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LUNAR LANDING AND SITE SELECTION STUDY

by James L. Lewis and Charles D. Wheelwright

Manned Spacecraft Center
Houston, Texas

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SUMMARY

The Apollo lunar excursion module (LEM) is presently scheduled for lunar landing in sunshine conditions. However, several operational constraints presently impose severe penalties on the Apollo mission launch window. The extension of the LEM landing capability to include certain earthshine conditions provides additional latitude where these constraints are concerned.

A study was made of the possible extension of the launch window for the Apollo mission by defining the minimum brightness level for successful lunar landing. The pilot's ability to select and commit to a landing site, the trajectory, and window visibility requirements were evaluated in various lunar brightness levels.

A helicopter with a modified LEM window was used on the LEM trajectories from 1000 feet altitude to the surface. Fifty flights were made over homogeneous terrain. Observers wore neutral density filters to simulate lunar brightness levels ranging from $\frac{1}{4}$ earthshine, lowest mare albedo, to full earthshine, maximum mare albedo.

Landing site selection, commitment to landing, and total time to touchdown are generally inversely proportional to the brightness level. Observer comments indicate that the pilot's landing commitment confidence level is unacceptable below a brightness level of 0.04 foot-lambert.

INTRODUCTION

Problems attendant to LEM earthshine landing indicate the need to study pilot ability to detect, select, and land at a satisfactory site. The LEM must be landed from an altitude of 1000 feet with the use of minimum fuel, under abnormal lighting conditions, and over unfamiliar terrain void of normal piloting cues. This study was primarily concerned with evaluating pilot performance in reduced earthshine lighting similar to that predicted for the lunar surface.

Specific objectives were to:

1. Evaluate the LEM F window configuration in simulated lunar lighting and terrain

2. Determine the minimum brightness levels to detect, select, and land at a satisfactory lunar landing site, starting at 1000 feet altitude

3. Study trajectory shape as a function of brightness level.

A Marine UH34D helicopter was used to simulate LEM landings from 1000 feet altitude to touchdown. Pilot performance was evaluated in terms of brightness level, altitude, and time at which site selection and landing commitments were made. Comparative landing times were studied as a function of various brightness levels from an initial point (IP) of 1000 feet altitude, 75 fps horizontal, and 0 vertical velocity. The assumption was made that terrain obstacle clearance had been accomplished previously. The program was conducted over an area free of familiar man-made or natural features that might enable observers to establish cues concerning size, shape, and slope of terrain.

FACILITIES AND EQUIPMENT

Facilities

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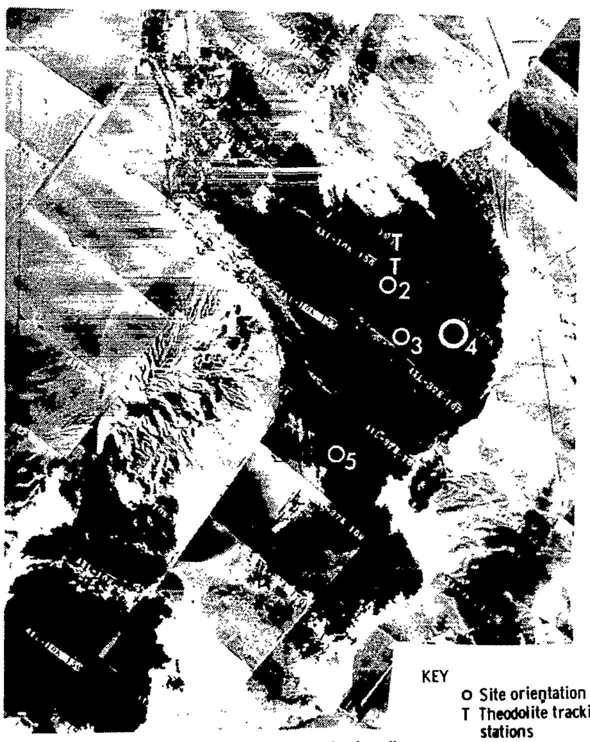

Figure 1. - Pisgah crater lava flow

The Pisgah Crater lava flow at the southern end of the Mojave Desert (fig. 1) was chosen as the testing area. The lava flow, which is located on the Marine Corps Base reservation, Twenty-nine Palms, California, has an area of 36 square miles and an elevation from 1886 to 2543 feet above m.s.l. The area was chosen because its terrain simulated the known lunar features of homogeneity, monochromaticity, low albedo, and no vegetation; it had few or no man-made structures. The area was near aircraft and equipment repair facilities.

The Marine Aircraft Group 36 of the Third Marine Aircraft Wing provided two UH34D helicopters and crews for the study.

Service facilities for the two aircraft and special equipment were provided at the Marine Corps Base, Twenty-nine Palms.

Site Orientation

Five sites (fig. 2) considered representative of expected lunar topography were chosen for initial trajectory orientation.

