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APOLLO 15

Time and Motion Study

(Final Report)

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

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(Final Report)

January 1972

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Submitted to
Medical Research and Operations Directorate
Project Support Division

Submitted by
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PREFACE

This report presents the results of the Time and Motion Study performed on Apollo 15 as authorized by the J-1 Mission Requirements Document (MRD). This study is the responsibility of the Medical Research and Operations Directorate and is performed by Fordham University under NASA Contract NAS 9-11839.

As stated in the MRD (Section 4, Detailed Objectives), the purpose of this study is "to evaluate the differences, correlation and relative consistency between ground-based and lunar surface task dexterity and locomotion performance." The ground-based (1-g) data were collected by performing time and motion studies of the crewmembers during their suited EVA simulations at KSC. Lunar surface data consists of television, motion picture film, air-to-ground voice transcriptions made during the lunar landing visit and subjective comments made during astronaut debriefing following the mission. No specific crew tasks were required to support this objective.

Various aspects of crewman activity are included in this report: an analysis of lunar mobility, a comparative activity analysis (1-g versus lunar) at three levels of complexity, a comparative analysis of metabolic rates during lunar activity and a fall/near-fall analysis. It is meant to provide a documented description of lunar surface performance, to isolate the variables which affect lunar surface performance, and hopefully to provide an input for future lunar activity planning.

ACKNOWLEDGEMENTS

The principal investigator wishes to thank the entire Fordham staff for their unstinting cooperation and whole-hearted effort over and above the call of duty during the hectic days of the "Quick Look" and Preliminary Reports.

He sincerely appreciates the support of Dr. Moseley and Dr. Humbert in making facilities available at NASA to view the Apollo 15 EVAs and for the metabolic data supplied by Dr. Humbert.

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SUMMARY

The Time and Motion Study of Apollo 15 lunar surface activity led to an examination of four distinct areas of crewmen activity. These areas are: an analysis of lunar mobility, a comparative analysis of tasks performed in 1-g training and lunar EVA, an analysis of the metabolic cost of two activities that are performed in several EVAs, and a fall/near-fall analysis.

An analysis of mobility showed that the crewmen used three basic mobility patterns (modified walk, hop, side step) while on the lunar surface. These mobility patterns were utilized as adaptive modes to compensate for the uneven terrain and varied soil conditions that the crewmen encountered.

A comparison of the time required to perform tasks at the final 1-g lunar EVA training sessions and the time required to perform the same task on the lunar surface indicates that, in almost all cases, it took significantly more time (on the order of 40%) to perform tasks on the moon. This increased time was observed even after extraneous factors (e.g., hardware difficulties) were factored out. Further, tasks which predominantly require fine motor activity are more likely to be adversely affected by lunar working conditions than those which require predominantly gross motor activities.

Metabolic cost decreases as the crewman repeats a task over successive EVAs. From the first to the second EVA performance, this decrease is on the order of 10%. In general there was an overall improvement in performance over the three EVAs.

A pilot study of falls and near-falls points up several contributing factors--the near-failure condition of soil at the edges of craters, the difference in angular and frictional forces (reduced traction), and limited visibility.

I. QUANTITY AND QUALITY OF DATA

A. Television

For general viewing, the quality of the TV transmission from the lunar surface undoubtedly exceeded expectations. Time and Motion (TAM) requirements, however, are much more stringent and a number of problems associated with the actual TV coverage have limited both the quantity and quality of the data available for analysis. In particular these problems were:

Deviations from planned TV coverage.
Direction of camera during TV coverage.
Quality of kinescopes.

1. Deviations from Planned TV Coverage

The discrepancy between the planned and actual TV coverage is summarized in Table 1.

2. Direction of Camera during TV Coverage

Our primary interest was in the activities of the crewmen as they performed their assigned tasks. However, it is recognized that geological and hardware priorities were paramount in Apollo 15. As a result of these emphases several important activities of prime interest to us were missed.

3. Quality of Kinescopes

Another obstacle to efficient analysis was the relatively poor quality of the black and white kinescopes compared to the color TV transmissions. Although these kinescopes are better than those obtained in previous missions, the loss of resolution and detail in kinescope reproduction coupled with the added loss of the color dimension makes detailed TAM analysis very difficult.

Table 1
PLANNED AND ACTUAL TV COVERAGE
(APOLLO 15)

Planned TV Coverage	Actual TV Coverage
EVA 1	
CDR and LMP Egress	As planned.
* LRV Off-load	As planned but too distant for detail.
LRV Configuration	Same as LRV off-load.
* Station #1 Geology	Activity in poor position in relation to sun. Extensive geological pans.
* Station #2 Geology	As planned - Generally good data.
Station #3 Geology	Short stop - TV not activated.
* ALSEP Off-load	No coverage - TV not activated.
* ALSEP Deploy	As planned - Coverage diffused by attempt to document both crewmen.
EVA Closeout	No coverage - TV not activated.
EVA 2	
Preparation for Traverse	No coverage - TV not activated.
* 5 Geological Stops Planned	Real-time Planning.
Station #6	TV coverage - good data for analysis.
Station #6A	No coverage - TV not activated.
Station #7	TV activated - good data for analysis.
Station #4	No coverage - TV not activated.
At LM (Real-time change)	No coverage - TV not activated.
* ALSEP Operations Completion including Station #8	TV - Station #8 coverage was good - but ALSEP coverage poor.
* EVA Closeout (with Flag deploy)	TV activated - poor coverage (Flag ok).
EVA 3	
Preparation for Traverse	TV activated - poor coverage.
* Core Stem Recovery	TV activated - very poor coverage.
* Station #9	TV activated - very poor coverage.
* Station #9A	TV activated - good coverage.
Station #10	TV activated - limited coverage.
EVA Closeout	TV activated - limited coverage.

* Where TV coverage was expected to give best opportunity for TAM analysis of crew activity. The phrase "poor coverage" refers to TAM requirements only.

4. General Comment

In spite of the fact that a good portion of the planned activity was not realized, enough of the TV coverage was adequate to accomplish a good deal of our planned analysis.

B. 16mm Lunar Surface Movie Film

Failure of the 16mm Data Acquisition Camera (DAC) system reduced the quantity of usable film to one roll. The sequences on this roll were shot during one of the LRV rides and were not of much use for this project.

An important phase of our analysis was dependent upon the 16mm DAC System, especially for the accurate measurement of the crewman's locomotion. The advantages of the DAC are that it uses a fixed lens system, it is not panned during use, and it has a much higher resolution than the TV camera.

C. Voice Data

Official transcripts of the voice transmissions during the three EVAs have been used in our analyses. Any discrepancies between the time given on the voice transcript as compared to the kinescopes have been corrected in our analyses.

D. Astronaut Technical Crew Debriefing

This information has been helpful in resolving difficulties in interpretation of the data.

E. Physiological Data

Wherever feasible and meaningful metabolic and heart rate data were compared with crewman mobility and task performance data.

F. EVA Timelines

The EVA timelines as determined by TAM analysis may be found in Appendix A. Within each EVA, a table is allotted to each crewman. The time points were determined from kinescopes and voice transcripts.

These tables present a succinct but synoptic view of the varied characteristics involved in the three EVA activities. They are valuable as quick reference markers to identify specific areas for analysis, to point up important correlations among variables and as inputs to the planning for future Apollo missions.

II. MOBILITY EVALUATION

A. Introduction

Mobility of crewmembers on the lunar surface is of prime interest in any lunar EVA. On Apollo 11, a specific segment of the EVA was devoted to mobility evaluation (Analysis of Apollo XI Lunar EVA [Mobility Evaluation]*). It was determined that no serious problems were presented by the lunar environment (1/6-g, soil conditions, pressure suits, etc.) and the crewmembers readily adapted to these factors. Two types of mobility are considered; (1) walking from one site to another, more or less "free" walking, and (2) manuevering at an experiment or similar site in the performance of a task. As contrasted to previous Apollo lunar missions, the crewmembers on Apollo 15, because of the LRV, had relatively short walking segments. The longest walk on Apollo 15 was about 400'-500' (from LM to ALSEP site), several were of 100'-200', but the majority of trips are estimated at less than 30'. However, more actual time was spent at task sites, which required a different kind of mobility. These situations are analyzed in detail in this section.

The low lunar gravity presented few problems. Although it (1/6-g) reduces mobility traction to 1/6 that on earth, only rarely did a crewmember slip and/or fall. (See Section V on Falls and Near Falls.) The reduced traction was compensated for by the lower weight of the crewmember, as well as by the ribbed boot design and soil characteristics. In general, sideways movements were noticed more frequently in task performance, while hopping type motions were observed more frequently in free walking. These

*Fordham University 1970

movements seem to be the crewmembers' methods of adapting to the lunar environment.

B. Factors Affecting Crewmembers' Mobility

A number of factors affect the crewmembers' ability to move about on the lunar surface. These are identified in the following outline.

1. Terrain
   a. Consistency, density, compactness, and other characteristics of soil.
   b. Slope of terrain.
   c. Presence of rocks, small depressions and rises, and other microfeatures of the area.
   d. Position of sun, which affects ability to pick up terrain features.
   e. Lunar gravity - 1/6-g.
2. Task, equipment, etc.
   a. Crewmember carrying objects of various sizes, bulk, mass, fragility, etc.
   b. Distance of traverse.
   c. Traverse configuration.
      (1) Straight line - forward, back, sideways.
      (2) Curved path - length of radius; forward, back, sideways.
   d. Nature of activity, such as photography, geological search, setup of equipment, or pure movement to another location.
3. Crewmember
   a. Previous experience, conditioning: amount of time spent in lunar mobility.

b. Familiarity with particular area.

c. Physical condition - fatigue, other physiological factors.

C. Types of Mobility

1. Walk

This involves the usual walking gait, but frequently in lunar translation one foot will lead, or take a longer stride.* Because of suit restrictions, soil conditions, and 1/6-g, the two step stride was not long (those measured were about 30"), and there was some "floating," or times at which both feet were off the ground. The suit also required the crewmember to walk with his feet spread apart 10" to 15".

2. Hop

a. In both short and long distances, crewmembers also moved (forward and back) by means of a hopping motion, in which one foot always preceded the other. It was not uncommon to have both walk and hop used intermittently during a particular traverse. The pattern frequently followed was to start out in a walking gait, but change to a hop. The soil appeared to be a factor in this, since in many areas the crewmember would kick up soil while walking, and then change to the hop, which meant that only one foot would kick up soil. Further, the hopping motion would lift the feet clear and avoid some soil kicking.

b. The length of a hopping stride, approximately 24", was shorter than that of a walk. Again the feet had to be carried 10 - 15" apart because of the suit.

c. Occasionally the crewmember would use a short shuffle. This appeared where the soil created an extra restriction, and where better control of locomotion was desired. This latter is a subjective evaluation,

*A stride is defined as two successive steps.

based on kinescope observation.

3. Side-step

Much of the activity in the equipment area required moving around or along side the equipment. The gait employed in these situations was frequently a side-step or shuffle, which occasionally included a hop. In many such cases, the general path was curved, the crewmember working and moving around an object or piece of equipment, or performing a task such as photography which required getting into position. The side-step was also used in changing directions (or heading), again with the hop as an integral part. This occurred especially on rough or rock terrain.

