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APOLLO 16

TIME AND MOTION STUDY

(FINAL MISSION REPORT)

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APOLLO 16

Time and Motion Study

(Final Mission Report)

by Joseph F. Kubis, John T. Elrod,
Rudolph Rusnak, John E. Barnes,
and Susan C. Saxon

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PREFACE

This report presents the results of the Time and Motion Study performed on Apollo 16 as authorized by the J-2 Mission Requirements Document (MRD). This study is the responsibility of the Life Sciences Directorate (LSD) 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 extravehicular activity (EVA) simulations at Kennedy Space Center (KSC). Lunar surface data consisted 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.

ACKNOWLEDGEMENTS

The staff of the Apollo Time and Motion Study is indebted to the Metabolic Assessment Team (MAT) for supplying heart rate and metabolic rate data. These data included the training session and lunar EVA.

Our appreciation is also given to Dr. E. Moseley for his cooperative efforts in our behalf.

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SUMMARY

The Time and Motion Study of astronaut lunar surface activity on Apollo 16 consists of five distinct analyses: an evaluation of lunar mobility, a comparison of task performance in 1-g training and lunar EVA, a study of metabolic costs and adaptation, a discussion of falls and retrieval of fallen objects.

Two basic mobility patterns, the hop or canter and the traditional walking gait, were consistently utilized in longer traverses. The metabolic rates associated with these two mobility types -- each used by a different astronaut -- were relatively equivalent.

The time to perform tasks on the lunar surface was significantly longer (on the order of 70%) than the time to perform the same tasks during the last 1-g training session. These results corroborated the findings on Apollo 15 and were not significantly different from them.

Metabolic rates (BTU/hr.) associated with task performance during the last 1-g training session were approximately 90% higher than those on the lunar surface. The average metabolic cost (BTU), however, was only slightly higher in the training session, because lunar task time was appreciably longer.

There was general improvement in lunar EVA performance upon repetition of tasks. Metabolic rate (BTU/hr.) and metabolic cost (BTU) decreased over successive EVAs. Specifically, the metabolic rate associated with riding the lunar roving vehicle (LRV) decreased by approximately 18% from EVA 1 to EVA 2 and by 15% from EVA 2 to EVA 3.

Falls observed on Apollo 16 seemed related to the method used in retrieving fallen objects and in operating the penetrometer.

Section I
QUANTITY AND QUALITY OF DATA

A. GENERAL COMMENT

Time and Motion Study (TAMS) personnel observed all three Apollo 16 EVAs in real time at the Manned Spacecraft Center (MSC) building 36, room 210. The quality of the television (TV) coverage was judged to be particularly good. In addition, there was an abundance of data available for analysis.

B. TELEVISION

Problems associated with Apollo 15 data, such as frequent panning and zooming, were not present in the Apollo 16 data. A previously unexperienced problem was the loss of TV coverage for the initial phase of EVA 1 activity due to the lunar module (LM) S-Band antenna failure. For the rest of EVA 1 and the other EVAs the TV coverage was very good.

There were only two major deviations from the planned TV coverage, these being the loss of initial EVA 1 activity (mentioned above), and those EVA 3 activities eliminated because of the shortened EVA 3 period. Of the activities lost, the more important were the initial EVA 1 activities such as LM egress, LRV offload, LRV configuration, and far-ultraviolet (Far-UV) camera deployment.

The overall direction of the TV camera by ground control during all three EVAs was generally excellent. Some tasks, however, performed by the commander (CDR) during Apollo lunar surface experiment package (ALSEP) deployment and observed on previous Apollo flights, could not be viewed on the TV. The quality of the kinescopes was the best received to date.

TV coverage of Apollo 16 introduced data which had been lacking from previous missions. There were several long traverses completely visible to the viewer and the amount of crew activity in the field of view exceeded that of all other missions. The end result is a representative cross section of crew geological activities and various modes of locomotion.

C. 16mm LUNAR SURFACE COLOR MOTION PICTURE FILM

It was anticipated that one magazine of film would be devoted to evaluating crew mobility. However, the early termination of EVA 3 brought about a cancellation of this test.

The film that was exposed on the lunar surface is spectacular and of the finest quality taken to date. Because most of the film was shot during LRV rides, the data obtained bear little relevance to TAMS objectives.

D. VOICE DATA

Official transcripts of the voice transmissions during the three EVAs were particularly important in analyzing the TV data because the time encoded on the kinescopes has not been accurate in some instances.

E. ASTRONAUT TECHNICAL DEBRIEFING COMMENTS

The debriefing comments provided additional information about terrain characteristics, suit comfort and capability, and work performance.

F. PHYSIOLOGICAL DATA

Metabolic and heart rate data are related to crewman activity where such analyses are feasible and meaningful.

G. EVA TIMELINES

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

Section II
MOBILITY EVALUATION

A. INTRODUCTION

Lunar mobility on two prior missions has been analyzed and reported previously by M151, Time and Motion Study.[1,2] Apollo 16 provided additional data for further understanding of this activity. Again, no serious problems developed, and the crewmen readily adapted to the lunar environment.