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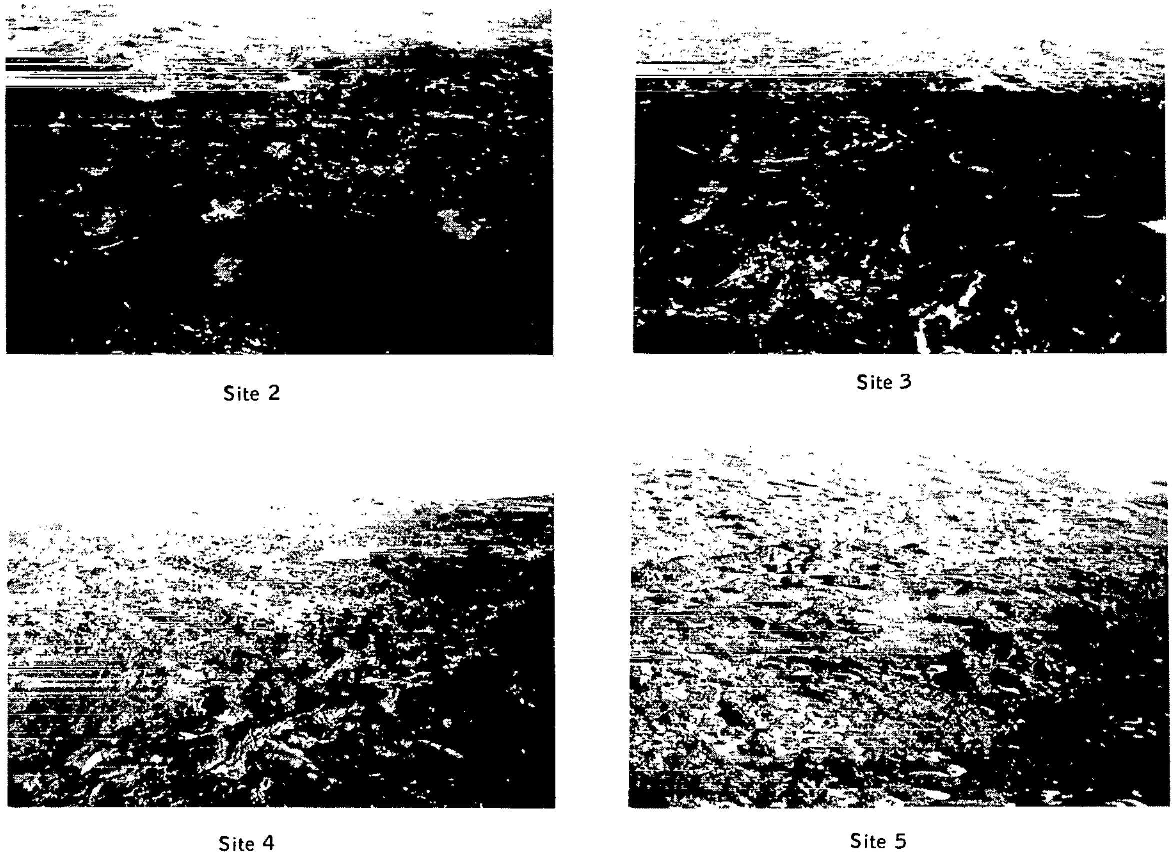

Figure 2. - Landing approach views of the selected sites

Site 1 was not used.

The average flight path to site 2 was over very rugged terrain with few landing sites along the flight path and three possible sites located at the end of the flight path, two of which were acceptable landing areas.

The average track to site 3 was over very rugged terrain with one large landing area lower than the surrounding terrain at the end of the trajectory.

The flight path to site 4 was over rugged terrain with several suitable landing sites at the end of the flight path.

The track to site 5 was over generally flat terrain with one exceptionally large landing site at the end of the flight path.

LEM landing footprints appropriate to this study were placed over a 1:20,000 scale aerial photograph to determine the applicability of these choices to LEM landing and to establish trajectory headings for consistent observer trials. Initial points were established consistent with these footprints. Trajectories were oriented so that the observer viewed the landing areas downsun. For each run, the trajectory was alined so that the site orientation was within ±30° of the initial heading.

Aircraft Modification

The co-pilot's window (left side) was modified with a LEM window mock-up based on the F configuration LEM forward face. Figure 3 shows the visual field

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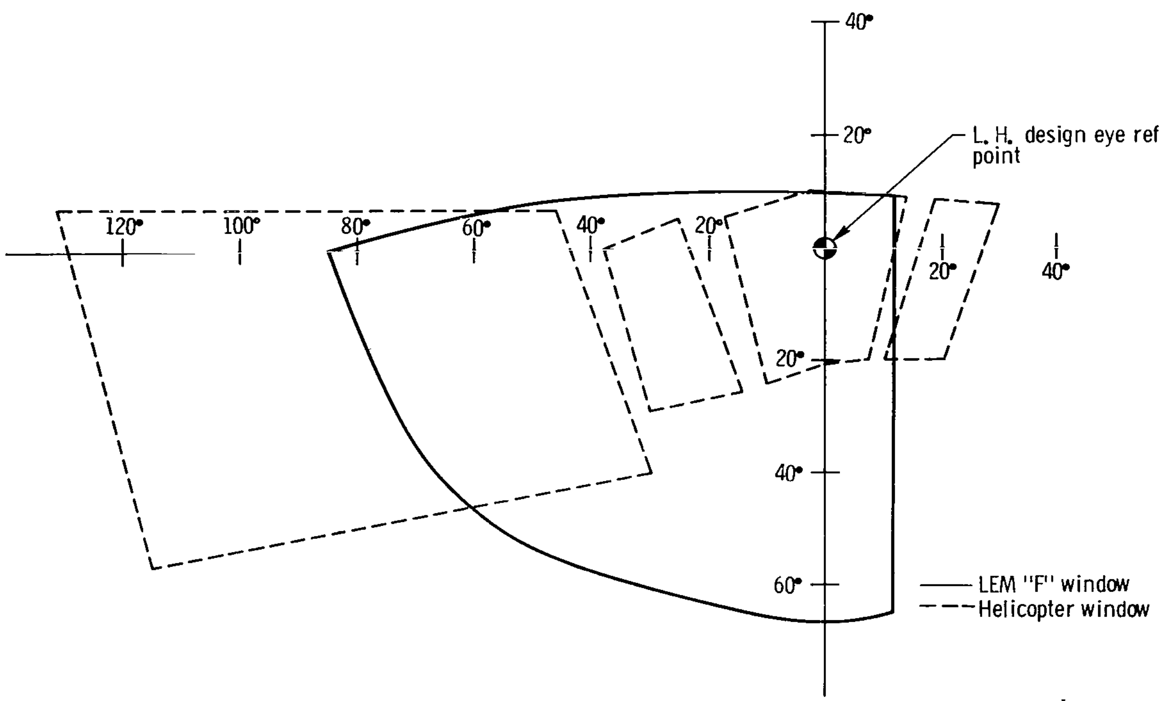

Figure 3. - LEM window field of view compared to helicopter installation

of the F window compared to the modified helicopter window. Figure 4 shows a LEM mock-up with the F window installed and the helicopter as it was flown. Forward down vision was limited to 22° by the aircraft structure. Down vision to the side was equivalent to that of the F window if the observer moved his head toward the window. LEM window coating material, and therefore, light attenuation, is presently undefined. It is felt that this light attenuation will be approximately 5 to 10 percent greater than the value used in this study.