D. Method of Analysis

1. Source of Data

The data and descriptions were obtained from the analysis of kinescope film of lunar TV. Kinescopes were projected on a Vanguard Motion Analyzer for frame-by-frame analysis. GMT is superimposed on the kinescope to the nearest second. Parts of seconds (1/24 second per frame) are obtained by reading the frame counter on the Vanguard.

2. Measurement of Distances

The distances crewmembers moved were determined by first measuring the height of the image of a PLSS or crewmember on the screen, and converting this to a scale factor (1" on screen = X inches on lunar surface). Use of X - Y crosshairs on the Vanguard screen (readout in .001") enables the analyst to determine actual distances moved, or other dimensions with good accuracy, probably within $\pm$ 5%. Accuracy is affected by distance of subject from camera, position of subject, resolution of the camera and film, etc.

An additional problem associated with measurement of mobility is that in many cases the camera was moving (panning or zooming). This prevented point-to-point scaling on the screen. Attempts were made, however, to select scenes for analysis in which the camera did not move, and also scenes in which the subject moved directly across the camera, or normal to the lens. Since these conditions coincided only rarely, approximations, averages, and single frame measurements, were used to secure reasonably accurate data.

3. Qualitative Analysis

In addition to the quantitative data, the kinescopes provided a good basis for the qualitative descriptions given earlier in this section. These descriptions revealed several different mobility patterns in the movement of astronauts on the lunar surface.

E. Analysis of Mobility Segments

1. EVA 1

a. CDR moves toward LM during LRV deployment.

(GMT 212:14:04:35). Time into EVA 1 - 52 min.

Location - at LM.

Mode: Hop and "bounce" forward in straight path: not carrying anything.

Data: Distance moved - 4.8' in 4.0 sec. for 1.2'/sec. rate.

Comment: Area near LM on slight slope and relatively smooth, with loose soil. Picture showed CDR to knees only, so that details of foot action not known. The appearance of short hops and a "bouncing" motion was evident.

b. LMP near LM, carrying 70mm camera.

(GMT 212:14:09:09). Time into EVA 1 - 57 min.

Location - at LM.

Mode: Walk in straight path with hop interspersed; 70mm camera mounted on pressure suit.

Data: Distance moved - 6.1' in 6.0 sec. for 1.0'/sec. Sec. by sec. rates in ft./sec: .9, 1.2, .9, .9, 1.2, 1.1.

Comment: Same conditions as in (1) above. Sec. by sec. rates indicate the variability in the walk-hop type of mobility.

c. LMP moving up slight slope on far side of LM, following CDR in LRV.

(GMT 212:14:10:35). Time into EVA 1 - 58 min.

Location - at LM.

Mode: Hopping walk up slope with 70mm camera.

Data: Distance moved - 6.7' in 7.5 sec. for .9'/sec.

Comment: This was a short segment of an extensive traverse (the first in this EVA). Only this portion was in camera range because the LM was between it and LMP. Movement was by characteristic hopping type walk with one foot leading the other most of the time.

d. CDR carries LCRU from MESA to LRV.

(GMT 212:15:20). Time into EVA 1 - 2 hr. 7 min.

Location - at LM.

Mode: Combination walk and hop.

Data: Distance moved - 9.0' in 6 sec. for 1.5'/sec. rate.

Comment: This traverse only included the actual walk-hop segment, and not the start and end. CDR took rather short steps, and varied the gait even in this short move. The LCRU is a relatively small object, and did not appear to impede mobility.

e. LMP carrying extension handle for core.

(GMT 212:16:40:59). Time into EVA 1 - 3 hr. 28 min.

Location - Station #2.

Mode: Walk with extension handle. Relatively level, smooth surface, except for slight depressions.

Data: This segment was analyzed for each step to show length of steps and rate of movement.

Step	Time (sec.) Unit	Cum.	Distance (ft.) Step	Cum.	Description
1	0	0	0	0	Left foot. Left surface during step. (Starting point.)
2	1.3	1.3	1.8	1.8	Right foot. Left surface during step.
3	.9	2.2	2.5	4.3	Left foot. Sank 8 - 10" into a depression.
4	1.6	3.8	1.1	5.4	Right foot. Kicked soil and shortened step.
5	1.2	5.0	2.1	7.4	Left foot. Recovered and took longer step.

Distance covered - 7.4' in 5.0 sec. for 1.5'/sec. rate. Rate fluctuated appreciably step by step.

Comment: In this case the left foot seemed to lead in that it took the longer steps, with the right foot pulling just ahead. It is also noted that frequently both feet are off the ground during a step, resulting in a bouncing or "floating" effect. The 1/6-g, soft soil, minor depressions, all tend to cause the irregular gait and the tendency for one foot to lead the other.

2. EVA 2

a. LMP on long straight path down gradual slope, then down steeper slope; and then level.

(GMT 213:13:52:57). Time into EVA 2 - 2 hr. 5 min.

Location - Station #6.

Mode: Walk, with right foot leading, or taking longer steps for first segment on relatively smooth, gradual slope. On steeper slope used shorter steps, or hops, then reverted to first mode. LMP carrying camera.

Data: Distance covered in first, relatively level, smooth segment - 38.5' in 20 sec. for a rate of 1.9'/sec. Second part - 42' in 20.8 secs. for a rate of 2.0'/sec. Overall average - approximately 2.0'/sec.

Comment: This represented a relatively long, straight, uninterrupted traverse over relatively smooth, level terrain, with one decline of a few feet in the middle. The soil seemed typical in that it was soft and was kicked up in small amounts. The 2.0'/sec. probably represents an optimum rate for this type of terrain for longer distances.

b. CDR in side-hop for short distance.

(GMT 213:13:58:07). Time into EVA 2 - 2 hr. 10 min.

Location - Station #6.

Mode: Side-hop in a circular path of about 90° arc, to pick up rock with tongs and return to place rock in container held by LMP. This is more a manuever to get into position to pick up specimen rock than perform a traverse as described above. Tongs held in right hand used to pick up and carry rock.

Data: Moves to right by alternately moving right foot then left, accompanied by a hop so that both feet are off surface. A turn is also made by pivoting as feet touch surface. Four such side hops in a 90° arc and traversing about 5' were accomplished in 5.5 sec. for a rate of 0.9'/sec.

After grasping rock in tongs, CDR pivots 90°, and returns to starting point in three hops, feet together and stops by sliding in soil. The distance traversed was about 3' in 1.6 sec. for a rate of 1.9'/sec.

Comment: The surface was relatively flat. The initial part included getting set to pick up a particular rock with tongs, which meant using more and shorter side hops. The return included a side hop and a forward hop to a not so precise location. The skidding stop with both feet kicked up a large amount of soil. The difference in velocities is a result of different objectives at the end of each short traverse.

3. EVA 3

a. LMP involved in geological description and taking photographs at the beginning of Station #9A. The camera is mounted on his suit and he is carrying tongs with his left hand.

(GMT 214:11:05:05). Time into EVA - 2 hr. 13 min.

Location - Station #9A.

Mode: Walk (in essentially a straight path).

Data: Distance moved is 15' in 12.6 seconds for a rate of 1.2'/sec.

Comment: The surface was smooth, compact and level. The LMP was merely walking from one spot to another. The length of the average step with the right foot was 1.1; with the left foot was 1.2; and with both feet was 1.2. The lengths of the steps ranged from .5' to 1.8'.

b. LMP moving to aid CDR after fall.

(GMT 214:11:06:49). Time into EVA - 2 hr. 15 min.

Location - Station #9A.

Mode: Walk

Data: A short segment, close up, showed LMP hurrying to aid CDR who had just taken a fall. It is assumed LMP is traveling at his best speed. He moved at the rate of 1.9'/sec. and one step was determined from foot imprints in soil to be 31". Distance moved was 4.8' in 2.5 sec.

Comment: Since this constituted what might have been an emergency, it is assumed that LMP moved as rapidly as possible. The rate (and length of step) may be close to maximum for short distances.

NOTE: The data for each of these mobility segments is summarized in Table 2.

Table 2
SUMMARY OF MOBILITY SEGMENTS

No.	CM	Clock(1) Time	Distance (feet)	Time(2) (sec.)	Rate (ft/sec)	Location	Conditions
EVA 1							
a	CDR	0:52	4.8	4.0	1.2	LM	Uphill slope, smooth
b	LMP	0:57	6.1	6.0	1.0	LM	Uphill slope, smooth
c	LMP	0:58	6.7	7.5	0.9	LM	Uphill slope, smooth
d	CDR	2:07	9.0	6.0	1.5	LM	Level, smooth carrying LCRU
e	LMP	3:28	7.4	5.0	1.5	Sta. 2	Level, smooth carrying extension handle
EVA 2							
a	LMP	2:05	(1st part) 38.5	20.0	1.9	Sta. 6	Downhill slope, smooth
			(2nd part) 42.0	20.8	2.0	Sta. 6	Downhill slope, smooth, carrying camera
b	CDR	2:10	(1st part) 5.0	5.5	.9	Sta. 6	Level, smooth
			(2nd part) 3.0	1.6	1.9	Sta. 6	Level, smooth
EVA 3							
a	LMP	2:13	15.0	12.6	1.2	Sta. 9A	Level, and relatively rough terrain
b	LMP	2:15	4.8	2.5	1.9	Sta. 9A	Level, and relatively rough terrain

(1) Hours, minutes into EVA.
(2) Seconds required to cover distance.

F. General Summary

1. Certain subtle changes are noted between EVAs 1, 2, and 3. Confidence is gained with experience and the crewmembers moved about the lunar surface with increasing confidence and skill. Velocity, too increases. However, part of the increase is due to the downhill segment in EVA 2. Compared to the first three uphill segments of EVA 1, downhill mobility is about twice as fast.

2. It appears that the soft, powdery characteristics of the soil (varying from one location to another), the presence of many small depressions and rises, even in smooth, uncluttered areas, and the other variables listed at the beginning of this report, induce variations in mobility on the lunar surface. Each step may be of different length and time duration, as well as varying in coordination. Crewmembers would frequently change from a walk, to a hopping-walk, or canter, with one foot in the lead, to a pure hop, and occasionally take two or three very short shuffling-like steps. Undoubtedly, the varying nature of the soil and terrain, plus restricted downward visibility, contributed to this pattern. It seemed as if the crewmembers had to "feel" their way along, and the hopping-like motion provided the greatest sense of security - the same foot was always in front.

3. The side-hop, with crewmen leaving the surface with both feet during the hop, was used primarily for work around equipment or for getting into position to pick up an object, to photograph or assist the other crewmember. Frequently, the hop, or occasionally a step, would be to the rear, and no particular difficulties were observed in such backward movements.

4. In general, man readily adapts to the lunar environment as far as mobility is concerned. The terrain, soil, and visibility factors seemed to present some difficulties and probably contributed to falls, mishandling of objects, etc. The constraints of the suit also affected mobility, causing a wide stance stride, and relatively short steps. A stride (two steps) was typically 30 - 36", and occasionally up to 48 - 52". Even in the longer strides, one foot would take a longer step than the other. This produced a hopping-like walk, somewhat resembling the canter of a horse.

