 presents a summary of the various systems.

Nitrogen Supply System

The provision of N_2 to the atmosphere can best be provided by pressurized vessel storage or cryogenic storage. Assuming the lunar shelter atmosphere leakage rate of 2.4 lb/day and 49.5 percent N_2 (by weight) in the shelter

Table 3. Oxygen Supply Systems

Type	System	Weight Ratio*	Remarks
Molecular	Compressed gas	1.8	High volume required.
	Cryoganic gas	1.3	Insulation required.
Chemical	H_2O_2	3.6	H_2O and heat by-products. Partial CO_2 adsorption and H_2O removal.
	KO_2	3.3	
	NaO_2	2.7	
Derivation from waste products	CO_2 photosynthesis		Advanced state-of-art
	H_2O electrolysis		High power requirements.

* Weight of containers plus gas/pound of oxygen.

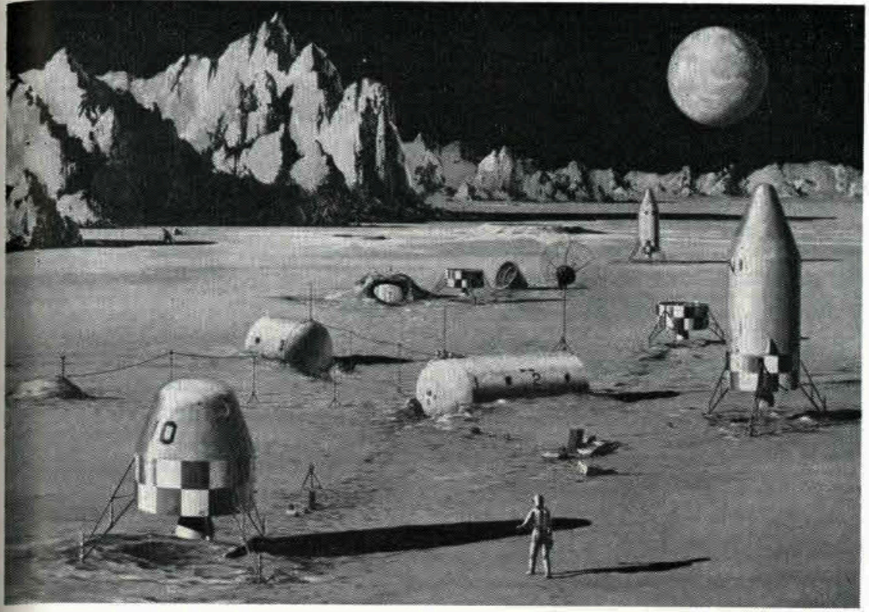

Fig. 6. Lunar base.

atmosphere, 1.19 lb of N_2/day will be lost by leakage. Using cryogenic storage and 1.3 lb of N_2 system/lb of gas, 556 lb of N_2 per man-year is required. Storing N_2 as a compressed gas at 1.8 lb of N_2 system/lb of gas, 781 lb of N_2 per man-year is required.

Carbon Dioxide Removal

Approximately 3.3 lb/day of CO_2 must be removed from the shelter atmosphere to enable control of the partial pressure. In addition, the CO_2 removal system, by proper incorporation of activated charcoal beds or other absorbers, provides odor and particulate matter removal from the atmosphere. Two classes of CO_2 removal system are available for use: nonregenerative and regenerative systems.

The regenerative systems include the use of solid or liquid adsorbents which, when saturated with CO_2 (and H_2O vapor), can be recycled by heating. The studies conducted to date, with such systems, indicate that the power requirements necessary to accomplish the recycling are relatively high for short missions. For longer mission durations and missions where solar energy is available as a power source, their use appears more attractive.