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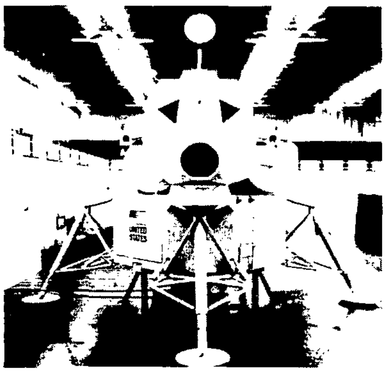

LEM

Marine UH 34D

Figure 4. - Marine UH 34D helicopter and present LEM configurations

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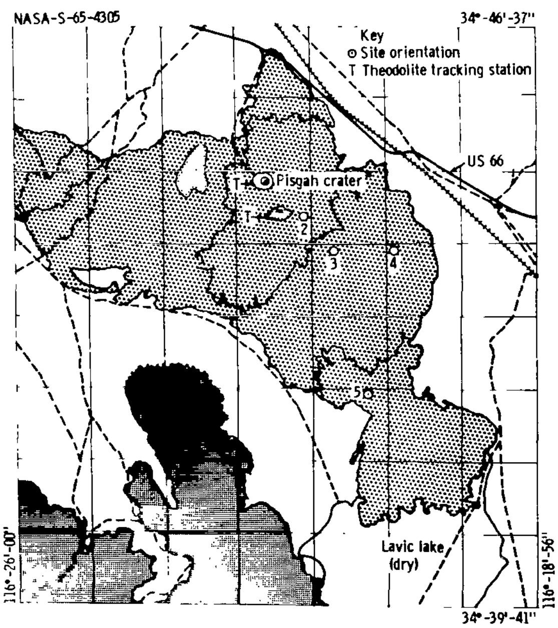

Figure 5. - Pisgah lava flow - lunar landing test area

Data were recorded on tape recorders and cameras both in the aircraft and on the ground. Aircraft instrumentation included three 16-mm motion picture cameras, one tape recorder, and radio communication equipment. Two of the movie cameras were mounted beneath the helicopter between the landing gear and were used alternately during approaches to record landing areas. The other movie camera was mounted between the two pilots on the aft cabin firewall and recorded airspeed, altitude, heading, descent rates, and elapsed time during approaches. One tape recorder, used for recording pilot-observer comments during each approach, was installed on the aircraft. This tape recorder was synchronized with the external cameras for sound track film of each approach. Radio equipment was installed in the aircraft to provide communication between the aircraft and ground personnel.

Ground Equipment

Ground installations included two theodolite tracking cameras, one tape recorder, radio communication equipment, and transit. The theodolite tracking cameras were located at high points on the lava flow 2000 feet apart and at approximate right angles to the trajectory paths (fig. 5). These cameras provided helicopter position in time histories for all approaches. The recorder was located at one of the theodolite stations for recording pilot-observer comments following each approach. This recorder was also available for backup in case of failure of the airborne unit. Radio equipment was located at each of the tracking stations and on the aircraft to provide communication between the two stations and the aircraft.

Crew

A total of seven pilot observers participated in this study; one was qualified in both fixed- and rotary-wing aircraft, and the others were qualified in fixed-wing only. These pilot observers represented engineering personnel from the Manned Spacecraft Center Astronaut Office, Flight Crew Support Division, Aircraft Operations Office, and Grumman Aircraft and Engineering Corporation.

Lighting

Nine neutral density (ND) filters with a transmittance from 0.002 to 2.9 percent of the visual spectrum were used to simulate the various lunar brightness levels. These filters used either separately, or in combination, enabled simulation of the complete range of lunar brightness from earth-phase incident light, lunar albedo, and photometric function. The percent of total light and wave length peak transmission of the filters was determined by spectrophotometry and light microscopy. Three analyses using each technique were made per filter (table I). The average of the six values was used as the transmittance of each filter.

Goggles fitted with the appropriate filter to give the desired brightness level (fig. 6) were worn by the observers.

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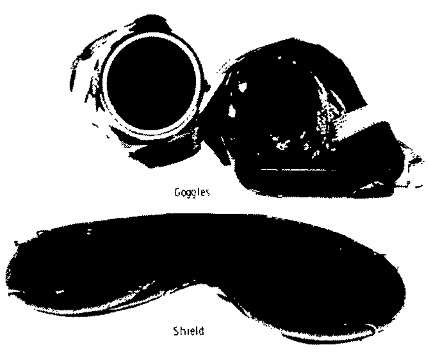


Figure 6. - Observer's goggles and dark adaption shield

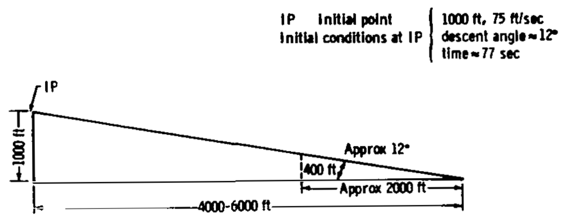
A spectra brightness spot meter was used to measure reflected brightness levels. A filter adapter was fitted to the meter so that direct measurements could be made through the neutral density filters during each landing approach. The meter has a 1.5° acceptance angle and a range from 10^{-4} to 10^{4} ft-L.

PROCEDURES

The observers were given a brief description of the objectives of the program. They were also briefed on suggested trajectories, the lunar brightness range to be simulated, and procedures for exchanging goggles.

Observers rode in the co-pilot seat and were familiarized in flight with the three basic trajectories shown in figure 7 before leaving Twentynine Palms Airfield. These trajectories were suggested as guides for the following conditions:

1. Trajectory 1 - A tentative landing site is selected at 1000 feet altitude which appears 4000 to 6000 feet horizontal distance from that point.