III. COMPARISON OF LUNAR EVA WORK PERFORMANCE WITH 1-g TRAINING

A. Introduction

1. Purpose

One of the principal purposes of time and motion analysis of Apollo 15 activities was to compare similar activities performed by crewmembers during 1-g suited training and during lunar EVAs. The basis for comparison was the time required for performance; however, other factors such as environmental conditions, difficulties encountered, nature of task, etc., were considered and evaluated.

These comparative analyses attempt to quantify task performance under 1-g and lunar conditions in order to develop a better understanding of how human activity is performed on the lunar surface and to facilitate future planning for such activities. Qualitative conclusions are drawn also, and these amplify and complement the quantitative results.

2. Definitions of Activity Segments and Criteria for Selection

Those activities were selected for analysis for which sufficient data (or opportunities for recording data) were available. Another criterion was that they be performed at least twice during the last three training sessions (especially the last one). The final criterion called for adequate lunar TV coverage.

a. Tasks. The largest activity segment is the task, a complete, identifiable activity with a single purpose. An example of this would be "Deploy Lunar Roving Vehicle." A task may be performed by one crewmember alone, or it may be a joint two-man effort. In the analysis of tasks, only the overall time for the task performance is considered.

Table 3, "Task Comparisons: Lunar EVA and 1-g Training," lists the task together with performance times during training and during EVA.

Most of the tasks shown in this table could not be further divided into sub-tasks because of data recording limitations. Four of the tasks (LMP, 4, 5, 7, 8) however, were divided into sub-tasks as shown in Appendix B.

b. Sub-tasks. The first level of task breakdown is the sub-task. A sub-task is identifiable as a complete unit of work within itself, and only has relevance as it fits into the patterned sequence of a total task. For example, "PSE Deploy" is a task, while "Unstow PSE Stool" is a sub-task.

Sub-tasks are created by grouping a series of items (elements) as listed in the "Detailed EVA Procedures" section of the "Apollo 15 Lunar Surface Procedures" document. Specifically, if it was not possible in training or EVA to distinguish or record such elements, they were combined into sub-tasks for this analysis.

c. Element. An element is the smallest unit of work which is still identifiable and homogeneous. For example, under the task "PSE Deploy" the sub-task "Unstow PSE Stool" was listed. This sub-task was further separated into the elements: "Stow carry bar on sub-pallet," and "Unstow PSE stool from sub-pallet."

Analysis at the element level was confined to selected segments of the "Comprehensive Sample Collection" and "Double Core Sample Collection" tasks. The reason for this is that in these two cases the elements in question were repeated a number of times within the task, providing not only a basis for statistical evaluation, but a more detailed insight into the nature of these activities.

B. Task Comparisons (Lunar EVA and 1-g Training)

1. Introduction

Tasks, as defined above in Section I, were chosen because they were the only ones for which time analyses could be made over a complete task. In some cases it was not possible to break the tasks into smaller segments (sub-tasks, elements - see Sections IIIC, IIID below) because of technical limitations. Four of the tasks (LMP 4, 5, 7, 8) are broken down into sub-tasks and analyzed in more detail in Section IIIC. The results of task analysis are therefore much more general than more detailed analysis.

Table 3 lists the activities, performance time (in minutes) during training sessions, performance time on the lunar surface, and the source of information specifying the end points of characteristic activities. It also presents the ratio of the EVA time and the last 1-g training time (D/C column in table). Training times were obtained through direct observation; EVA times were determined from kinescope (TV) and voice (V) transcripts.

2. Results

The outstanding characteristic of these data is the relatively greater time it takes to perform activities on the moon as compared to the last training session. For both astronauts the time increase ranges from 20% to 97% (items LMP 5 and 6 in Table 3).

The overall increase for both CDR and LMP on all total tasks is 58%. Although the CDR had an average increase of 38% and LMP 63%, the

Table 3

TASK COMPARISONS: LUNAR EVA AND 1-G TRAINING

TASK	1-G TRAINING SESSION 6/4/71 (A)	7/1/71 (B)	7/16/71 (C)	EVA 1 7/31/71 (D)	RATIO D/C	EVA DATA SOURCE
A. Commander						
1. Deploy Lunar Roving Vehicle	N.D.	5.75	3.64	5.88*	1.62	TV
2. Deploy High Gain Antenna & TV Camera on LRV	N.D.	6.34	6.10	7.57	1.24	V
B. Lunar Module Pilot						
1. Align High Gain Antenna	2.10	3.10	1.42	2.78	1.96	V
2. Contingency Sample Collection (Stowage not included)	1.30	N.D.	1.30	2.08	1.46	V
3. Deploy Lunar Roving Vehicle	3.60	2.65	2.95	5.12*	1.74	Both
4. ALSEP Interconnect	10.25	8.88	8.99	15.95	1.77	Both
5. Deploy Passive Seismic Experiment	8.05	7.02	6.91	8.27	1.20	Both
6. Deploy Solar Wind Experiment	3.10	2.70	1.85	3.65	1.97	V
7. Deploy Lunar Surface Magnetometer	7.10	5.85	5.67	8.62	1.52	Both
8. Deploy Sunshield & ALSEP Antenna Installation	10.67	12.90	12.50	20.07	1.61	Both
9. Deploy SIDE	N.D.	5.35	4.62	8.41	1.82	Both
TOTAL FOR CDR & LMP			55.95	88.40	1.58	

N.D. - No Data
*Time spent troubleshooting LRV deployment problem (5.4 min.) not included.
TV - Television
V - Voice

fact that only two samples were available for the CDR and that the tasks were not completely comparable makes it inappropriate to emphasize these differences. The high average ratio of 1.63 for LMP is also attributed, partially, to the fact that his tasks contained a relatively high portion of "fine motor control" activities. (See Section IIIE below.)

3. Discussion

There are many factors that contribute to the fact that activities usually take longer to accomplish on the moon than they do on earth. One such factor is that the crewmen are more careful on the moon than during the training session. On the lunar surface, there is no one there to assist them if they have problems. In addition, the experiments that they deploy and the equipment that they operate are much more fragile than the 1-g experiment mockups and equipment used in training.

The unusual environment of the lunar surface also causes problems. The crewmen have to adapt to their weight of about 67 lbs. on the moon (with their EMUs) compared to about 330 lbs.* during the training sessions. The high intensity and some times low angle of the sun has to be dealt with. Other factors such as absence of dust in the atmosphere and absence of familiar objects of known size contribute to problems of distance determination. The lunar soil and terrain are also relatively unique and difficult to simulate.

The use of tasks as a basis for analysis presents certain limitations on conclusions that can be drawn. A total task generally contains

*Training suit and hardware with 180 lb. man (1-g) weighs 330 lbs. The same man with lunar suit weighs 404 lbs. in 1-g, or 67 lbs. on the lunar surface.

smaller segments of more homogeneous nature (sub-tasks and elements) which can be more readily classified and analyzed as to effects of variables. The total tasks also frequently contain segments which are beyond the control of the crewmember, or are extraneous to the main task. In some cases these can be deducted from the task time (see Table 3), but frequently this is not feasible, resulting in artificially higher times. The total task analysis is useful from an overall standpoint, but to satisfactorily determine effect of variables on work performance, it is necessary to be able to analyze sub-tasks and/or elements.

The high work load of the EVAs compared to the training sessions must also be considered. There is a considerable amount of work performed by the astronauts before each EVA in donning and checking out the EMUs within the limiting confines of the LM, whereas in training the crewmen are suited up in an area which is not cramped and are assisted by suit technicians.

It is not possible to determine the relative contribution of these factors during the performance of a particular activity. However, it would be accurate to say that all the activities that have been analyzed have been affected by most of these factors.

C. Sub-task Comparisons (Lunar EVA and 1-g Training)

1. Introduction

The tasks discussed under Section IIIB above and listed in Table 3 are made up of smaller segments or sub-tasks. These sub-task activities and data are tabulated in Appendix B.

One objective of sub-task analysis is to determine more precisely which types of activity are affected positively by lunar conditions, which apparently are not affected, and which show performance deterioration in the lunar environment.

Another reason for partitioning the tasks into sub-tasks is to provide a better understanding of the effects of the lunar environment on human task performance. For example, segments of some activities are not performed in the same way in training as on the lunar surface: (1) TV deployment is done at a greater distance on the moon, (2) adjustments on mockups are often simulated, (3) apparatus may get stuck, as for example, Boyd bolts on the lunar surface, drill in bore stems, and (4) soil characteristics may differ and affect some types of activities. Most of these differences are due to situational or instrumental factors and not to the work efforts of the crewmen. If one were to eliminate the effect of these differences from the analysis, the result could more clearly be attributed to other effects as, lunar gravity, visual perception, etc.

2. Table of Sub-tasks (Appendix B)

It was not possible to partition all the activities into relatively small segments. The data source (kinescopes and voice transcripts) did not always provide enough information to determine end points of all activities. Consequently, in some situations where it was known that several sub-tasks had taken place, but the time could not be broken out for each, the sub-tasks or elements were analyzed in groups.

3. Results

a. The ratio of the time required for sub-tasks on the lunar surface to the last suited training session at Cape Kennedy (D/C ratio - see Appendix B) is in the range of 1.20 to 1.90 for most activities. There are some instances where the ratio is much greater than this, and there is one where the ratio is .74. In most cases where the ratio was greater than 2.00, the accomplishment of the sub-task was not nominal, with crewmen encountering some technical difficulty in performing the task.

b. It was noted earlier that a number of situational and instrumental differences between 1-g suited training and lunar EVA task performance tended to increase the time for the EVA tasks. For example, TV deployment is done at a greater distance on the moon. When activities affected by the more obvious of these factors were eliminated from calculation, the D/C ratio is of the order of 1.39 for the CDR and 1.43 for the LMP, resulting in a combined ratio of 1.41, a substantial decrease from combined ratio of 1.58 for the CDR and the LMP as shown in Section IIIB, Task Comparisons (Lunar EVA and 1-g Training).

4. Comments

The implication of this analysis is that, if all the situational, operational, and technical differences between working conditions on the lunar surface and training site can be minimized, the time increase for lunar activity could be completely attributed to lunar conditions. At the same time elemental activities with shorter lunar than 1-g training times would become more apparent and more easily isolated for analysis.

Films of training sessions, especially those close to flight, and films of lunar activity would help immeasurably in attaining such goals.

D. Element Comparisons (Lunar EVA and 1-g Training)

1. Introduction

a. The Comprehensive Sample Collection and Double Core Tube Sample Collection activities have been chosen for detailed element comparison of 1-g training and lunar surface performance.

b. The data for the training sessions were obtained from direct observation. The lunar EVA data were obtained from TV kinescopes.

c. The data for Comprehensive Sample Collection are presented in Table 4. Double Core Tube Sample data are presented in Table 5. The tables show the data from training at two different stations, and data from three EVAs.

d. Both tasks are performed primarily by the LMP with assistance from the CDR.

2. Comprehensive Sample Collection

a. Description

Two successive elements of the Comprehensive Sample Collection have been selected for analysis. The Rake and Shake element consists of the LMP using the rake to scrape a swath approximately one meter long by ten inches wide by two to three inches deep. He then shakes the rake in order to have the fine particles drop out while retaining the larger ones. The second element, Fill Bag, consists of the LMP lifting the rake with the larger rock fragments inside, positioning it over the sample bag held by the CDR and then rotating the rake so that the rocks pour out of the rake into the bag. This procedure requires coordination between the two men.