Two nonregenerative CO_2 removal techniques are available: chemical adsorption and freezing out. The chemical techniques are furthest advanced and appear to offer the greatest potential for application. A large number of chemical adsorbents are available for use; the analyses and experimental research conducted to date point to LiOH as the most promising. The gas containing CO_2 is passed through a LiOH cannister and the CO_2 is adsorbed. Approximately 1.35 lb of LiOH per pound of CO_2 adsorbed is required. Estimating the cannister weight to be approximately 25 percent of the chemical weight, approximately 1.69 lb of LiOH system/lb of CO_2 adsorbed is required. On the basis of 3.3 lb of CO_2 generated per man-day, approximately 2,037 lb of LiOH must be provided per man-year.

Temperature Control

As indicated earlier, it is desirable that the lunar shelter be covered by a protective layer of lunar rubble to provide the necessary radiation protection, micrometeorite protection and thermal environment control. The depth of this layer will be determined primarily by the requirements for radiation protection. At the present time, estimates of the depth requirement vary from 6 ft to 34 ft. However, in the case of thermal control, it is important to note that at a depth of approximately one yard, it is estimated that a constant temperature of approximately $-38°F$ is reached by the lunar ground.

In view of the wide variation in the heating and cooling requirements when the shelter is exposed directly to daily fluctuations of solar radiation input associated with the lunar day and night, it is obvious that burial of the shelter greatly simplifies the temperature control problems. The moon's surface is predicted to have a very low thermal conductivity, $K = 0.0373$ BTU/ft, hr, $°R$ and a specific heat of 0.2 BTU/lb, $°R$. These characteristics, coupled with its relatively constant temperature of $-38°F$ at depths of 3 ft or greater may be used to advantage in reducing the long term heating and cooling requirements.

Extravehicular Environmental Control System

Some means of providing the man with the capability to move about on the lunar surface and engage in the required work activities is necessary once the man leaves his shelter. A minimum system would consist of a specially designed full pressure suit which would provide the lunar explorer with a self-contained environment meeting minimum physiological requirements. This suit must be designed with maximum flexibility to enable the explorer to engage in the necessary work involved in activating the lunar site and handling supplies as well as conducting relatively long duration explorations on the lunar surface. Based on preliminary estimates, a four-hour mission duration is required with 100 percent back-up. The materials to be employed in the fabrication of the full pressure suit are critical because of the hard vacuum, potentially high radiation field, lunar terrain, and micrometeorite population.

The atmosphere provided in the full pressure suit can be supplied by any of the techniques described in previous sections. However, since a preliminary decision in favor of cryogenic techniques was made for the lunar shelter, such techniques should be employed with the extravehicular system as well. A small back-pack atmospheric control system integrated with the full pressure suit would supply on demand the necessary 100 percent oxygen at somewhere between 3.5 to 5.0 psia.

The control of the thermal environment within the pressure suit will be one of the major problems which must be handled by the environmental control system. Assuming the heat generated by the lunar explorer, 2,000 BTU's per hour during periods of heavy work, is relatively constant, we note that the internal suit heat load will change as the man moves from direct solar radiation to the shadow of a crater wall, etc.

To minimize the presence of local hot or cold spots in the suit and to maintain a relatively constant temperature across the entire body surface, it will be necessary to continuously circulate the air through the pressure suit. Reasonable values for this circulation are a gas velocity of 3 ft/sec and a gas volume of approximately 30 cu ft/min.[11]

Lunar Base

A lunar base established in conjunction with the one-way mission is represented in Fig. 6. Two shelter modules have been laid on their sides and joined by winching them together. To the above left of these units is a cargo vehicle which is being used to store equipment and supplies. The manned lunar capsule is shown in the lower left corner mounted atop its retropropulsion stage. Located to the rear center of the picture is a storm cellar type radiation shelter. This specially designed module which has shielding in the entrance end and has been covered with lunar rubble provides an emergency shelter which the one-way space man can occupy during periods of high radioactivity. Near the extreme left of the picture is a nuclear power source which has been covered with lunar rubble to shield its radioactivity from the base area. Other portions of the base area show landed cargo vehicles, retrostages, supplies, equipment, etc. The illustration is only conceptual. The optimization of such a base arrangement could be defined as our unmanned lunar programs uncover information on the nature of the Moon.