(a) Trajectory 1

Figure 7. - Trajectories

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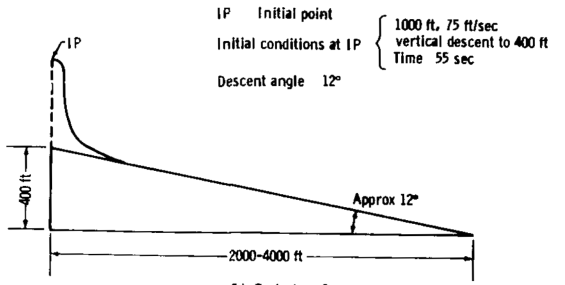

(b) Trajectory 2

Figure 7. - Trajectories (cont)

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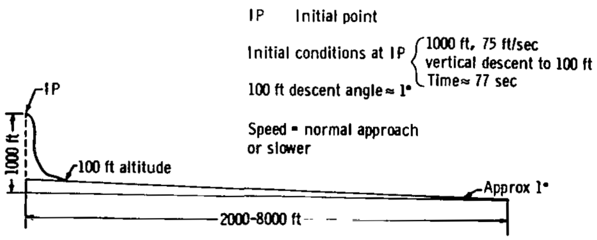

(c) Trajectory 3

Figure 7. - Trajectories (concl)

2. Trajectory 2 - A tentative landing site is selected at 1000 feet altitude which appears 2000 to 4000 feet horizontal range from that point.

3. Trajectory 3 - A tentative landing site can not be selected at 1000 feet altitude because of low brightness levels. This trajectory provides a method of quickly reaching a low altitude so the remaining time of the flight can be used for low-altitude search.

The 4000- to 6000-foot distances were estimated as placing the landing site at a comfortable normal straight-in approach angle. At 2000 to 4000 feet, the landing site appeared close to the helicopter, making a vertical descent to an intermediate altitude necessary until a comfortable straight-in approach angle was attained.

Observers were instructed to use these suggested trajectories, or any modifications thereof, to accomplish a landing within 2 minutes at a satisfactory site.

Following the trajectory familiarization period, the observers wore a light shield over their eyes for dark adaptation during the 45-minute flight to the lava flow. Prior to the first data run, the light shield was exchanged for a pair of goggles with neutral density filters. The observer kept his eyes closed until 30 seconds prior to the initial point.

The pilot transmitted a 60-second mark prior to the initial point. At this point, the ground-based theodolites began tracking the aircraft, and each tracking site reported its readiness state. With both tracking sites ready, a 30-second mark was transmitted, and the observer began his search for a landing site. At a 10-second mark, the onboard cameras and the tape recorder were started, the ground-based theodolites were turned on, and the run number and brightness level were recorded on the onboard tape recorder. The pilot transmitted "Mark I" at the initial point to indicate the beginning of a run and initiated a descent using trajectory 1.

At this point the observer had the choice of continuing this type of descent, requesting a change to trajectory 2 or 3, or requesting a modification of these. When the observer had directed the pilot to a point approximately 20 feet over the landing site, or when the 2-minute period had been exceeded, the pilot transmitted "Mark II," signalling the end of the run.

Successive approaches were made in a non-repetitive sequence to different orientation sites. Each observer directed a minimum of one approach to each area under various brightness levels.

Lunar brightness levels were calculated as a function of the following (ref. 1):

1. Earth phase (incident light intensity)

2. Lunar albedo (reflective characteristics)

3. Lunar photometric function (viewing angle with respect to incident light).

The illumination levels simulated covered the range of those expected on lunar surface under full-, $\frac{3}{4}$-, $\frac{1}{2}$-, and $\frac{1}{4}$-earth phase; viewing angles of 0°, 70°, and 76°; and lunar albedos of 9 percent, 6.5 percent, and 5 percent (table II).

Fifteen values representative of the lunar reflected light range were selected for use in this study (table II). Prior to each run, a neutral density filter was selected which would provide the desired brightness level. This was accomplished by placing a neutral density filter in the light meter adapter, fitting the adapter to the meter, and measuring the desired brightness level by pointing the meter at the landing area along the flight path to be followed. The correct filters were then placed in the goggles and given to the observer. During each run, a duplicate filter was kept in the meter to insure that any change of brightness caused by meteorological conditions could be recorded.

During the runs, light levels were chosen at random without repetition, within the range of 0.0005 ft-L to 0.113 ft-L. Figure 8 is a photographic reproduction of figure 2 showing each orientation site in reduced brightness. Because of the limitations involved in the reproduction process, it is not possible to estimate the exact simulated brightness level of the photograph.

RESULTS

Fifty test runs covered the range of predicted lunar brightness levels (table II) and met the standardized conditions of the study. Of the 50 runs, 7 resulted in unsatisfactory landing attempts. Unsatisfactory landing attempts were defined as attempts to land in unacceptable terrain or those cases in which

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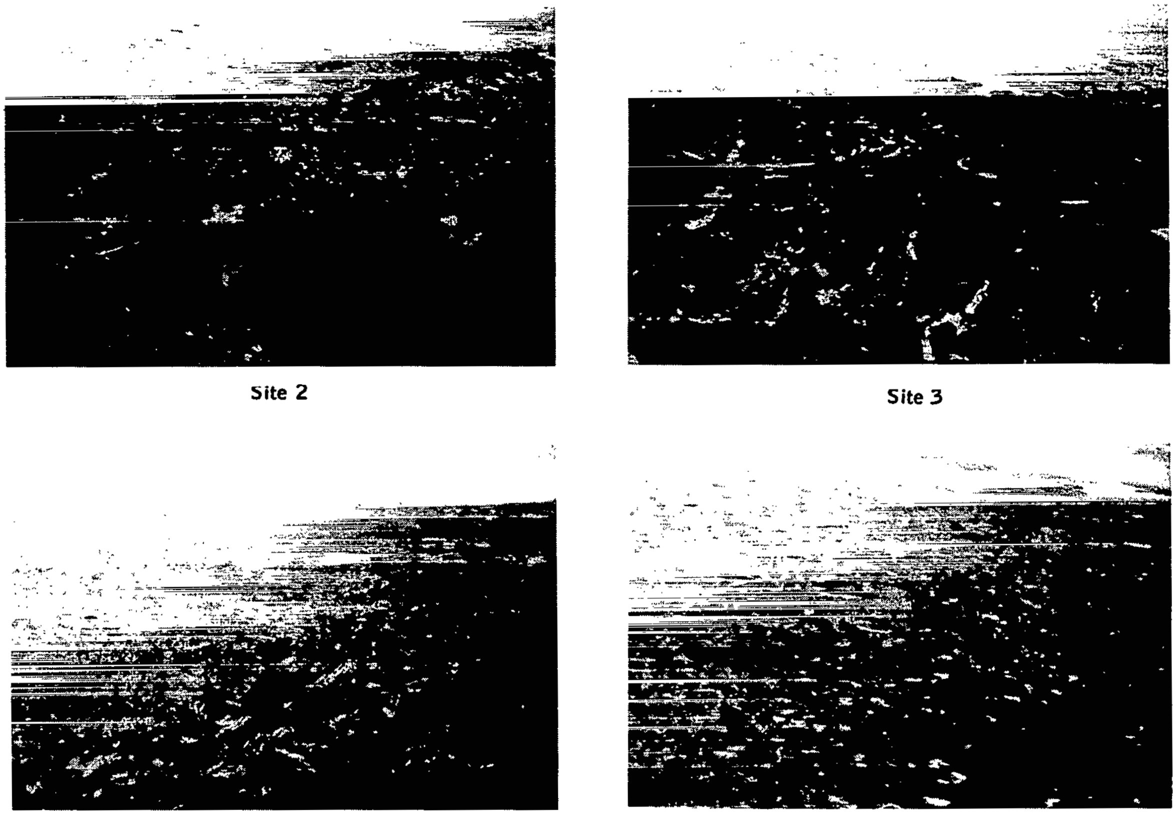