TABLE 4

COMPREHENSIVE SAMPLE COLLECTION

Time Analysis

	LUNAR MODULE PILOT (LMP)				
	TRAINING (7-19-71)		EVA		
TRIALS	1	2	1	2	3
1. Rake and Shake*	.65#	.60	.42	.38	.42
Fill Bag*	.20	.20	.25	.40	.28
(Total)	(.85)	(.80)	(.67)	(.78)	(.70)
2. Rake and Shake	.70	.75	.45	.38	.33
Fill Bag	.20	.26	.25	.30	.17
(Total)	(.90)	(1.01)	(.70)	(.68)	(.50)
3. Rake and Shake		.85		.52	.62
Fill Bag		.34		.22	.20
(Total)		(1.19)		(.74)	(.82)
4. Rake and Shake					.33
Fill Bag					.22
(Total)					(.55)
Average: Rake & Shake	.675	.733	.435	.427	.425
Fill Bag	.200	.267	.250	.307	.218
(Total)	(.875)	(1.000)	(.685)	(.730)	(.643)
Range: Rake & Shake	.05	.25	.03	.14	.29
Fill Bag	.00	.14	.00	.18	.11
(Total)	(.05)	(.39)	(.03)	(.10)	(.32)

(#) All times are in minutes.

(*) Element Description:

(1) Rake and Shake: using the rake, LMP scrapes swath approximately 1 meter long by 10" wide by 2-3" deep of lunar soil, then shakes out the fine particles.

(2) Fill Bag: after shaking, LMP lifts rake with rock fragments inside, positions it over sample bag held and positioned by CDR, and then rotates rake so that rocks pour out of the rake into the bag. This requires close coordination by both men.

The entire sequence is repeated from two to four times during each performance of the Comprehensive Sample Collection.

b. Results

(1) Rake and Shake

(a) The average for the five training data points is .71 min; that for the nine EVA trials is .43 min.

(b) The difference between these means is statistically significant, with the element "Rake and Shake" performed appreciably faster on the lunar surface than on the training grounds at Cape Kennedy.

(c) There is no appreciable difference in the ranges.

(2) Fill Bag

(a) The average for the five training data points is .24 min; that for nine EVA trials is .25 min.

(b) There is no significant difference between these means.

(c) There is no appreciable difference in the ranges.

3. Double Core Tube Sample

a. Description

The double core tube sample task consists of: (1.0)* The LMP obtaining the core tubes from the CDR's sample container bag and assembling them. (2.1) He then positions the tube over the chosen sample location, (2.2) and pushes it into the ground as far as possible. (2.3) The LMP next hammers the tube into the ground. (3.1) The LMP carefully removes the double core tube. (3.2) The tubes are capped, tamped, separated and stowed in the CDR's sample bag container. The CDR assists by handing the LMP the hammer, caps, etc. and takes pictures of the activity.

*The numbers correspond to the element numbers in Table 5.

Table 5

DOUBLE CORE SAMPLE COLLECTION - LMP

Elements	Training 7-19-71 1	Training 7-19-71 2	EVA 1	EVA 3
1.0 Assemble	.85 (1)	1.40	1.08	1.43
2.0 Implant				
2.1 Position	(2)	(2)	.40	.32
2.2 Push	(2)	(2)	.20	.15
2.3 Hammer	(2)	(2)	.50	.83
(Total)	(1.15)	(.95)	(1.10)	(1.30)
3.0 Stow				
3.1 Remove	(2)	.26	.43	.55
3.2 Disassemble & Stow	(2)	(3)	4.60	3.38
(Total)	(2.70)		(5.03)	(3.93)
TASK TOTAL	4.70		7.21	6.66

(1) All times in decimal minutes.

(2) Individual element times not determined; therefore, only total times for training exercises were used.

(3) In this trial the core tubes could not be separated. Therefore, the training exercise was terminated.

b. Results

As shown in Table 5, element breakdown was limited to EVA. Such a breakdown could not be used during training because of technical problems in data recording. Thus only <u>total</u> sub-task time can be used for comparative purposes. The results represent three different types of activities, viz., (1.0) <u>Assemble</u>, a manually controlled mechanical operation requiring moderate care and precision, with the times not significantly different between training and EVA; (2.0) Implant, an operation depending to a large extent on the relative characteristics of the soils; and (3.0) Stow, a manually controlled mechanical operation requiring extreme care and precision, in which the lunar time was significantly greater than in training. The first and third items apparently are affected by the nature of the activities themselves, in this case the degree of care and precision required, with the increased care and precision resulting in greater times for lunar activities. (See Section IIIE on Fine and Gross Motor Control.) The Implant sub-task, however, involved the driving of the core tube into the soil, this latter being a variable factor on which no data are available as to resistance to penetration. However, if times for the individual elements could have been obtained through film (movie, kinescope) during training, more definitive analysis and conclusions could have been drawn. For example, the Position element is a manually controlled operation requiring primarily gross motor control, with no effect of soil being present. The Hammer element, however, is directly affected by the soil characteristics.

4. Discussion

The results from the Comprehensive Sample Collection (Table 4) and the Double Core Tube Sample Collection (Task 5) are summarized on the basis of time considerations, namely, whether performance time is longer or shorter during lunar EVA than during training. In addition, the factors which apparently affect the relative times for individual element (or sub-tasks) are pointed up in the analysis of the data, and types of activities are categorized. The lack of data breakdown into elements during training for the Double Core Sample Collection study prevented a more complete analysis of this task.

a. The elements "Remove" and "Disassemble and Stow" took considerably longer to perform during EVA because of the extreme care and precision required in handling the lunar core samples to insure that the strata inside the cores would not be disturbed. Also the flight core tube caps were more difficult to assemble on the cores than were the caps used in training.

b. The "Rake and Shake" element took less time. This element required only gross motor control, but other factors, as yet unidentified, probably contributed to the rather large (41%) time reduction. This was one of only two activities which were observed and analyzed as requiring less time on the lunar surface. The relatively large number of data points (training - 5; EVA - 9) which were quite consistent as indicated by the ranges, point to reliable data values. Causal factors need to be identified, and if possible quantified, to explain this phenomenon.

c. Some elements took approximately the same time on the lunar surface as they did during 1-g training. The elements "Fill Bag," "Assemble," and "Implant" represent this type.

d. Certain groupings or categorizations can be made in connection with the elements analyzed herein:

(1) An activity (element, sub-task) which is a manually controlled mechanical operation requiring moderate care and precision, and not materially affected by unusual or limiting conditions imposed by equipment, soil, or other external factors. "Assemble," and "Position," are examples of this category.

(2) An activity, similar to (1) above but requiring a high degree of care and precision. "Remove" and "Disassemble and Stow" are

examples of this category.

(3) An activity which is primarily affected by external conditions such as machine control of operation, soil conditions which vary from trial to trial, physical variables such as degree of adhesion between two surfaces, all beyond the control of the crewmember. An example of this is "Hammer," the time for which is a function of soil characteristics.

e. Photography of training sessions would greatly improve the usefulness and accuracy of the data for the basic comparisons in this study. Lunar photography (either TV or DAC) could provide more useful data by concentrating on crewmembers performing tasks, by holding the TV camera as still as possible (minimum of pans and zooms) during task performance. In addition, voice documentation could be more explicit as to comments pertaining to task performance.

E. Fine and Gross Motor Control and Dexterity (Lunar EVA and 1-g Training)

1. Introduction and Purpose

Although lunar task performance usually takes a longer period of time than that required during the last 1-g training session, the ratio of sub-task EVA time to training time vary over a wide range, viz., 4.06 to 0.74. (See Appendix B.) These are identified as D/C ratios. In order to account for differences in D/C ratios, the hypothesis was established that gross motor activity would be less affected by lunar conditions than would fine motor activity. To test this hypothesis, motor dexterity was classified into fine and gross, with the expectation that the ratio of lunar-performance-time to last-training-session-time (D/C) would be greater for tasks (or sub-tasks or elements) requiring fine motor dexterity than for those requiring gross motor dexterity.

2. Definitions and Classification of Activities

Precision required for the execution of motor activities can be classified as fine or gross. Fine motor control activities will be defined as those requiring motions with an accuracy of approximately $\pm$ 1/4". Gross motor control activities are those requiring less precision than this criterion.

A number of sub-tasks, selected from Appendix B, were identified as requiring predominantly fine or gross motor activity. These are shown in Tables 6 and 7, with the same list numbers as assigned in Appendix B.

Sub-tasks in which anomalies occurred were not included in the analysis. Similarly, sub-tasks in which motor activity was about equally divided between fine and gross were not considered.

TABLE 6

TRAINING AND EVA TIMES FOR SUB-TASKS REQUIRING GROSS MOTOR CONTROL

COMMANDER		Training 7/16 (C)	EVA 7/31 (D)	Ratio (D/C)
LRV Offload				
2. Continue offload of LRV until front wheels on surface		1.67*	1.75	1.04
HFE Deploy				
3. Deploy electronics box & prepare rack and drill		5.83	7.70	1.33
	TOTAL	7.50	9.54	(1.27)
LMP				
LRV Configuration				
Photo CDR/LRV & configure		4.59	4.96	1.08
PSE Deploy				
1. Remove carry bar from C/S		.33	.83	2.51
2. Align C/S		.51	.38	.74
3. Unstow PSE stool		.92	1.06	1.15
4. Deploy PSE stool		.73	.82	1.12
	TOTAL	7.08	8.05	(1.13)
	GRAND TOTAL	14.58	17.59	(1.20)

*Time is expressed in decimal minutes.

TABLE 7

TRAINING AND EVA TIMES FOR SUB-TASKS
REQUIRING FINE MOTOR CONTROL

COMMANDER	Training 7/16 (C)	EVA 7/31 (D)	Ratio (D/C)
LRV Configuration & Traverse Prep			
2. Mount TCU on LRV & connect power cable	.85	1.47	1.72
4. Unstow HGA	.44	.80	1.81
5. Mount HGA on LRV	.55	.87	1.58
HFE Deploy			
2. Release & remove electronics box from pallet	1.62	2.45	1.51
Deep Core Sampling			
5. Assemble 5th & 6th core stem sections onto core stem	.69	1.98	2.86
6. Retrieve drill & attach to core stems	.48	.63	1.31
TOTAL	4.63	8.20	(1.77)
LMP			
ALSEP Interconnect			
2. Deploy subpallet	1.00	4.06	4.06
PSE Deploy			
7. PSE level and align	.66	.93	1.40
LSM Deploy			
2. Carry, deploy & align LSM	4.17	6.02	1.44
Sunshield Deploy & ALSEP Antenna Installation			
2. Complete sunshield deployment	5.03	6.02	1.19
3. Complete antenna alignment	1.42	2.78	1.95
TOTAL	12.28	19.81	(1.61)
GRAND TOTAL	16.91	28.01	(1.65)

3. Results and Conclusion

The basic data and the ratios of lunar-performance-time to last-training-time (D/C) are given in two tables, Table 6 and Table 7. Table 6 presents gross motor activities executed by the Commander and LMP. In general the ratios are rather low, averaging 1.27 for the Commander, 1.13 for the LMP. In contrast, the data in Table 7 (Fine Motor Control) produces corresponding ratios of 1.77 and 1.65. The averages for the Commander and LMP are not significantly different either for the fine or the gross motor sub-tasks; in fact they were unusually close and homogeneous. In view of this, the data (i.e., the D/C ratios) for both crewmen were combined and a sum of ranks procedure applied to test for the significance of the difference between fine and gross motor dexterity (i.e., between the Grand Total ratios of 1.65 and 1.20).