On Apollo 16, two distinct types of mobility were used for those traverses greater than 5-10 feet. The CDR used a walking gait, while the lunar module pilot (LMP) generally used the hopping mode. In addition, both crewmen used the side-step in moving short distances, especially while working around equipment, or performing other tasks such as photography, etc. One general feature of all mobility is the variation in step or stride (two successive steps) length, although the average number of strides per time unit is quite consistent from one traverse to the next. The terrain conditions undoubtedly contribute to the uneven stride and step pattern.

B. METHOD OF ANALYSIS

While a large number of mobility segments occurred during Apollo 16, only nine were suitable for analysis. The principal reasons for this were that (1) the crewmen moved directly toward or away from the camera, and (2) the camera panned and zoomed during traverses. Both of these condi-

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[1] Fordham University, ANALYSIS OF APOLLO XI LUNAR EVA (MOBILITY EVALUATION), 1970.

[2] Fordham University, APOLLO 15 TIME AND MOTION STUDY (FINAL REPORT), 1972.

tions made accurate distance determination difficult. Also at times only portions of the crewmen were visible. When the camera is at maximum or minimum focal length, and the crewman is completely in view, the distance from camera to crewman can be determined. Otherwise measurements such as length of stride have to be determined by using a known measurement (e.g., height of crewman) and scaling the desired measurement. This latter method was used in most mobility analyses.

C. ANALYSIS OF SPECIFIC TRAVERSES

Table 1, Mobility Evaluation, lists the pertinent data on seven mobility traverses which were suitable for complete analysis. Two of these, segments 2 and 7, are discussed in detail in Appendix B. One other traverse, the ALSEP traverse, is covered in Section D below and in Appendix B.

Certain general trends in mobility rates and other measures can be noted. With the exception of segment 2, the terrain was level, with only slight inclines or downhill slopes. Thus, no data are analyzed for effect of slope. Mobility rate, length of stride, and metabolic rate tend to increase with distance covered in traverse. Other variables such as objects carried, nature of terrain, preceding activities, motivational or other situational conditions, etc., influence these factors. Shorter traverses (e.g., 23-25 ft.), showed mobility rates at less than 2.0 ft./sec., stride length less than 3.0 feet, and metabolic rates less than 1000 BTU/hr. An exception to this was the short beginning segment of the ALSEP traverse, which is reported in Section D below. For longer traverses (e.g., 50 ft. or more) the mobility rates exceeded 2.0 ft./sec., the stride lengthened ranging from 3.4 to 4.6 feet, and metabolic rates exceeded 1100 BTU/hr. Exceptions occur here also. For example, segment 1 in Table 1, shows a

Table 1
MOBILITY EVALUATION

Seg. No.	Crew-Man	Clock Time[1]	Dist. (ft.)	Time[2] (sec.)	Rate (ft./sec.)	Avg. Stride Length (ft.)	Strides Per min.	Metab. Rate (BTU/hr.)	Conditions
1	LMP	5:10:26 EVA 1	53	30.9	1.73	2.8	36.0	652	Level, small rocks, carrying scoop.
2	CDR[3]	2:15:15 EVA 2	169	76.0	2.22	4.2	32.0	767	Downhill, carrying rake and gnomon.
3	LMP	3:40:31 EVA 2	23	11.6	1.98	2.9	41.4	818	Level to uphill, small rocks, carrying tongs.
4	LMP	6:34:44 EVA 2	54	21.7	2.49	3.4	44.4	1464	Level, loose soil, carrying penetrometer.
5	LMP	1:42:47 EVA 3	25	15.8	1.58	2.3	42.0	890	Level, small to large rocks.
6	LMP	1:43:07 EVA 3	25	15.3	1.63	2.3	43.2	898	Same as Seg. 5, but carrying scoop.
7	CDR[3]	2:20:00 EVA 3	297	99.0	3.00	4.56	39.5	1112	Level with depressions, few large rocks.

[1]Hours, minutes and seconds into EVA
[2]Seconds required to traverse distance
[3]See Appendix B for detail analysis

lower rate and stride length, but also a very low metabolic rate, indicating a less than average energy expenditure for the 53 foot traverse.

The above mobility examples are based on complete traverses, or nearly so, in that in some cases the TV camera missed a small part of the start or end of a traverse. Apollo 15 analysis studied short segments of traverses to determine specific types and modes of accomplishing mobility. The specific types were repeated in this mission, but with the CDR basically using the "walk," the LMP using the "hop." Based on the analysis of the traverses reported herein, plus the less rigorous analysis of 30 other traverses, no real difference appears to exist in the results of these two types. In one specific case (segment 7 in Table 1) both the CDR and the LMP completed the traverse simultaneously, each using his own mobility type. The metabolic rate for the LMP was 1185 BTU/hr., compared with the CDR's rate of 1112, indicating relatively equivalent expenditure rates.