Site 2

Site 3

Site 4

Site 5

Figure 8. - Photographic reproduction showing each orientation site in reduced lighting.

the 2-minute time limit had been reached. These 7 occurred at brightness levels of 0.0325 ft-L or less, and represented 21 percent of the trials in this brightness range. There were no unsuccessful landing attempts at brightnesss levels above 0.0325 ft-L.

Brightness level was plotted against time for site selection, landing commitment, and total approach times (fig. 9). Indicated in figure 9 are several factors applicable to human vision capabilities which occur in the simulated brightness range (0.0005 ft-L to 0.113 ft-L). Rod-dominated vision is prevalent in the 0.0005 ft-L to 0.009 ft-L range (ref. 2). Terrain contrast can be perceived at 0.02 ft-L (ref. 3), terrain texture is discernible at 0.04 ft-L, and elevation at 0.06 ft-L. These factors, in general, support the results of this study. Time for site selection, landing commitment, and total approach decreased as brightness increased. Compared to the lowest level of brightness (0.0013 ft-L), site selection time at the 0.039 ft-L level had decreased an average of 32 percent, landing commitment times by 19 percent, and total approach times by 11 percent. At the brightest level simulated (0.113 ft-L), site selection, landing commitment, and total approach times had

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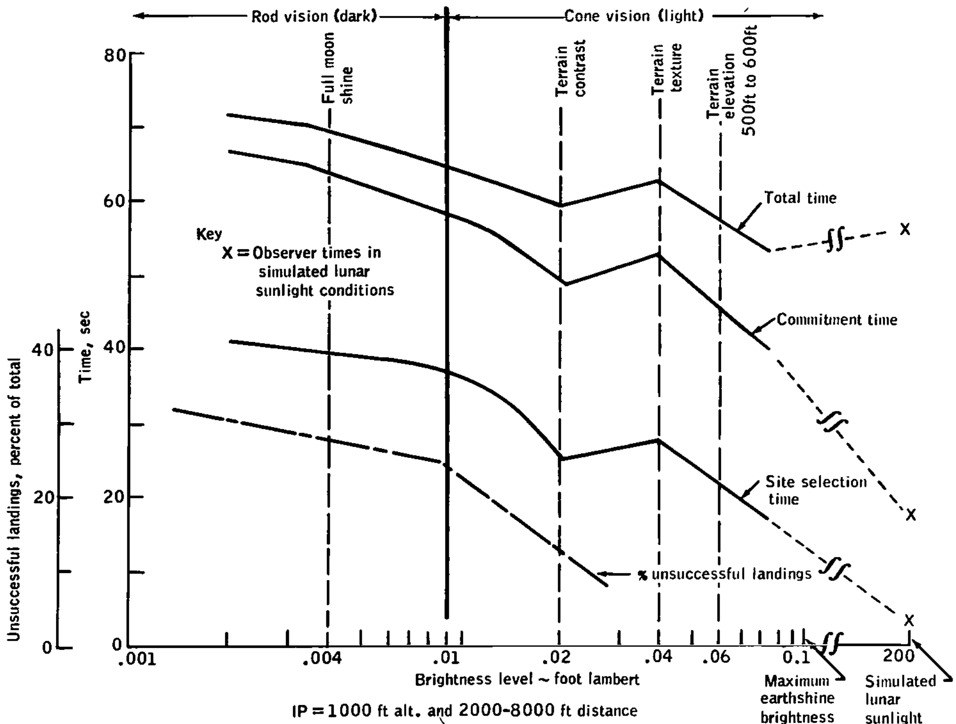

Figure 9. - Brightness vs site selection, commitment, and total time from IP

decreased a total of 59 percent, 38 percent, and 25 percent, respectively.

These times decreased steadily as brightness increased until dark shadows were discernible as terrain contrast (0.02 ft-L). At this point the times increased uniformly to a point at which texture could be discerned (0.04 ft-L) (table III, fig. 9). The times decreased in an essentially identical manner at brightness levels above 0.04 ft-L. Perception of terrain elevation did not further change the rate of decrease of these times.

Site selection time began to decrease more rapidly at a point where cone vision replaced rod vision (0.009 ft-L) (ref. 3). No significant change occurred in commitment times, and a slight decrease in slope occurred at this point for total time.

Initial runs for each observer were categorized separately, and average times were found to be significantly greater than those for the above-mentioned 50 runs. Of the seven initial runs, five were made at the highest predicted lunar brightness level (0.113 ft-L) (fig. 9). Of these five, two resulted in attempts to land in unacceptable areas.