The results of this test indicate that the D/C ratios for the fine dexterity tasks are significantly greater than those for the gross dexterity tasks. This result supports the hypothesis that fine motor tasks are more significantly affected by lunar conditions than gross motor tasks.

IV. METABOLIC ANALYSES

A. Metabolic Analysis of Traverse Segments

1. Purpose

The purpose of this analysis was to determine if short segments of physical activity which require different energy expenditures would be reliably detected by corresponding changes in metabolic rates. For our purposes the variation in the inclination of the lunar terrain provided work situations with different energy requirements. Specifically, we wished to determine if metabolic rates were affected by the inclination of the terrain that the crewmen were traversing, with particular attention to those traverse segments in view of the TV camera and easily identified as uphill, level, or downhill. Further, to insure that the traverse activities have a measurable impact on the one minute metabolic rate averages, traverse sections of about 20 seconds or more were selected.

Metabolic rate (BTU/HR) was determined through a regression equation with heartrate as the independent variable. There are acknowledged difficulties in such procedures but, for present purposes, consistent and positively related metabolic changes to differing "work loads" would be adequate. These "work loads," as mentioned earlier were three types of traverse: uphill, level, and downhill. It was anticipated, naturally enough, that the metabolic readings would be greatest for the uphill traverse and smallest for the downhill ones.

2. Traverse Data

A total of 19 traverse segments were selected, almost evenly divided between the CDR (9) and the LMP (10). Five of these were downhill, six level and eight uphill -- evenly divided except for the downhill segments, two of which were executed by the CDR and three by the LMP.

The median time length for the CDR's segments was 30 seconds, that for the LMP's segments 50 seconds.

On the basis of an estimate provided by Dr. David Carrier of the NASA MSC Geophysics Branch, we can assume that the slopes of all segments analyzed in this report are no greater than about 12°.

The crewman's activities five minutes before and after each traverse segment were examined for any anomalous influences and for a better understanding of the traverse data.

3. Results

The metabolic data are summarized in Table 8 which presents the averages for each crewmember for each type of slope. The results show a

Table 8

AVERAGE METABOLIC RATE (BTU/HR) ASSOCIATED WITH MOBILITY ALONG TRAVERSES WITH VARYING SLOPES

	Character of Traverse		
Crewmen	Downhill	Level	Uphill
CDR	717	1183	1337
LMP	743	869	1164
Weighted Averages	733	1026	1251

consistent rise in metabolic rate with increase in slope of terrain, the lowest rate associated with downhill traverses and the highest rate with uphill traverses. The incremental changes are not the same for the CDR and LMP, but the averages of the different types of traverses show a definite linear trend. The statistical evaluation indicates significant variation in metabolic rate among the different types of traverses.

4. Conclusion

Despite the difficulties involved in metabolic estimates, in evaluating the character of the terrain, and in obtaining representative mobility segments, the consistency of the results tends to confirm the usefulness of the basic approach for estimating the metabolic rates for crewman activities even though they be relatively short in duration.

B. Metabolic Analysis of Two Lunar Activities

1. Introduction

The purpose of this analysis was to examine the metabolic cost of an activity that was performed in several EVAs to determine if adaptation to the lunar environment affected the crewman's metabolic cost for that activity.

2. Data

The activities selected, "Double Core Tube Sampling" and "Comprehensive Sample Collection" were analyzed in detail on the element level in Section IIID. In the present analysis the "Rake and Shake" and "Fill Bag" elements of the Comprehensive Sample Collection were combined to form the "Rake, Shake and Fill Bag" sub-task. Also, the Double Core Tube Sample Collection was analyzed on a sub-task level. This consolidation of elements into sub-tasks was to insure that the activity was long enough to have a measurable impact on the one minute metabolic rate averages.

3. Results

The data for the two performances of the Double Core Tube Sample Collection and for the nine performances of the Comprehensive Sample Collection are presented in Table 9. It may be observed that the metabolic cost on performing the Double Core Tube Sample Collection decreases from

TABLE 9

METABOLIC CHANGES ASSOCIATED WITH
ADAPTATION TO LUNAR EVA TASKS (LMP)

	EVA 1	EVA 2	EVA 3
DOUBLE CORE			
1. Assemble	18.4*		15.0
2. Implant	18.7		23.2
3. Stow	65.0		54.2
TOTAL	102.1		92.4
RAKE, SHAKE & FILL BAG			
Trial 1	10.7	10.1	10.3
Trial 2	11.4	9.7	7.5
Trial 3		9.2	10.4
Trial 4			7.3
AVERAGE	11.1	9.7	8.9

*All values in table are in BTUs. They are calculated by multiplying the metabolic rate by the time (to perform activity).

the value 102.1 BTU during EVA I to 92.4 BTU in EVA III, a decrement of 9.5%.

Similar results are noted for the performance of the Comprehensive Sample Collection. A general decrease in metabolic cost may be observed -- with a value of 11.1 BTU for EVA I, 9.7 BTU for EVA II, and 8.9 BTU for EVA III. Successive decrements amount to 12.6% from EVA I to EVA II and 7.9% from EVA II to EVA III.

4. Conclusion

There is a general tendency for metabolic cost to decrease as performance of a specific task is repeated over successive EVAs. This can be taken as evidence of adaptation to the general working conditions on the lunar surface. For the two different tasks selected for study the decrement from the first to the second EVA performance is of the order of 10%.

V. FALL AND NEAR-FALL ANALYSIS

A. Introduction

1. Objective

During the Apollo 15 lunar EVAs there were instances where the astronauts momentarily lost their balance and sometimes even fell. The purpose of this analysis is to determine the characteristics of such falls (and near-falls as well) and to identify the specific reasons for their occurrence.

2. Procedure

Black and white kinescopes (frame rate - 24 FPS) of all three lunar EVAs plus the voice transcripts were available for analysis. The segments of film involving the falls or near-falls were analyzed in detail using a Vanguard motion analyzer. The in-flight voice transcripts were used with the films to establish the events that occurred before and after the actual fall.

B. Description of Visible Falls

1. CDR Scott's Fall At Station #6

This fall occurred at GMT 213:14:02:00 (GET 6:00:28:00) at Station #6 during the second EVA. LMP Irwin has just dug a trench near the edge of a small crater. CDR Scott is photographing the trench. CDR Scott walks near the rim of the crater with the camera mounted and carrying the tongs; he proceeds without any problem until he is near the trenching site. At that point he takes a short hop and steps onto the inside slope of the rim. This slope is unexpectedly soft and he loses his balance and starts falling forward and to the left. With both arms extended to break the fall, he lands on his left side. He turns clockwise until he is sitting on the ground and then turns counterclockwise until he is kneeling on the ground. He does not attempt to get up by himself; instead he stays on his knees with his left hand on the ground and his right arm extended overhead and waits for the LMP to help him.

2. CDR's Fall At Station 9A

This fall occurred at GMT 214:11:06:28 (GET 6:21:32:28) during the third lunar EVA. CDR Scott and LMP Irwin are at Station 9A describing the area and Scott is taking photographs. The CDR begins moving toward a new area as he gives the camera reading and summarizes the description of the area. He steps around a group of rock fragments and then his right foot steps into a small depression and he begins to lose his balance. As he steps with his left foot, it slides off a small rock and continues sliding on the loose surface soil. While trying to drive his feet back under his center of gravity, Scott increases his forward velocity. He then falls forward with both hands extended to break the fall. Landing on his left side, he rolls counterclockwise and on his back and is then out of view of the TV camera.

C. Description of Visible Near Falls

1. The LMP's Near Fall at the ALSEP Site

This near fall occurred at GMT 212:14:14:50 (GET 5:04:40:50) during the first EVA. CDR Scott and LMP Irwin are at the ALSEP site deploying experiments. Irwin is trying to attach the SIDE cable connector to the central station (C/S), but he is having difficulty. While leaning over the C/S, the SIDE cable connector pulls loose. He loses his balance and begins leaning to his right with his hands on the C/S. He turns counterclockwise with his right hands on the C/S and the weight of his body tipping the C/S. He continues to turn until his back is to the C/S at which point he regains his balance and turns clockwise to face the C/S and continue working.

2. CDR Scott's Near Fall at the ALSEP Site

This near fall occurred at the ALSEP site at GMT 212:18:21:50 (GET 5:04:47:50), just seven minutes after the LMP's near fall. The CDR has been working on the Heat Flow Experiment and is going to throw the pallet away and give a demonstration of 1/6 gravity. With the pallet in his left hand he steps back and then swings his body and the pallet clockwise. As he throws the pallet in the air, his body is extended and pulled slightly off the ground. He lands on his right foot which slides under his body and to the left. At one point he is leaning right with both his feet off the ground to the left. Once again he steps on his right foot and with his right arm extended he falls to the right and supports his weight on his right leg and right hand. He turns clockwise until he is facing the ground and then takes a few quick steps to get his feet back under his body and to regain his balance.

D. Discussion

1. Possible Causes

a. Surface Conditions. An important and obvious cause of falls and near-falls is the condition of the surface, or rather the crewmembers' inability to recognize and/or cope with certain surface conditions. Such surface features as minor depressions, frequently associated with loose soil at the edges, sloping terrain with soil of varying density, strength and compressibility(1), scattered rocks of various sizes, reflectivity and other changing or unexpected conditions, may contribute to slipping, tripping, or otherwise temporarily losing footing and balance. Falls from this cause (surface conditions) did occur at Hadley Rille (Station 9A) where the CDR tripped over some rock fragments and stepped on loose soil (at near failure condition at the edge of a depression), which did not support him. Another fall occurred at Station 6 where the CDR stumbled as he stepped onto the relatively steep inside slope of a crater, where again the soil may have been in near failure condition and could not support him.

b. Visibility. The unexpected surface characteristics (see above) may not have been recognized as potentially hazardous because of limitations on visibility. First, the angle, position and glare of the sun and subsequent changing of reflectivity of the surface can affect visual acuity. Second, the position of the RCU on the A7LB suit interferes with full-range downward visual perception. In addition, objects mounted on the RCU (camera, sample bags, etc.) being carried by the crewman may also obscure downward vision. This, of course, prevents the crewmember from recognizing and avoiding hazards immediately in front of him, particularly if he has just made a turn or pivot and then stepped forward. This may have been the situation in the CDR's fall at Station 9A.