The principal difference in the two types of mobility is in stride length. The walking type mobility generates a stride length in excess of 4 feet, while the hopping type is generally less than 3 feet. Exceptions to the latter appear when the LMP was carrying the ALSEP package in the early parts of his traverse (see Table 2, LMP ALSEP Traverse, and Appendix B). Here he was exerting considerably more effort, as evidenced by the BTU/hr. rates, resulting in larger hops. In the part of the traverse following recovery of the fallen ALSEP package, the LMP utilized a fast walk with the same stride length, but much more rapid rate of stride. The exceptionally high effort involved in walking at the rate of 3 ft./sec. with a 41 pound (lunar weight) load is shown by the 2300 BTU/hr. metabolic rate.

D. ALSEP TRAVERSE

At 1.67 hours into EVA 1, the LMP carried two large packages from the LM toward the ALSEP site, a distance of about 230 feet. Each of the packages was approximately 21 pounds lunar weight, and approximately 25X27X21 inches in dimension. They were carried at shoulder height, one on each side, by means of a "barbell" arrangement. Early in the traverse, due to a malfunction of the retaining clip, Package #2, the radioisotope thermoelectric generator (RTG) package fell to the surface. The LMP reacted to this by stopping quickly, experiencing temporary imbalance, but not falling. In about 6 seconds he had recovered, turned 90° and located the package. He reassembled the package to the support in slightly less than 3 minutes and continued toward the ALSEP site, covering 180 feet up a slight incline (5%) in 1 minute, or at a rate of 3.0 ft./sec.

Detailed analysis of the individual segments, or portions thereof, are given in Appendix B and are summarized in Table 2. The outstanding features observed in this traverse are:

1. Change from "hopping" type mobility. After the RTG package fell, the LMP changed to a "walking" mode.

2. High rates of traverse and energy expenditure. Short initial segments of approximately 20 feet and 52 feet were covered at rates of 2.3 ft./sec. and 2.15 ft./sec. respectively. Appendix B includes portions of these as Segments 1, 2, and 3 with detailed analyses. These segments are only portions of the total ALSEP traverse. The high 1600 BTU/hr. metabolic rate for these segments is also significant, and results from a combination of mobility rate and load. During these segments the LMP used the hopping type mobility referred to above.

Table 2
LMP ALSEP TRAVERSE

Seq. No.	Δ Time (sec.)	Cum. Time (sec.)	Dist. (ft.)	Rate (ft./sec.)	Avg. Stride Length (ft.)	Strides Per min.	Metab. Rate (BTU/hr.)	Comments[1]
1	08.7	08.7	20	2.30	3.33	41.4	1600	Hopping type locomotion.
2	06.0	14.7						Stopped to adjust load.
3	25.3	40.0	52	2.15	3.43	36.6	1600	Hopping type locomotion, seq. ends when RTG pkg. falls.
4	174.5	214.5					1992	Reassemble ALSEP package.
5	60.5	275.0	180	2.98	3.43	52.5	2300	Walking type locomotion.
6	60.0	335.0					2134	Set ALSEP pkg. down, rest.
7	60.0	395.0					1497	Rest, comment on ALSEP site.
8	60.0	455.0					1282	Same as Sequence 7.

[1] Conditions: Terrain generally even and level with few rocks. The last 180 feet (Seq. 5) was up a slight slope of approximately 5%.

After the dropped package was reassembled (a 2.91 min. operation with an average metabolic rate of 1992 BTU/hr.) the LMP picked up the package and moved toward the ALSEP site area. This 180 foot distance was covered in just over 60 seconds, up a slight (approximately 5%) incline, over relatively even, uncluttered terrain for an average rate of 3.0 ft./sec. The heavy "workload" of this segment is evidenced by the metabolic rate of 2300 BTU/hr. This was one of the highest rates registered by the LMP on any EVA. Table 2 shows also that the LMP made quick recovery from the high energy rate. The BTU rate dropped from 2300 to 1282 BTU/hr. in 3 minutes. During this traverse the stride rate was also high, at 52.5 strides/min., or 105 steps/min. (For comparison, a 3 mile/hr. walking rate and a 30 in. step is considered a good pace for a man on earth. At this pace he is taking 105.6 steps/min.) The entire ALSEP traverse was an example of maximum or near maximum effort over a nearly 5 minute period (total 4.62 min.).

3. Reaction to load, and emergency. This was the bulkiest and heaviest load carried by a crewman under lunar conditions. The event of the package falling was met with quick reactions and prompt correction. But the energy cost of the total effort was unusually high, and such performance probably cannot be maintained for long periods of time.

E. GENERAL SUMMARY

1. Analysis of longer, complete traverses again showed the excellent adaptability of crewmen to the lunar environment. One measure of this adaptability was evidenced by the strides per minute which increased from an estimated average of about 35 on EVA 1 to better than 40 on EVAs 2 and 3. Each crewmember chose to utilize a type of mobility which seemed to

suit him best. The CDR used a more conventional walk, while the LMP adopted the now familiar hopping type lunar mobility. Each was equally successful in moving about on the lunar surface, with comparable expenditure of energy.