In order to obtain control times, seven runs were made by a helicopter pilot in normal daylight conditions. Resulting times for site selection and landing commitment were significantly lower than the averages for simulated earthshine conditions (fig. 9). Control run total times were approximately equivalent to total times in the 0.06 ft-L to 0.113 ft-L brightness range. At these brightness levels, maximum rate descents consistent with LEM capability could be accomplished and were similar to those made in daylight conditions.

Helicopter position-in-time histories for all runs were obtained from theodolite tracking cameras. Velocities and accelerations were computed and applied to LEM vehicle dynamics under the influence of the lunar environment. Accelerations, velocities, and thrust vector orientation angles were then computed to determine applicability of this study to actual lunar landing dynamics. Results of the data reduction showed that the helicopter maneuvers did not exceed LEM capabilities.

CONCLUSIONS

No visual problems existed with the simulated LEM window during any of the approach trajectories.

Trajectories were used as suggested in prerun briefings. In the brightness range of 0.053 ft-L to 0.113 ft-L, the trajectory selected appeared to be a function of pilot preference and site location rather than brightness level (table IV). These independently established trajectories compare favorably to those used during the Vertical Take-off and Landing Program (ref. 5).

The results of this study indicate that lunar earthshine landing operations should not be attempted at or below 0.009 ft-L. The percentage of unsuccessful approaches (fig. 9) and observer comments (table III) indicate that LEM operations in brightness levels between 0.009 ft-L and 0.04 ft-L could endanger crew safety. Observer comments indicate that a high level of confidence did not occur until a brightness level of 0.06 ft-L was obtained. The acceptable pilot's confidence level appears directly related to the brightness level at which terrain elevation could first be observed. Terrain texture, visible at 0.04 ft-L, was the final factor to cause a change in rate of selection, commitment, and approach times. There were no unsuccessful approaches at or above the brightness level of 0.0325 ft-L. These factors indicate that 0.06 ft-L is definitely an operationally feasible brightness level. It is also apparent that a lower minimum could exist at 0.04 ft-L. Simulators should be used to train the flight crew in initial lunar approaches.

Referring to figure 9, there is a change in the rate of decrease in site selection time at 0.009 ft-L. This is expected because of the dominant selective sensitivity of the cone receptors. At this point, shadows change gradually to contrast gradation as the brightness level continues to increase.

At a brightness level of 0.02 ft-L, the time required by the observer to make a decision increased. At this level of illumination, the cones are stimulated sufficiently for color and marginal terrain contrast definition (ref. 2).

The decrease in time at brightness levels greater than 0.04 ft-L indicates quicker differentiation by the pilot when selecting a suitable landing site if terrain texture and elevation are discernible (refs. 3 and 4).

Table II shows that 0.04 ft-L, and above, can be obtained by viewing parallel to the incident light with the source to the rear of the observer in full-earth phase (maximum incident light conditions) in a mare area, or in $\frac{3}{4}$-earth phase, if average to high mare albidos exist. This constraint dictates orienting the LEM vehicle flight path along the line of incidence, and precludes, to a great degree, pilot scan of adjacent landing areas.

The results of a study to describe the amount of light available to the pilot are contained in the appendix. The conditions discussed in the appendix are predicated on an estimate of the severity of the lunar photometric model. If future investigation indicates this model is less severe, or even non-existent for operational purposes, a greater latitude would exist in the viewing and approach angles in the $\frac{3}{4}$- to full-earth phase incident light range.

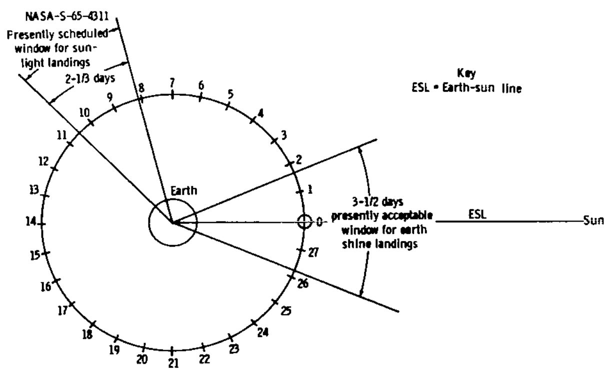

Figure 10. - Apollo vehicle launch window

If the LEM thermal design permits, the Apollo monthly launch window could by increased by approximately $3\frac{1}{2}$ days (fig. 10 and the appendix). This additional period would require precise calculation after the photometric model. has been determined to yield the correct degree of shadow, contrast, and reflected brightness. According to existing ground rules, this period would exist during the 7-day interval shown in figure 10 and would precede the presently planned $2\frac{1}{3}$-day launch window by $6\frac{5}{12}$ days.

APPENDIX

ANALYTICAL STUDY OF THE OPERATIONAL IMPLICATIONS RESULTING FROM THE LUNAR LANDING AND SITE SELECTION STUDY AND THE PHOTOMETRIC MODEL

In order to determine the periods of earthshine in which an adequate range of vision in the vertical plane is available for landing, an analysis was made of the results of this study and the technical data from the photometric model presented in reference 2. The following assumptions were made:

1. Lunar landing would be accomplished at zones selected between 28° and 41° longitude for purposes of shadow effect and contrast definition.

2. The minimum acceptable reflected brightness is 0.04 ft-L.

3. The photometric model presented in reference 2 is accurate.

4. The local landing surface was considered flat with respect to the horizon.

5. The vertical plane is defined as the plane containing the local vertical and the line of incidence of earthshine.

In order to maintain 0.04 ft-L during any earth phase, the maximum attenuation due to the photometric function can be determined from the following formula:

$$\Phi_{max} = \frac{0.04 \text{ ft-L}}{\rho E}$$

E	Incident light
Φ	Photometric attenuation in percent
ρ	Lunar albedo
0.04 ft-L	Minimum acceptable brightness as determined in this study

By applying the maximum acceptable photometric attenuation to the photometric model of reference 2, the correct phase angle and viewing angle projection can be determined as a function of the incident light direction, which is, in turn, a function of the longitude selected for lunar landing (fig. 11).