(1) Mitchell, J. K., et al. Preliminary Analysis of Soil Behavior, MSC (1971): "...considerable variability in soil properties, both regionally and locally and with depth...In-situ densities range from 1.36 to 2.15 g/cm^3, a range which indicates very great ranges in strength and compressibility behavior..., and the soil on steep slopes along the (Apennine) Front is in a near failure condition." (p. 2)

c. Gravitational Effects. The lower gravitational forces (1/6-g) on the moon is an important factor in falls and near falls. In general, crewmembers have adapted very well to this environmental condition, but under certain circumstances where "instinctive" reflex action occurs, such as in tripping or stumbling, the 1-g conditioned reflex takes over, and a slip or fall may occur. Reactive forces and those involving turning or torque are a function of mass, not weight, and give essentially the same results on the moon as on earth. However, the crewmens' resistance to torque, due to contact of the boots with the lunar surface, is (1/6) of what it would be on earth.

2. Analysis of the Specific Cases

a. The two falls occurred under somewhat similar conditions in that the crewmembers were walking on uneven terrain, then slipped and/or tripped. In the Station 9A fall the CDR, carrying the 500mm camera, moved off from a standing position, turned to the left at the same time, placing first his left and then his right foot, utilizing about one second for each step, a rather slow gait. It was here that his right foot slipped in the loose soil (probably at near failure condition) on the edge of a small depression, and his left struck and slipped on, or by, a small rock between the feet. The combination of the right foot losing traction, and the left foot striking the rock and slipping, created an imbalance where the center of gravity was past the support base, and momentum carried the CDR forward more rapidly than his feet could compensate for due to slippage. This illustrates the 1/6th frictional force's (as compared to earth conditions) effect on traction. On the other hand, the acceleration due to lunar gravity (1.63 m/sec^2 compared to 9.8 m/sec^2 on earth) will cause an object to fall 1/6 slower. Thus, if an unexpected event occurs, such as tripping on a rock, or a sudden release of a connector, the low frictional force between boot and surface would cause slipping much sooner, and reflexes, accommodation and balance would not serve to correct the anomaly as effectively as under 1-g. But, since a person falls much slower on the moon, he has more time to correct for a slip before reaching the surface. This is apparent from the kinescope which gives the impression of a slow-motion film. The same causal relationships would seem to apply to the other fall at Station 6. The soil condition at crater and depression edges appears, as mentioned above, to be at near failure, thus not being able to support the crewmember. This knowledge of the near failure condition of soil on the slopes of depressions and the 1/6th frictional force for traction, can be used to help avoid or reduce the possibility of falls.

b. Two near-falls occurred at the ALSEP site. One occurred when the LMP was attempting to attach the SIDE connector to the C/S. In this case the connector mounted horizontally, was difficult to attach, and as the LMP tried to complete the connection it suddenly released, creating the horizontal reactive force (torque) causing the LMP to spin around. This force was the same as it would have been on earth. However, since the LMP's resistance to torque was through contact of his boots with the surface, and the reactive force exceeded the resistance forces, the spin and near-fall resulted. Fortunately, the surface was relatively smooth and level and the LMP used the C/S to catch himself, both of which probably prevented a fall.

The other near-fall occurred when the CDR attempted to throw a pallet much as a discus is tossed. The rotational forces (torque) were not affected by the low gravity; but the frictional resistance at boot-soil interface was 1/6 earth force. This unusual combination, and the rapid, complex motions caused the CDR to temporarily lose "balance."

Both observed near-falls shared the same phenomena - sudden rotation of the body and momentary loss of traction due to low frictional resistance at the boot-surface interface.

VI. CONCLUSIONS

A. Mobility Evaluation

Because of the LRV, Apollo 15 EVAs required no lengthy mobility segments, the longest being about 400'-500'. Factors influencing mobility, other than 1/6-g, appear to be: uneveness of terrain, due to small depressions, rocks or other "micro" features and due to variation in slope and other "macro" features; nature of soil, which is loose, dry and easily dislodged, and particularly soil on the edge of craters, both large and small, which frequently is in near failure condition; reflectivity and sun angle, tending to make visual perception difficult; pressure suit restrictions, including limited visibility.

Most traverses by crewmembers revealed that steps were irregular, uneven in length, and changed frequently from a walking gate, to a hopping-walk, or canter, to a pure hop depending on the surface conditions encountered. The nature of many tasks on the lunar surface require movement for short distances in which side-hops, or side shuffle together with short steps, both forward and back were observed. These types of mobility indicate an adaptive procedure to compensate for the uneven terrain and soil conditions.

Rates of movement varied from 0.9 ft/sec to about 2.0 ft/sec, the latter occurring on relatively long traverse (about 41 ft.) over "smooth" terrain, partially downhill. The slight increase in rates that occurred over the three EVAs indicated adaptability and increased confidence as crewmembers gained experience.

B. Comparison of Lunar EVA Work Performance With 1-g Training

1. The results indicate that tasks take longer to do on the moon than in the last training session before flight. A measure of this discrepancy is the ratio (lunar-performance-time)/(last-training-time). This ratio is of the order 1.58, or, a 58% increase in time for lunar performance compared to 1-g training.

2. A review of the basic data and the circumstances associated with lunar EVA pointed up a number of situational and instrumental factors impacting task time on the lunar surface. Though increasing the time to do a task, these factors could not be considered as components of astronaut performance. When these were eliminated from the calculations, the ratio of lunar-performance-time to last-training-time was considerably reduced. It became 1.39 for the CDR and 1.43 for the LMP.

3. In two cases element analysis was possible (Comprehensive Sample Collection and Double Core Sample Collection), in which the elements were repeated a number of times. Such data were the basis for identifying homogeneous work segments for which accurate times were obtained. In one case, Rake and Shake, the lunar time was 41% lower than training time, an exceptional occurrence. Although this element involved gross motor control, the lack of film analysis of the training performances precludes determination of identifiable causal factors for this unusual difference in times.

4. Although tasks on the average took longer to do on the moon than in training, a few activities were performed more quickly on the lunar surface. An examination of such tasks led to the hypothesis that performance involving gross motor activity would be less affected than fine motor

activity by lunar working conditions. It was found that ratio of lunar-performance-time to last-training-time was 1.20 for gross dexterity tasks and 1.65 for fine dexterity tasks. In other words, fine motor activity takes about 65% more time. This difference is statistically significant.

C. Metabolic Analysis of Lunar Activities

1. The usefulness of the regression equation for estimating metabolic rates for short time intervals is confirmed by its ability to significantly differentiate traverse segments of differing slope (downhill, level, uphill).

2. Metabolic cost decreases as the crewman repeats a task over successive EVAs. From the first to the second EVA performance, this decrement is of the order of 10% for two different types of tasks. This may be taken as evidence of adaptation to the general working conditions on the lunar surface.

D. Fall and Near Fall Analysis

During Apollo 15 lunar EVAs instances occurred in which crewmembers momentarily lost their balance resulting in a fall or near-fall. The two falls occurred as the CDR was moving over uneven terrain and encountered the edge of a crater, soil of which could not support him. The limited visibility may have also contributed to the falls.

The near-falls occurred when crewmembers went into rotation or angular motion in which mass affected the motion as it would under 1-g, but the traction, or frictional resistance of the boots with the surface was only 1/6th of what it would be on earth. The sudden rotating motions (induced by LMP when a balky connector pulled loose, and by CDR in tossing, discus style, a pallet) and lack of traction were quickly compensated for by the crewmembers so that an actual fall did not occur.

Recognition of hazardous surface conditions, especially at crater edges, and the difference in angular and frictional forces will assist crewmembers in avoiding possibly dangerous situations resulting from falls.

APPENDIX A

EVA TIMELINES - CDR & LMP

CDR EVA #1

	GET(1)	T(2)	GET(1)	T(2)
Start EVA Watch			04:23:38:33	
Pre-Egress			04:23:50:45	12.20
Egress			04:23:59:28	8.72
TV Deploy			05:00:11:13	11.75
LRV Offload and Deploy			05:00:31:40	20.45
LRV Config. and Trav. Prep.			05:01:44:35	72.92
Trav. to Station #1(3)			05:02:10:46	26.18
Station #1 Tasks:				
Geol. Site Selection	05:02:14:52	4.10		
Radial Sample	05:02:24:04	9.20		
Trav. Prep.	05:02:28:36	4.53	05:02:28:36	17.83
Trav. to Station #2			05:02:35:20	6.73
Station #2 Tasks:				
Geol. Description & Doc. Samples	05:02:57:22	22.03		
Comprehensive Sample	05:03:05:11	7.82		
Double Core	05:03:16:04	10.88		
500mm Photo and Trav. Prep.	05:03:26:02	9.97	05:03:26:02	50.70
Trav. to Station #3			05:03:42:50	16.80
Station #3 Tasks:				
Samples and Trav. Prep.	05:03:47:08	4.30	05:03:47:08	4.30
Trav. to LM			05:03:59:35	12.45
ALSEP Offload			05:04:24:05	24.50
ALSEP Trav.			05:04:33:28	9.38
ALSEP Tasks:				
HFE Deploy	05:05:24:01	50.55		
LR^3 Deploy	05:05:33:21	9.33		
ALSEP Photo and Trav. Prep.	05:05:38:17	4.93	05:05:38:17	64.81
Trav. to LM			05:05:42:36	4.32
EVA Closeout			05:05:57:40	15.07
SWC Deploy and EVA Termination			05:06:12:23	14.72

Total EVA #1 - 6 hr 33.83 min

(1) GET is in days:hours:minutes:seconds and represents the end point of a specific activity.

(2) ΔT is in decimal minutes and represents elapsed time.

(3) Unless otherwise noted, all traverses are via LRV.

LMP - EVA #1

	GET	ΔT	GET	ΔT
Start EVA Watch			04:23:38:33	
Pre-Egress			05:00:00:00	21.45
Egress			05:00:03:39	3.65
Contingency Sample			05:00:13:45	10.10
LRV Offload and Deploy			05:00:30:51	17.10
LRV Config.			05:01:15:41	44.83
Pallet Trans., LM Pwr. Down & Trav. Prep.			05:01:44:35	28.90
Trav. to Station #1			05:02:10:46	26.18
Station #1 Tasks:				
Photo Pan	05:02:14:35	3.82		
Radial Sample	05:02:24:04	9.48		
Trav. Prep.	05:02:28:36	4.53	05:02:28:36	17.83
Trav. to Station #2			05:02:35:20	6.73
Station #2 Tasks:				
Photo Pan and Documented Samples	05:02:57:22	22.03		
Comprehensive Sample	05:03:05:11	7.82		
Double Core	05:03:16:04	10.88		
70mm Pan and Trav. Prep.	05:03:26:02	9.97	05:03:26:02	50.70
Trav. to Station #3			05:03:42:50	16.80
Station #3 Tasks:				
Monitor CDR From LRV	05:03:47:08	4.30	05:03:47:08	4.30
Trav. to LM			05:03:59:35	12.45
ALSEP Offload			05:04:23:42	24.12
ALSEP Trav. (walking carrying ALSEP Barbell)			05:04:26:51	3.15
ALSEP Tasks:				
ALSEP Interconnect	05:04:42:49	15.97		
PSE Deploy	05:04:51:06	8.28		
SWE Deploy	05:04:54:45	3.65		
LSM Deploy	05:05:04:03	9.30		
Sunshield Deploy	05:05:18:14	14.18		
ALSEP Antenna Installation	05:05:25:05	6.85		
Side Deploy	05:05:33:30	8.42		
C/S Activate & LSM Sunshield Deploy	05:05:38:33	5.05	05:05:38:33	71.70
Trav. to LM			05:05:42:49	4.27
EVA Closeout			05:05:53:32	10.72
EVA Termination			05:06:12:23	18.65
			Total EVA #1 6 hr	33.83 min