2. Apollo 16 provided the opportunity to study the carrying of a large, bulky load over a considerable distance. The LMP carried the ALSEP package a distance of over 250 feet toward the ALSEP site at a faster than average rate. While the energy expenditure was high (2300 BTU/hr. for a segment lasting one minute in which 180 ft. were traversed), this particular traverse did demonstrate the capability of a crewman to carry a heavy, bulky object some distance at a fast rate. An interesting feature of the traverse was that the LMP changed from his usual hopping type of mobility to a walking type during the long traverse.

3. The general mobility patterns, except as mentioned above for the different types used, were essentially similar to those of previous Apollo missions. The lunar soil characteristics cause uneven strides, and occasional change from walk to hop and vice versa. However, no major problems presented themselves, and adaptability to lunar mobility was again demonstrated.

Section III
TIME COMPARISONS: LUNAR WORK PERFORMANCE AND 1-G TRAINING

A. INTRODUCTION

The objective of this section is to compare the time it takes to complete a task during lunar EVA with the time to perform the same task in the last suited EVA training session on earth.

Comparable tasks have been analyzed as well as those sub-tasks which were free of anomalies. In addition, tasks performed in identical fashion during Apollo 15 and 16 were given separate treatment.

The terms used -- task, sub-task, element -- are described as follows. "The largest activity segment is the task, a complete, identifiable activity with a single purpose . . . 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 . . . An element is the smallest unit of work which is still identifiable and homogeneous" (pp. 17-18 of Apollo 15 Time and Motion Study Final Report).

B. TASK TIME COMPARISONS (LUNAR EVA AND 1-G TRAINING)

The tasks chosen were those for which time analyses could be made over the complete task. Table 3 lists the activities, performance time during training sessions, performance time on the lunar surface, and the source of the data. It also presents the ratio of the EVA time and the last 1-g training time (D/C column in the table). Training times were obtained through direct observation; EVA times were determined from kinescopes (TV) and voice (V) transcripts.

Table 3
APOLLO 16
TIME COMPARISONS: LUNAR EVA AND 1-G TRAINING TASKS

Task	1-G Training Session 2/24/72 (A)	3/29/72 (B)	4/11/72 (C)	EVA 1 4/21/72 (D)	Ratio (D/C)	EVA Data Source
A. Commander						
1. Offload LRV	10.50	10.10	7.30	12.37	1.69	V
2. Setup LRV	5.10	4.10	4.20	5.88	1.40	V
3. Offload Far U.V.	9.80	8.40	8.75	17.67	2.02	V
4. Load LRV	14.75	16.25	13.85	20.68	1.49	VTV
5. Flag Deploy	4.01	4.90	3.30	7.13	2.16	VTV
6. Connect RTG	6.60	7.15	7.60	12.52	1.65	V
7. Deploy PSE	8.30	5.90	5.70	10.70	1.87	VTV
8. Remove LSM	1.40	1.35	1.40	2.12	1.51	TV
9. Erect Central Station[1]	N/D	4.95	4.70	7.80	1.66	VTV
10. Deploy LSM	N/D	5.45	4.05	6.52	1.61	TV
11. Deploy Geophones	N/D	10.60	8.90	12.90	1.44	VTV
B. Lunar Module Pilot						
12. Setup LRV	3.20	3.50	3.40	5.45	1.60	V
13. ALSEP Package Placement & Deploy HFE Hardware	9.85	13.39	10.00	23.08	2.31	VTV
TOTAL FOR CDR & LMP		96.04	83.15	144.82	1.74	

[1]Not including fastening thermal curtains
V - Voice
TV- Television
N/D - No Data

The data in Table 3 confirm the results obtained for Apollo 15. It took more time to perform activities on the moon than it did during the last 1-g training session at KSC. The time increase ranges from 40% (D/C ratio 1.40) to 131% with the average increase being 74%. This average is slightly larger than the average increase of 58% obtained on Apollo 15. The difference is not statistically significant.

C. IDENTICALLY PERFORMED TASKS (APOLLO 15 AND APOLLO 16)

The slightly larger overall D/C ratio for Apollo 16 could be due to a number of factors among which a difference in task requirements from Apollo 15 to Apollo 16 might be relevant. To offset such differences only those tasks which were performed in identical fashion during Apollo 15 and 16 are included in Table 4.

The outstanding features of this table are the consistencies, especially those observed in the EVA column. In three of the four tasks, there is almost exact correspondence in lunar performance times for Apollo 15 and Apollo 16. The only discrepancy is in Deploy PSE which took appreciably longer to do on Apollo 16. Contrariwise, performance time for this task during the last training session (Column C) was appreciably shorter on Apollo 16. The combination of these effects produced the large discrepancy in the D/C ratios. Nevertheless, considering the varied nature of the tasks, the complexities of the conditions under which they were performed, and the inherent individual differences in performance style, it is a remarkable fact that the congruences between Apollo 15 and Apollo 16 performance times were as close as indicated in Table 4.