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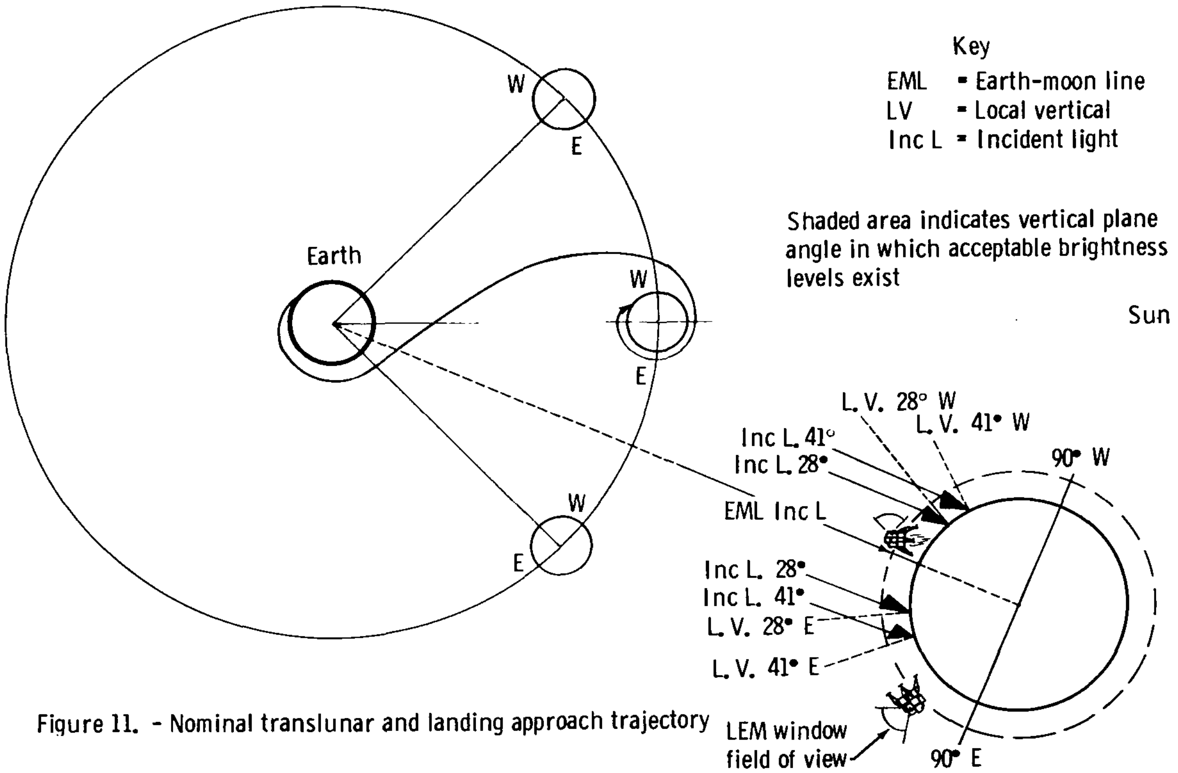

Figure 11. - Nominal translunar and landing approach trajectory

The projection of the viewing angle onto the phase plane is of operational significance. Figure 12 (a) shows that to maintain 0.04 ft-L during $\frac{3}{4}$-earth phase, the range of vision in the vertical plane about any line of incidence between 28° and 41° longitude is limited to 2° below the incidence line and 0° above it.

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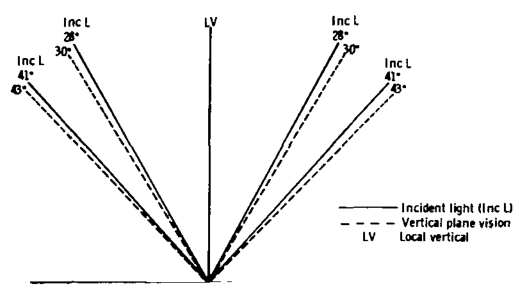

Conditions: 3/4 earth phase; 0.065 albedo; 0.63 ft -c incident light; 2.3% photometric attenuation represents maximum allowable angle in vertical plane for 0.04 ft -L reflected

(a) 3/4 Earth phase

Figure 12. - Range of vision in the vertical plane for 28° and 41° longitudes

This indicates that the flight-path approach angle and pilot-viewing angle will have to be alined with the incident light. This, then, precludes landing in an eastern longitude with conventionally acceptable approaches (fig. 11).

As the earth approaches 0° phase angle, or its full position, and as incident light increases, the range of vision about the line of incidence increases to a maximum of approximately 60°. At 28° longitude, the range extends from 24° above the incidence line

line to 38° below it, and at 41° longitude, from 17° above to 40° below the line of incidence (fig. 12 (b)). Western longitude landing zones are also required for these cases (fig. 11).

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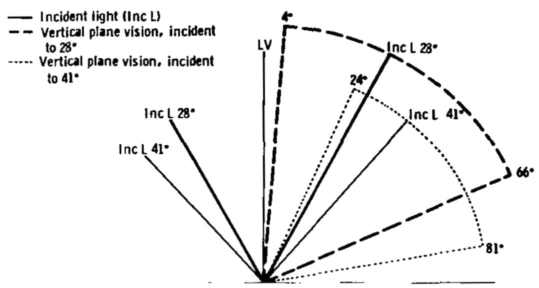

Conditions: Full earth phase; 0.065 albedo; 1.25 ft -c incident light; 50.8% photometric attenuation represents maximum allowable angle in vertical plane for 0.04 ft -L reflected

(b) Full-earth phase

Figure 12. - Range of vision in the vertical plane for 28° and 41° longitudes (cont)

In the available range of vision, full earthshine lighting conditions are considered acceptable from past aircraft and helicopter experience. Three-quarter-earth phase lighting conditions are considered unacceptable for the same reasons. A decision as to the exact point between these two extremes where adequate range of vision exists must await further definition of control-system and descent-engine response characteristics, landing area requirements, trajectory shaping requirements, and lunar surface characteristics. At $\frac{7}{8}$-earth phase, a range of vision of approximately 30° exists about the line of incidence (fig. 12(c)), and appears to merit consideration as a suitable minimum until further information is available. This represents a total range of $3\frac{1}{2}$ days from $\frac{7}{8}$- to $\frac{1}{8}$-earth phase (figs. 10 and 13).