CDR - EVA #2

	GET	ΔT	GET	ΔT
Start EVA Watch			05:22:14:20	
Pre-Egress			05:22:24:03	9.72
Egress			05:22:29:28	5.42
Equip. Prep.			05:23:03:45	34.28
LRV Nav. Init.			05:23:11:13	7.47
Trav. to Station #6			05:23:53:56	42.72
Station #6 Tasks:				
Documented Samples	06:00:25:33	31.45		
Soil Mech. Trench	06:00:34:50	9.45		
Single Core	06:00:38:55	4.08		
Documented Samples	06:00:43:57	5.03		
500mm Photo and Trav. Prep.	06:00:58:29	14.54	06:00:58:29	64.55
Trav. to Station #6A			06:01:00:59	2.50
Station #6A Tasks:				
Samples and Trav. Prep.	06:01:22:40	21.68	06:01:22:40	21.68
Trav. to Station #7			06:01:25:46	3.10
Station #7 Tasks:				
Documented Samples	06:01:57:20	31.57		
Comprehensive Sample	06:02:06:52	9.53		
Documented Samples & Trav. Prep.	06:02:15:28	8.60	06:02:15:28	49.70
Trav. to Station #4			06:02:28:24	12.93
Station #4 Tasks:				
Documented Sample	06:02:41:35	13.18		
Trav. Prep.	06:02:45:44	4.15	06:02:45.44	17.33
Trav. to LM			06:03:08:08	22.40
Config. LRV for ALSEP Tasks			06:03:19:33	11.42
Trav. to ALSEP Site			06:03:21:15	1.70
ALSEP Site Tasks:				
HFE Deploy Completion	06:03:57:13	35.97		
Select Geol. Site for LMP	06:04:14:05	16.87		
Deep Core and Trav. Prep.	06:04:31:08	17:05	06:04:31:08	69.88
Trav. to LM			06:04:32:17	1.15
EVA Closeout:				
Closeout Activities	06:04:53:14	20.95		
Flag Deploy	06:04:57:40	4.43		
Continue Closeout Activities	06:05:18:51	21.18	06:05:18:51	46.57
EVA Termination			06:05:27:21	8.50

Total EVA #2 - 7 hr 13.02 min

LMP - EVA #2

	GET	ΔT	GET	ΔT
Start EVA Watch			05:22:14:20	
Pre-Egress			05:22:35:56	21.60
Egress			05:22:37:33	1.62
Equip. Prep.			05:23:03:46	26.22
LRV Nav. Init.			05:23:11:13	7.45
Trav. to Station #6			05:23:53:56	42.72
Station #6 Tasks:				
Photo Pan	05:23:58:17	4.35		
Documented Samples	06:00:26:01	27.73		
Soil Mech. Trench	06:00:34:50	8.82		
Single Core	06:00:38:55	4.08		
Documented Samples	06:00:43:57	5.03		
70mm Mag. Ch. & Trav. Prep.	06:00:58:29	14.54	06:00:58:29	64.55
Trav. to Station #6A			06:01:00:59	2.50
Station #6A Tasks:				
Photo Pan and Geol. Desc.	06:01:19:10	18.18		
Trav. Prep.	06:01:22:40	3.50	06:01:22:40	21.68
Trav. to Station #7			06:01:25:46	3.10
Station #7 Tasks:				
Photo Pan	06:01:34:30	8.73		
Documented Samples	06:01:55:04	20.57		
Comprehensive Sample	06:02:06:52	11.80		
Documented Samples & Trav. Prep.	06:02:15:28	8.60	06:02:15:28	49.70
Trav. to Station #4			06:02:28:24	12.93
Station #4 Tasks				
Photo Pan and Documented Samples	06:02:41:35	13.18		
Trav. Prep.	06:02:45:44	4.15	06:02:45:44	17.33
Trav. to LM			06:03:08:08	22.40
Config. LRV for ALSEP and Photo			06:03:30:24	22.27
Trav. to ALSEP Site (walking)			06:03:34:31	4.12
ALSEP Site Tasks:				
ALSEP Photo and Ch. 70mm Mag.	06:03:48:26	13.92		
Samples and C/S Align Check	06:03:55:15	6.82		
Photo and Description	06:04:02:10	6.92		
Soil Mech. Trench	06:04:17:39	15.49		
Penetrometer	06:04:28:18	10.65	06:04:28:18	53.78
ALSEP Photo and Trav. to LM (walking)			06:04:33:11	4.88
EVA Closeout:				
Closeout Activities	06:04:52:18	19.11		
Flag Deploy	06:04:57:40	5.37		
Continued Closeout Activities	06:05:04:22	6.70	06:05:04:22	31.18
EVA Termination			06:05:27:21	22.98

Total EVA #2 - 7 hr 13.02 min

CDR - EVA #3

	GET	ΔT	GET	ΔT
Start EVA Watch			06:19:17:38	
Pre-Egress			06:19:28:16	10.63
Egress			06:19:32:19	4.05
Equip. Prep. & LCRU Activate			06:20:04:13	31.90
Trav. to ALSEP Site			06:20:07:07	2.90
ALSEP Site Tasks:				
Recover Core Tubes	06:20:17:57	10.83		
Disassemble Core Tubes	06:20:36:42	18.75		
LRV Photo/16mm	06:20:45:15	8.55	06:20:45:15	38.13
LRV Nav. Init.			06:20:48:26	3.18
Trav. to Station #9			06:21:01:44	13.30
Station #9 Tasks:				
Documented Samples & Trav. Prep.	06:21:16:50	15.10	06:21:16:50	15.10
Traverse to Station #9A			06:21:19:26	2.60
Station #9A Tasks:				
Geol. Desc. & 500mm Photo	06:21:36:00	16.57		
Documented Samples	06:21:53:10	17.17		
Comprehensive Sample	06:22:00:58	7.80		
Double Core	06:22:08:34	7.60		
Samples & Trav. Prep.	06:22:14:25	5.85	06:22:14:25	54.98
Trav. to Station #10			06:22:16:45	2.33
Station #10 Tasks:				
500mm Photo, Samples & Trav. Prep.	06:22:28:49	12.07	06:22:28:49	12.07
Trav. to ALSEP Site			06:22:43:40	14.85
Trav. to LM			06:22:45:45	2.08
EVA Closeout:				
Closeout Activities	06:23:15:08	29.38		
Demonstration (Stamp and Gravity)	06:23:23:06	7.97		
Position LRV for Liftoff	06:23:52:30	29.40		
Continue Closeout Activities	07:00:00:37	8.03	07:00:00:37	74.78
EVA Termination			07:00:08:09	7.62

Total EVA #3 - 4 hr 50.52 min

LMP - EVA #3

	GET	ΔT	GET	ΔT
Start EVA Watch			06:19:17:38	
Pre-Egress			06:19:32:21	14.88
Egress			06:19:34:11	1.67
Equip. Prep.			06:20:02:30	28.32
Trav. to ALSEP Site (walking)			06:20:07:07	4.62
ALSEP Site Tasks:				
Recover Core Stems	06:20:17:57	10.83		
Disassemble Core Stems	06:20:21:43	3.77		
ALSEP Photo	06:20:28:35	6.87		
Disassemble Core Stems	06:20:36:42	8.12		
LRV Photo & Trav. Prep.	06:20:45:15	8.55	06:20:45:15	38:13
LRV Nav. Init.			06:20:48:26	3.18
Trav. to Station #9			06:21:01:44	13.30
Station #9 Tasks:				
Troubleshoot Camera Malfunction	06:21:08:53	7.15		
Documented Samples & Trav. Prep.	06:21:16:50	7.95	06:21:16:50	15.10
Trav. to Station #9A			06:21:19:26	2.60
Station #9A Tasks:				
Documented Samples	06:21:53:10	33.73		
Comprehensive Sample	06:22:00:58	7.80		
Double Core	06:22:08:40	7.70		
Samples & Trav. Prep.	06:22:14:25	5.75	06:22:14:25	54.98
Trav. to Station #10			06:22:16:45	2.33
Station #10 Tasks:				
70mm Photo Pan	06:22:20:02	3.28		
Samples & Trav. Prep.	06:22:28:49	8.78	06:22:28:49	12.07
Trav. to ALSEP Site			06:22:43:40	14.85
Retrieve Core Stems			06:22:45:23	1.72
Trav. to LM (walking)			06:22:46:47	1.40
EVA Closeout				
Closeout Activities	06:23:14:06	27.32		
Transfer Samples & Film Mags. to MESA	06:23:55:34	41.47	06:23:55:34	68.70
EVA Termination			07:00:08:09	12.58

Total EVA #3 - 4 hr 50.52 min

APPENDIX B

PARTITION OF TASKS INTO SUB-TASKS

PARTITION OF TASKS INTO SUB-TASKS*

Commander	1-G Training 6/4 (A)	7/1 (B)	7/16 (C)	EVA 1 7/31 (D)	Ratio (D/C)	EVA Data Source
TV Deploy						
1. Unstow, Configure TV & Position at 12:00/50'	(1)	1.72 (2)	1.71 (2)	3.13	1.83	TV
2. Adjust TV		.50 (3)	.41 (3)	1.43	3.48	TV
LRV Offload						
1. Offload LRV until rear wheels on surface		2.16	2.71	4.82 (4)	1.77	VTV
2. Continue offload of LRV until front wheels on surface		1.89	1.67	1.75	1.04	VTV
LRV Configuration & Traverse Prep.						
1. Mount LRV and complete LRV checklist		2.75 (5)	2.20 (5)	3.85	1.75	VTV
2. Mount TCU on LRV and connect power cable		.88	.85	1.47	1.72	VTV
3. Install LGA on LRV		2.10	1.90	2.25 (6)	1.18	VTV
4. Unstow HGA		.80	.44	.80	1.81	TV
5. Mount HGA on LRV		.50	.55	.87	1.58	TV
6. Connect HGA & install TV on LRV		5.04	5.11	5.90	1.15	VTV

(1) No data collected on CDR on 6/4/71.

(2) In training the TV was positioned at 25' from the LM, rather than the 50' EVA distance.

(3) In the training sessions a mockup camera was used, adjustments were only simulated.

(4) Subactivities were interrupted for .7 min. when the CDR helped the LMP to his feet after a fall.

(5) In training crewmen always required assistance when mounting the LRV.

(6) Subactivities were interruped for 1.20 min. when the CDR refastened a LMP PLSS flap.

*See pages 65 to 70 for a complete description of the sub-tasks.