Table 4

COMPARISONS OF TASKS IDENTICALLY PERFORMED ON APOLLO 15 AND APOLLO 16

Task	Mission	1-G Training (A)	(B)	(C)	EVA 1 (D)	Ratio (D/C)
CDR						
Set up LRV	A-16	5.1[1]	4.1	4.2	5.9	1.40
	A-15	N/D	5.7	3.6	5.9	1.62
LMP						
Set up LRV	A-16	3.2	3.5	3.4	5.4	1.60
	A-15	3.6	2.7	3.0	5.1	1.74
Deploy PSE[2]	A-16	8.3	5.9	5.7	10.7	1.87
	A-15	8.0	7.0	6.9	8.3	1.29
Deploy LSM[2,3]	A-16	N/D	6.8	5.5	8.6	1.56
	A-15	7.1	5.9	5.7	8.6	1.51
TOTAL	A-16	N/A	N/A	18.8	30.6	1.63
	A-15	N/A	N/A	19.2	27.9	1.45

[1]All times are in decimal minutes.

[2]Task performed by LMP on A-15 and CDR on A-16

[3]A-15 task "Deploy LSM" equivalent to A-16 tasks "Remove LSM" plus "Deploy LSM."

N/A - Not Applicable

N/D - No Data

D. SUB-TASK TIME COMPARISONS (LUNAR EVA AND 1-G TRAINING)

The tasks discussed in the previous section can, in general, be partitioned into smaller segments or sub-tasks. Such sub-tasks are listed in Appendix C.

By partitioning the tasks into smaller segments it is possible to identify anomalous conditions affecting performance time. The elimination of segments so affected improves the validity of comparisons within and between missions. With this objective in mind, all sub-tasks in which performance was nominal were selected from Appendix C and developed into Table 5. In other words, these sub-tasks were relatively free from anomalous or unusual conditions present either in the 1-g training sessions or in lunar EVA.

The D/C ratio for sub-tasks in Table 5 ranges from 1.16 to 2.18. Not included in the table is one sub-task performed by the LMP -- "obtain and configure Apollo lunar surface drill (ALSD)" -- with a D/C ratio of 1.43. When this sub-task is added to those of the CDR, the weighted D/C average becomes 1.66. This ratio is slightly larger than the corresponding Apollo 15 average of 1.41. Again, the difference between these ratios is not statistically significant.

E. FACTORS AFFECTING LUNAR EVA AND 1-G TRAINING COMPARISONS

A number of factors can be proposed to explain the differences in lunar EVA and 1-g training comparisons. The more obvious of these are rooted in the differences associated with lunar and earth-bound conditions -- gravitational effects, differences in soil and terrain, in visibility, etc. That these are important in any evaluation of the results is not to be denied. There are, moreover, attitudinal influences which

Table 5
APOLLO 16
TIME COMPARISONS OF SUB-TASKS

Sub-task	1-G Training 2/24 (A)	3/29 (B)	4/11 (C)	EVA 1 4/21 (D)	Ratio (D/C)	EVA Data Source
Commander						
Offload Far U.V. Camera						
1. Remove camera from LM and carry to deployment site	3.90[1]	3.20	2.60	4.80	1.85	V
2. Deploy camera & battery on surface	1.75	1.40	1.90	2.68	1.41	V
Flag Deploy						
1. Unstow and assemble flag	2.10	2.00	1.80	3.58	1.99	TV
2. Deploy flag on surface	.55	.35	.55	.92	1.67	V
3. Photography at flag	1.36	1.55	.85	1.12	1.32	TV
Connect RTG						
Remove subpallet and PSE stool from Package 2	3.70	4.95	3.60	5.21	1.45	VTV
Deploy PSE						
Deploy and level PSE	6.40	4.45	4.00	8.47	2.12	V
Offload Mortar Package						
Remove and deploy mortar package (M/P)	2.40	2.45	2.00	2.38	1.19	TV
Assemble and Align Antenna						
Activate central station	.50	N/D	.45	.98	2.18	V
Deploy LSM						
1. Carry LSM to deploy site	N/D	1.85	1.55	1.80	1.16	TV
2. Deploy and align LSM	N/D	3.55	2.50	4.72	1.89	VTV
Set Up Mortar Package						
1. Deploy M/P	N/D	1.60	.95	1.76	1.85	VTV
2. Place M/P in base	N/D	1.05	1.75	3.75	2.14	VTV
TOTAL			24.50	42.17	1.72	

[1]All times are in decimal minutes.
V - Voice
TV - Television
N/D - No Data

are relatively pervasive and important.