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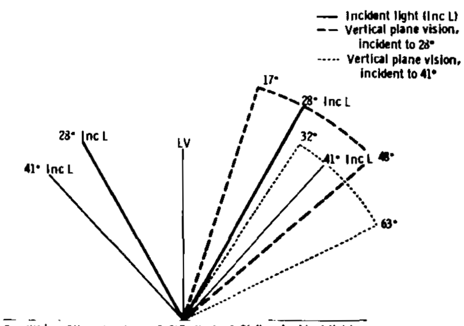

Conditions: 7/8 earth phase; 0.065 albedo; 0.96 ft -c incident light, 35.9 photometric attenuation represents maximum allowable angle in vertical plane for 0.04 ft -L reflected, and yields the fans shown for 28° and 41° longitudes

(c) 7/8 Earth phase

Figure 12. - Range of vision in the vertical plane for 28° and 41° longitudes (concl)

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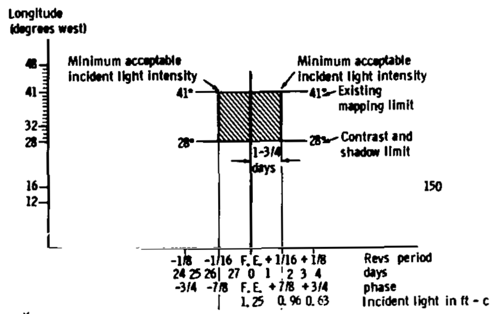

Key
F.E. Full earth
-1/8-3/4 earth phase prior to full earth
+1/8-3/4 earth phase after full earth

Figure 13. - Earthshine launch window with presently defined limitations

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TABLE I.- TRANSMISSION SPECTRUM OF NEUTRAL DENSITY FILTERS

Filter number	Peak transmission wave length, mu	Transmission - percent total visual spectrum				
		Manufacturer's Specifications		Light microscopy	Spectro photometry	Average micro and spectro
		Range	Average			
5	540-560	3.2 - 1.2	2.2	3.26	2.68	2.970
6	560	1.2 - 0.44	0.82	0.746	0.671	0.708
7	560	.44 - .16	.30	.294	.246	.270
8	563, 700	.16 - .06	.11	.1156	.0968	.106
9	450, 637	.06 - .02	.04	.0395	.0329	.036
10	535, 605	.02 - .009	.0145	.0249	.0208	.023
11	533, 610	.009 - .003	.006	.0088	.0078	.008
12	572, 460	.003 - .001	.002	.0043	.00396	.004
13	562, 550	.001 - .0004	.0007	.0024	.0021	.002

TABLE II.- THEORETICAL EARTHSHINE CONDITIONS SIMULATED FOR FORMAL ILLUMINATION

	Earthshine incident light conditions											
Lunar maria albedo in percent (ρ)	Full earth, E = 1.25 ft-c			$\frac{3}{4}$ earth, E = 0.63 ft-c			$\frac{1}{2}$ earth, E = 0.26 ft-c			$\frac{1}{4}$ earth, E = 0.05 ft-c		
	0° viewing, ft-L	70° viewing angle, ft-L	76° viewing angle, ft-L	0° viewing, ft-L	70° viewing angle, ft-L	76° viewing angle, ft-L	0° viewing, ft-L	70° viewing angle, ft-L	76° viewing angle, ft-L	0° viewing, ft-L	70° viewing angle, ft-L	76° viewing angle, ft-L
9	[a]0.113	[a]0.032	0.028	[a]0.057	[a]0.016	0.014	[a]0.023	[a]0.007	[a]0.006	0.0045	[a]0.0013	0.0011
6.5	[a].081	[a].023	[a].020	[a].041	[a].011	[a].010	.017	[a].005	[a].004	.0032	[a].0009	.0008
5	[a].063	.018	[a].016	[a].032	[a].009	[a].008	.013	[a].004	[a].003	[a].0025	.0007	[a].0006

[a]Values used during test.

These values were calculated by the following formula:

$$B = E\rho\phi$$

where:

B = brightness of reflecting surface in foot-lamberts (ft-L)

E = luminous flux incident on the surface in foot-candles

ρ = albedo

ϕ = lunar photometric function

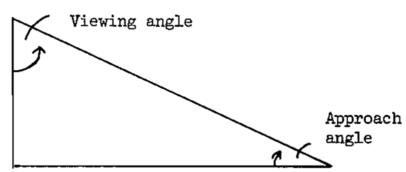

TABLE III.- BRIGHTNESS LEVEL EVALUATION

Brightness level, ft-L	Observer comments
0.0005	Very dark, hard to see. Impossible.
.0015	No contrast, cannot see site until on top or over it. Very dark, hard to see. Cannot see.
.0025	Viewing to left better than straight ahead. Contrast is not good. Could see site area from IP. Had to get fairly close in order to make sure it was level and not covered with rocks.
.0030	Impossible to pick out anything.
.0039	About equal to full moonlight.
.0040	Equal to full moonlight. (Earth average)[1]
.0046	Contrast very poor until 50 feet altitude. Cannot detect slope. Brighter than moonlight.
.009	Rod-cone take over.[1]
.0090	Uniform appearance to lava.
.0100	Visibility poor.
.0150	Have to get close to see any pattern.
.0160	Fair contrast, varied, visibility not good.
.0200	Fair contrast.
.0250	IFR approach, good contrast. Visibility fair. Some texture.
.0260	Can tell contrast fairly well; have to get down to make out detail.
.0370	Cannot make out vertical projection. Have to come down lower.
.0520	Contrast definition, looks pretty light. Cannot see elevations until you get down low.
.0600	Good lighting, 700 feet before texture shows.
.0620	200 feet texture good.
.0680	Good visibility.
.0790	Can see various terrain features.
.0820	Excellent lighting.
.1120	Rough and smooth terrain definition.

[1] Not observer comments, but reference brightness levels.

TABLE IV.- TRAJECTORY UTILIZATION VERSUS BRIGHTNESS LEVEL

Trajectory Brightness level, ft-L	 6-1	 6-2	 6-3
0.005 - .006	1	3	5
.007 - .015	3	3	1
.016 - .025	4	1	1
.026 - .052	5	3	1
.053 - .115	6	2	4
Total	19	12	12

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