PARTITION OF TASKS INTO SUB-TASKS (continued)

Commander	1-G Training 6/4 (A)	7/1 (B)	7/16 (C)	EVA 1 7/31 (D)	Ratio (D/C)	EVA Data Source
HFE Deploy						
1. Offload LR & lunar drill, deploy HFE pallet & prepare for first drill side.	(1)	7.63	8.28 (7)	14.71	1.77	VTV
2. Release & remove electronics box from pallet.		1.30	1.62	2.45	1.51	TV
3. Deploy electronics box & prepare rack & drill.		5.71	5.83	7.79	1.33	VTV
4. Prepare first bore stem sections.		1.60	.92	.94	1.02	TV
5. Carry rack, rod & drill to 2nd site & drill 1st bore stems into surface.		1.81 (8)	2.40 (8)	3.24	1.35	VTV
6. Remove drill from bore stems.		.21	.26	3.17 (9)	12.19	VTV

(7) CDR encountered some difficulty with "stuck" Boyd bolts during this group of subactivities.

(8) In training the soft soil made the drilling activity very easy.

(9) To accomplish this subactivity the CDR had to obtain the vise from the 1st site and use it on the drill and bore stems at site 2.

PARTITION OF TASKS INTO SUB-TASKS (continued)

Commander	1-G Training 6/4 (A)	7/1 (B)	7/16 (C)	EVA 2 8/1 (D)	Ratio (D/C)	EVA Data Source
Deep Core Sampling						
1. Lift & Place core bit into treadle.	(1)	.23	.35	.43	1.22	TV
2. Drill core stem into surface.		.23	.23	.35	1.52	TV
3. Remove drill from core stem & place on surface.		.27	.40	2.18 (10)	5.45	TV
4. Assemble & drill 3rd & 4th core stem sections into surface.		1.60	1.74	3.33	1.91	VTV
5. Assemble 5th & 6th core stem sections onto core stem.		.82	.69	1.98	2.86	VTV
6. Retrieve drill & attach to core stems.		.35	.48	.63	1.31	VTV
7. Drill core stem into surface.		.22	.20	1.22 (11)	6.10	VTV

(10) CDR encountered much difficulty removing drill.

(11) Lunar subsurface rock is much more difficult to penetrate with the drill than the sand at the training site.

PARTITION OF TASKS INTO SUB-TASKS

Lunar Module Pilot	1-G Training 6/4 (A)	7/1 (B)	7/16 (C)	EVA 1 7/31 (D)	Ratio (D/C)	EVA Data Source
LRV Offload						
Pull LRV aft cable.	ND	4.20	3.40	3.78(1)	1.11	VTV
LRV Configuration						
Photo CDR/LRV & configure.	4.50	4.90	4.59	4.96	1.08	VTV
ALSEP Interconnect						
1. Connect power pack to central station (C/S).	4.20	3.10	3.00	4.53	1.51	VTV
2. Deploy subpallet.	2.05	1.10	1.00	4.06	4.06	V
3. Release & connect SIDE to C/S.	4.00	4.68	4.99	7.36(2)	1.47	VTV
PSE Deploy						
1. Remove carry bar from C/S.	1.20	.50	.33	.83	2.51	VTV
2. Align C/S.	.75	.77	.51	.38	.74	VTV
3. Unstow PSE stool.	ND	.85	.92	1.06	1.15	VTV
4. Deploy PSE stool.	ND	.80	.73	.82	1.12	TV
5. Remove C/S dust cover.	.20	.60	.23	.55	2.39	TV
6. PSE deploy.	3.60(3)	2.90(3)	2.63(3)	3.70	1.40	VTV
7. PSE level and align.	.80	.60	.66	.93	1.40	V

(1) The subactivity was interrupted for .72 min. when the LMP fell.

(2) LMP had difficulty connecting SIDE cable to C/S.

(3) In training the wind caused problems for the LMP deploying the thermal skirt.

PARTITION OF TASKS INTO SUB-TASKS

Lunar Module Pilot	1-G Training 6/4 (A)	7/1 (B)	7/16 (C)	EVA 1 7/31 (D)	Ratio (D/C)	EVA Data Source
LSM Deploy						
1. Release LSM from C/S.	1.50	1.30	1.50	2.60[4]	1.73	VTV
2. Carry, deploy & align LSM.	5.80	4.55	4.17	6.02	1.44	V
Sunshield Deploy & ALSEP Antenna Installation						
1. Release & raise sunshield.	4.40	4.30	4.22	11.27[5]	2.67	VTV
2. Complete sunshield deployment.	6.00	5.50	5.03	6.02	1.19	VTV
3. Complete antenna alignment.	2.10	3.10	1.42	2.78	1.95	V

(4) Subactivities were interrupted for .68 min. when the LMP encountered a PLSS problem.

(5) Hardware malfunction: A cord broke requiring LMP to get down on hands and knees to pull some pins.

SUB-TASK DESCRIPTIONS

This section of Appendix B presents a full composition of sub-tasks which were synoptically presented in the previous tables comparing the 1-g training and lunar EVA. These sub-tasks are those which appear in the "Detailed EVA Procedures" section of the Apollo 15 Lunar Surface Procedures Document. The number preceding the list of sub-tasks corresponds to the same number for the snyoptic term in the comparison tables, pages 59 to 64.

SUB-TASK DESCRIPTIONS (1)

COMMANDER

TV Deploy

1. Unstow and mount TV camera on tripod.
   Position TV at 12:00/50'.
2. Adjust TV per MCC request.

LRV Offload

1. Deploy LRV aft cable.
   Deploy right LRV offload tape.
   Check LRV released from LM
   Pull offload tape until rear wheels on surface.
2. Remove right outrigger cable.
   Remove left outrigger cable.
   Pull offload tape until front wheels on surface.

LRV Configuration and Traverse Preparation

1. Mount LRV.
   Accomplish LRV post-deploy checklist.
2. Mount TCU on front of LRV.
   Connect TCU power cable.
3. Unstow rake and move aside on MESA.
   Open LRV antenna stowage can.
   Unstow LGA from cannister.
   Mount LGA in CDR handhold.
4. Unstow HGA from cannister.
5. Mount HGA on LRV.
6. Rotate antenna onto staff.
   Unstow cable.
   Connect HGA cable to LCRU.
   Retrieve and carry TV camera/tripod to +X strut.
   TV power switch-off.
   Disconnect and stow TV cable.
   Remove TV camera from tripod.
   Mount TV on TCU.
   Connect TV power cable.

(1)a. Tasks (underlined) correspond to those listed in this Appendix, pages 59 to 64.
b. Sub-tasks (numbered) are not necessarily all those required for the Task, but are restricted to those for which analysis times are available.
c. Some sub-tasks (e.g., LRV Offload, 1) consist of more than one element; elements are listed in sequence and make up the sub-task.

HFE Deploy

1. Offload LR and set on surface.
   Offload drill and set on surface.
   Release HFE pallet Boyd bolts.
   Lift HFE pallet from power package.
   Carry HFE pallet 15' N. of C/S.
   Unstow HFE connector.
   Place HFE pallet on surface.
   Connect HFE cable to C/S.
   Carry HFE pallet 30' N. of C/S.
   Place HFE pallet on surface and fold braces.
   Tip pallet down.
   Release probe box Boyd bolts.
   Lift probe box from pallet.
   Separate box and lean probe with tool against pallet.
   Carry other probe to drill site, deploying cable.
   Place probe on surface.
   Carry first probe to drill site, deploying cable.
   Place probe on surface.
2. Release electronics box Boyd bolts.
   Lift electronics box from pallet.
   Place box on surface.
3. Remove dust cover.
   Level and align electronics box.
   Throw pallet clear of area.
   Walk to LRV.
   Erect LMP seat post and lower seat pan.
   Retrieve drill from surface.
   Place drill on LMP seat.
   Push drill switch to test drill.
   Install handle on drill.
   Remove rack from treadle and deploy rack legs.
   Place rack on surface.
   Remove drill from treadle.
   Carry drill and rack to first drill site.
   Place rack and drill on surface.
4. Remove and discard stem cover.
   Release stem retaining Velcro.
   Assemble first two bore stem sections.
5. Carry rack rod and drill to second site.
   Place equipment on surface.
   Assemble first two bore stems sections.
   Insert sections into drill chuck.
   Set drill bit down on surface at mark on HFE cable.
   Drill bore stems into surface.
6. Remove drill from bore stems.

Deep Core Sampling - EVA 2

1. Lift drill and place core bit into treadle.
2. Drill core stem into surface.
3. Remove drill from core stem and place on surface.
4. Assemble third and fourth core stem sections.
   Thread sections onto stem.
   Retrieve drill and attach drill to core stem.
   Drill core stem into surface.
   Remove drill from core stem and place on surface.
5. Assemble fifth and sixth core stem sections.
   Thread sections onto core stem.
6. Retrieve drill and attach drill to core stem.
7. Drill core stem into surface.

LUNAR MODULE PILOT

LRV Offload

1. Pull LRV aft cable as required to offload LRV.

LRV Configuration

1. Photo CDR/LRV, 16mm camera.
   Stow 16mm on LRV.
   Unstow 70mm from MESA.
   Remove filter and reseal cover from 70mm and stow.
   Obtain magazine from ETB and attach to 70mm camera.
   Stow 70mm camera in CDR floor pan.

ALSEP Interconnect

1. Disconnect power package from bar.
   Reposition power package 10' East.
   Remove HFE stowage pins.
   Tilt power package down.
   Release RTG cable Boyd bolts.
   Deploy RTG cable and discard cable reel.
   Report shorting switch reading.
   Connect RTG cable to C/S.
2. Release subpallet Boyd bolts.
   Lift subpallet from power package and place 10' N. of power package.

3. Release SIDE Boyd bolts and CCIG cover.
   Lift SIDE from subpallet.
   Remove Boyd bolt blocking cable reel.
   Unstow cable reel.
   Deploy SIDE legs and place SIDE on surface.
   Unstow SIDE cable connector.
   Open EXPTS. package dust cover.
   Connect SIDE cable to C/S.

PSE Deploy

1. Remove carry bar from C/S.
2. Tip C/S down and align.
3. Stow carry bar on subpallet.
   Unstow PSE stool from subpallet.
4. Carry PSE stool 9' W. of C/S.
   Implace PSE stool.
5. Remove C/S dust cover.
6. Release PSE Boyd bolts.
   Carry PSE to stool.
   Remove Boyd bolts from PSE.
   Place PSE on stool.
   Deploy thermal skirt.
7. PSE level and align.

LSM Deploy

1. Release LSM Boyd bolts.
   Remove tie down and discard.
   Lift LSM from C/S.
2. Check cable free of sunshield.
   Carry LSM 50' W.NW., deploying cable.
   Select LSM site.
   Remove stowage bracket.
   Deploy legs.
   Align LSM and place on surface.
   Remove from collar.
   Deploy sensor arms.
   Remove dust covers and PRA covers.
   Align and level LSM.
   Check doors open.
   Report level and alignment.

Sunshield Deploy and ALSEP Antenna Installation

1. Release perimeter Boyd bolts.
   Release two inner Boyd bolts.
   Release center Boyd bolt and raise sunshield.
2. Remove side curtain covers and discard.
   Check side curtain and engage Velcro tabs.
   Retrieve and install antenna mast.
   Release antenna gimbal Boyd bolts.
   Remove gimbal from subpallet.
   Remove gimbal housing cover.
   Install gimbal on mast.
   Remove housing and discard.
   Install antenna on gimbal.
3. Check C/S alignment.
   Level and align antenna base.
   Enter elevation and azimuth offsets.
   Report antenna level and alignment.

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