Central to these is the attitude of care or carefulness. Lunar equipment is not damage-proof and the crew has very limited repair capability available to them on the lunar surface. During lunar EVA, the astronaut has no one to correct mistakes or to help in difficult situations. This is in contrast to the training sessions where numerous individuals were available to check experiment deployment and equipment setups. The simulated lunar surface at KSC is not only smoother than the actual lunar terrain but is also more familiar and creates no problems relative to site selection for experiment deployment. When on the moon, the astronaut is keenly aware of the fact that he has only one chance to complete his task and that that performance must be efficient. And, in this performance, he is being intently observed by a large portion of the world population. In short, lunar EVA induces an attitude of great care in the execution of the allotted tasks.

There are also matters of rest and pacing. During training, it would not be possible to continue working for very long in the suited condition. Work periods are shorter and astronauts tend to mobilize their energies for swift but effective performance. Training time, then, would tend to be shorter.

These are some of the factors that must be kept in mind in a proper evaluation of any differences in performance during training and lunar EVA.

Section IV
METABOLIC COMPARISONS: 1-G TRAINING VS LUNAR EVA

A. INTRODUCTION

The purpose of this section is to compare the metabolic data associated with tasks performed during 1-g training and during lunar EVA. In this analysis, rate of energy expenditure and total metabolic cost per completed task are utilized.

It may be recalled that some preliminary results concerning metabolic rates have been presented in Section II: Mobility Evaluation. Those results tended to confirm the data obtained in Apollo 15 and indicated some variation in rate of energy expenditure due to changes in work conditions.

B. TASKS ANALYZED

Those tasks were chosen whose activity patterns were identical during training sessions and lunar EVA. On the basis of this criterion seven of the CDR's tasks and one of the LMP's tasks were selected for analysis. These are presented in Table 6. It may be recalled that no biomedical data were available for approximately the first hour of EVA 1 because of a problem with the S-band antenna.

C. CALCULATION PROCEDURE

Crewmen heart rates served as the bases for computing metabolic rates (BTU/hr.). For the training session the following regression functions were developed by the LSD Metabolic Assessment Team:

<u>CDR</u>: Metabolic Rate = 36.9 (heartrate) - 2136

<u>LMP</u>: Metabolic Rate = 29.5 (heartrate) - 1568

Table 6
METABOLIC COMPARISONS: 1-G TRAINING AND LUNAR EVA

Task	Training				Lunar EVA				Training/Lunar	
	Elapsed Time[1]	Heart Rate[2]	Metab. Rate[3] (A)	Metab. Cost[4] (B)	Elapsed Time[1]	Heart Rate[2]	Metab. Rate[3] (C)	Metab. Cost[4] (D)	Metab. Rate Ratio (A/C)	Metab. Cost Ratio (B/D)
CDR										
Flag Deploy	3.30	109.7	1912	105	7.13	96.4	1198	142	1.60	.74
Connect RTG	7.60	98.8	1509	191	12.52	88.6	936	195	1.61	.98
Deploy PSE	5.70	100.4	1568	149	10.70	85.1	819	146	1.91	1.02
Remove LSM	1.40	84.3	974	23	2.12	83.3	759	27	1.28	.85
Erect C/S	4.70	95.7	1394	109	7.80	81.0	683	89	2.04	1.22
Deploy LSM	4.05	101.4	1606	108	6.52	78.5	598	65	2.69	1.66
Deploy Geophone	8.90	111.8[5]	1991	295	12.90	81.6	908	195	2.19	1.48
Total	35.65		(1649)[6]	980	59.69		(863)[6]	859	(1.91)	(1.14)
LMP										
ALSEP Placement & Deploy HFE	10.00	120.6	1991	332	23.08	96.3	607	233	3.28	1.42

[1]Decimal minutes
[2]Beats/minute
[3]BTU/hr.
[4]BTU
[5]Heart rate data not complete for this training activity
[6]Weighted Average

Similar linear functions were used for lunar EVA. These, however, changed each hour depending on the average heart rate and O_2 consumption exhibited during the preceeding hour. With this improvement, first used on Apollo 16, BTU rates were more reliably determined.

Metabolic cost (BTU) was calculated in the usual straightforward manner:

$$BTU = (\text{Elapsed Time}/60) \times \text{BTU Rate}$$

D. RESULTS

A study of Table 6 reveals several definite uniformities. As found in previous analyses, training times are all shorter than corresponding lunar performance times. Heart rates are uniformly higher for the training sessions with correspondingly higher metabolic rates. Metabolic cost during training, however, is sometimes larger and sometimes smaller than the corresponding metabolic cost during lunar EVA. These results are in agreement with the simulation studies reviewed by Shavelson (1968).[1]

Two ratios, A/C and B/D, were calculated to provide a precise measure of the percentage increase or decrease in metabolic rates and metabolic costs. The A/C ratios, which compare the metabolic rates in training with those in lunar EVA, consistently demonstrate a higher rate of energy expenditure during training over that during lunar EVA. The weighted average for the CDR is 1.91 indicating that on the average metabolic rates during training are 91% higher than those obtained during lunar EVA. (Since only one task has been analyzed for the LMP, his result can be given only passing attention in this report. However, the A/C rate for his data is

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[1]Shavelson, R. J. Lunar gravity simulation and its effect on human performance. Human Factors 1968, 10 (4), 393-402.

relatively high in comparison to those computed for the CDR.)