Logistics Requirements

The logistics requirements for the one-way manned space mission are based on the unmanned cargo vehicle described earlier. While the vehicle depicted is not intended to represent a final optimum design, it is typical of representative configurations.

Several typical cargo payloads have been envisioned based on the 910-lb payload capability. Among the most important is a life support payload containing food, water, and replenishable elements of the environmental control system. A "baggage allowance" of 150 lb has been made in this payload to cover additional items required such as medical supplies, small tools and instruments, personal and recreation material, etc. This allows 760 lb for the basic life support payload per cargo vehicle.

It is assumed that an air lock concept that loses only 6 lb of O_2 and N_2 per day is employed in lunar shelter. Fifty percent of the required water is assumed to be provided by recovery. Based on these assumptions the total yearly life support requirements (including containers) per man are estimated to be:

O_2 and N_2 breathing	1230 lb
O_2 and N_2 leakage	1140
O_2 and N_2 air lock loss	2850
CO_2 removal	2040
Food	950
Water	1700
Total life support	9910 lb/year/man

On this basis, 13 life support payload launches are required per year per man. A two-man system does not require twice as many launches because some of the required payload, such as leakage, is not proportional to the number of shelter occupants.

The basic living module or shelter constitutes an important cargo payload. Whether one or more should be sent would be developed from operational studies. The basic living shelter module would consist of the cargo vehicle shell. The 910-lb cargo payload capability could be apportioned as follows: 400 lb for the shelter environmental control system; 250 lb for breathing supplies; and 260 lb for built-in furnishings and equipment.

Another cargo payload would consist of power supply and communications equipment. A nominal 2,000-watt nuclear power source should weigh approximately 500 lb without shielding. The remaining 410 lb of cargo payload could be apportioned among communication links; amplifiers, recorders, and displays; antennas; telemetry instrumentation; emergency batteries; wiring and hardware.

An estimate of the number of cargo payload launches required to sustain the one-way space man on a per man per year basis follows:

Life support payload	13 per year
Basic living module	2
Power supply and communications	1
Surface vehicle/construction equipment	3
Utility payloads	3
Total	22

For a two-man mission, the number of life support payloads would increase to less than two times the 13 required. The expanded nature of the base operation with two men would probably require more of the other payloads such as the utility payload. It is estimated that a two-man system would require a total of 30 to 35 payloads per year.

An important part of the logistics system would be an emergency supply system. This would furnish critical equipments and supplies on a demand short notice. This system might consist of a standby cargo vehicle ready for a utility payload. It might be advantageous to consider a smaller payload system based on a solid propellant booster, and might even be hard-landed at the lunar base site.

Conclusions

The One-Way Manned Space Mission has been described and analyzed with respect to technical requirements. It is not the intent of the authors to propose that such a mission be accomplished. The technical analysis of the mission indicates, however, that the concept is feasible with respect to lunar missions, and that the system elements are within the current state of the art. The booster requirements are shown to be significantly below that for missions with return capabilities. This could result in a one and one-half to two year advantage over similar lunar missions with return capability. The concept evolved for One-Way Manned Lunar Missions consists of a 2,190-lb manned lunar mission capsule, a series of cargo vehicles with a 910-lb payload capability, and the necessary life support, communications, and power supply systems. These are integrated into a conceptual lunar base complex.

It is difficult to formulate firm recommendations for the One-Way Manned Space Mission without reconciling the moral and ethical aspects of the mission. It is sincerely believed that capable and qualified people could be found to volunteer for the mission even if the return possibilities were nil. However, the fact that a man is willing to go does not alone justify our sending him.

The significant areas of insuring man's survival on the Moon and on other planets and of safely returning him to Earth will certainly be the object of extensive research as our space program progresses. Various concepts of survival and return will be studied and developed. If, in the future, these aspects of a one-way mission could be firmly resolved, an adequate probability level of mission success would be established. If this can be demonstrated, the One-Way Manned Space Mission becomes a two-way mission, and not only a feasible concept, but one which we can and should use.

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