The case is quite different for metabolic cost. In some cases it is smaller in the training sessions than in lunar EVA. The weighted average is 1.13, indicating a slightly greater total energy expenditure during training than during lunar EVA.

In summary, then, although the metabolic rate is almost twice as large in training sessions than in lunar EVA, the energy cost for the same tasks is only slightly greater during the training sessions.

E. COMMENTS

The higher metabolic rates during training can be attributed to several factors among which the most important is the extra weight (approximately 100 lbs. for a 180-lb. man) associated with the suited condition. Heat storage, fatigue, a strong desire to complete the tasks as quickly as possible also contribute to this effect. On the other hand, there seems to be a greater overall equivalence of metabolic cost for 1-g training and lunar EVA task performance.

Section V
METABOLIC ADAPTATION

This section examines the metabolic rates (BTU/hr.) and energy costs (BTU) associated with repeated lunar activities as these were performed on at least two EVAs. This type of analysis should provide some information as to the presence or absence of adaptation over repeated performances.

The three activities chosen for analysis included a sedentary mode and two active energy-consuming activities. These were: Riding the LRV, Double Core Tube Sampling, and Hammering.

A. RIDING THE LRV

During the three EVAs the crewmen spent approximately 8 man-hours riding on the LRV. In these excursions the CDR was the driver, the LMP the navigator.

Metabolic rates (BTU/hr.) were computed for both the CDR and the LMP during twelve LRV riding segments. Three of these occurred in EVA 1, six in EVA 2, and three in EVA 3. The average metabolic rates are presented in Table 7.

Table 7

AVERAGE METABOLIC RATES ASSOCIATED WITH RIDING THE LRV

Crewman	EVA I	EVA II	EVA III	Average for Crewman
CDR	596[1]	531	472	532
LMP	669	509	412	525
Average For EVA	633	520	442	529
% Decrement	18% (I–II)	15% (II–III)		

[1]All rates in BTU/hr.

Both crewmen show pronounced adaptation in metabolic rate over the three EVAs. The decrease in BTU/hr. (633 to 520) is approximately 18% from EVA 1 to EVA 2 and 15% from EVA 2 to EVA 3. An analysis of variance indicates that the decrement over EVAs is significant at the .01 level. It is clear that there is no significant difference between metabolic rates for the two crewmen.

B. DOUBLE CORE SAMPLING - LMP

Four double core tube samples were collected during the Apollo 16 EVAs. Of these, three were visible on television and two of these were performed by the LMP. One of these was on EVA 2 (Station 8), the other on EVA 3 (Station 10). The data for the activities associated with these tasks are presented in Table 8. These include Time (in decimal minutes), Metabolic Rate (BTU/hr.), and Metabolic Cost (BTU). For completeness and better understanding, a single core sampling activity performed by the LMP at Station 9 is also included. It is felt that the activity associated with Station 9 is relevant to and enhances the adaptation effect. The inclusion of the data from Station 9 (single core) enables one to observe the regular progression in the adaptation effect over repeated similar operations.

(Hammering was excluded from this analysis because its performance was dependent on soil conditions at each location. Hammering as an operation is analyzed separately in the next section.)

An examination of Table 8 reveals progressive decrements in Time, in Metabolic Rate, and in Metabolic Cost. All indices reveal an increase in efficiency with time and task repetition.

Table 8

CORE TUBE SAMPLING (LMP)

Activity	EVA II Sta. 8			EVA II Sta. 9			EVA III Sta. 10'		
	Time (min.)	Rate (BTU/hr.)	Cost (BTU)	Time (min.)	Rate (BTU/hr.)	Cost (BTU)	Time (min.)	Rate (BTU/hr.)	Cost (BTU)
Assemble Transport Position Push	3.08	1019	52.3	2.22	1002	37.0	2.95	913	45.0
Photography	.55	1313	12.0	.55	906	8.3	.80	800	10.7
(Hammering)	Analyzed in separate section.								
Remove	.10	1389	2.3	.08	1024	1.3	.23	842	3.2
Transport Disassemble Stow	6.37	1097	116.5	5.33[1]	1038	92.2	2.48	760	31.4
Total	10.10	1087[2]	183.1	8.18	1018[2]	138.8	6.46	839[2]	90.3

[1]Done in two parts - 2.15 min. and 3.18 min.
[2]Weighted Average

C. HAMMERING - LMP AND CDR

During the core tube sampling, a considerable amount of hammering was required. This activity was analyzed in terms of Hammer Hits, Time, Metabolic Rate (BTU/hr.), Metabolic Cost (BTU), Hits/BTU, and Hits/minute. These data are presented in Table 9 which parallels the analysis presented in the previous table. One added feature is the data for the CDR on EVA 2 - Station 10.

Table 9
METABOLIC INDICES ASSOCIATED WITH HAMMERING

Crewman	Hits	ΔT[1]	BTU/hr.	BTU	Hits/BTU	Hits/min.
LMP						
EVA 2 - Sta. 8	69	2.28	1308	49.71	1.39	30.26
EVA 2 - Sta. 9	8	.20	936	3.12	2.56	40.00
EVA 3 - Sta. 10'	28	.58	807	7.80	3.59	48.28
CDR						
EVA 2 - Sta. 10	45	1.65	1129	31.04	1.45	27.27

[1]Elapsed time is in decimal minutes.

The data for the LMP clearly indicate a decrement in Metabolic Rate, a progressive increase in Hits/BTU (another measure of energy cost) and Hits/minute (a measure reflecting increased efficiency). These progressive changes occur over EVA and task repetition.

Of significant interest and importance are the data for the CDR during EVA 2 at Station 10. The congruence of his set of data with that of LMP during EVA 2 at Station 8 is particularly striking. Of direct relevance are the data for BTU/hr., Hits/BTU, and Hits/minute. These indicate that the metabolic and efficiency indices are relatively equivalent. This is a meaningful result since both crewmen were at equivalent stages in their EVA Hammering experience. The LMP used the hammer very briefly before Station 8 and the CDR used the hammer for a few rounds before Station 10 in order to get samples from a large boulder.

D. CONCLUSION

In Apollo 16, as in Apollo 15, there is strong evidence of adaptation to task performance from one EVA to the next. There are decrements in Metabolic Rate, Metabolic Cost and increases in efficiency. These results hold for both a sedentary type of activity, as Riding the LRV, and a vigorous type, as Hammering.

Section VI
FALL ANALYSIS

A. INTRODUCTION

1. Purpose

During the three lunar EVAs of Apollo 16 six falls of the crewmen were recorded on the TV kinescopes. The two falls of the CDR occurred in his attempt to pick up an object. Two of the LMP's falls occurred in a similar fashion; the other two involved the use of the penetrometer. The purpose of this analysis is to investigate the falls -- to determine the manner of falling and recovering and to determine the reasons for the falls.

2. Procedure

The TV kinescope segments comprising the falls were analyzed qualitatively and, where possible, quantitatively. The qualitative analysis included descriptions of the terrain, what the crewman carried, the activity preceding the fall, the recovery, and the apparent reason for the fall. Time into EVA was also obtained. The quantitative analysis included the measurement (at every 1/2 second) of the angles of the right knee, left knee and the body (measured from the horizontal) as well as descriptions of the arms, upper torso and lower torso. Both types of analysis were accomplished by using the Vanguard motion analyzer.

B. DESCRIPTION OF FALLS

Two different types of falls were observed on Apollo 16. One type was related to the procedure used by the crewmen when picking up objects without the aid of tongs or other hardware. This procedure involved approaching the object, hopping, bending the knees, grabbing the object and getting up; all done in one continuous motion. Variations included hopping and kneeling on one knee, kneeling down on both knees (without hopping); hopping up, stepping forward and up, stepping back and up.

The other type of fall occurred when the LMP was pushing the penetrometer.

1. Pickup Falls

a. LMP's fall at the ALSEP site. EVA 1.

Time: 05:01:53:32 - 53:39 Ground Elapsed Time (GET)

Terrain: Loose surface soil; small to medium-sized rocks scattered about; LMP is standing within the rim of a small crater and facing uphill. ALSEP site.

Carrying: He was holding a small object.

Apparent Reason: He slipped (slid) on the loose surface soil.

Previous Activity: LMP had jacked up the deep core, emplaced the heat flow probe, and attempted to pick up the rammer.

Description - Fall: On the second attempt to pick it up, the LMP went down on his knees. As he tried to get up, his feet slid on the loose soil and he fell to his knees and hands. (Feet could not get the necessary traction in the loose soil.)

Description - Recovery: To recover, the LMP leaned forward on his hands. He then pushed himself back with enough momentum to bring himself to his knees and then to his feet.

Time into EVA: 3:00:36

Quality of Film: Good view of the fall and recovery.

b. CDR's fall near the LM at closeout. EVA 1.

Time: 05:05:32:32 - 32:42 GET

Terrain: Loose surface soil; small rocks scattered; level; near the LM and LRV.

Carrying: Nothing.

Apparent Reason: Feet slipped on the loose soil.

Previous Activity: Both the CDR and LMP were dusting each other when the brush fell to the surface. The CDR went to pick up the brush.

Description - Fall: The CDR's usual procedure in picking something up is to approach the object (brush), bend one knee (in this case the right knee is bent), pick up the object, and stand up on both feet. All this is done in a somewhat continuous motion. In this particular instance, the CDR appeared to slip as he was about to stand up after getting the brush. His feet slid and would not take hold on the loose soil and so he ended up on his hands and knees.

Description - Recovery: The CDR knelt upright (his hands were no longer on the ground) with the brush in his right hand. His left hand gets a little support from the LMP. Then he extends his left hand; the LMP holds the hand and elbow and he helps the CDR to stand on his feet. CDR rolls back on his feet and then steps to his left, then right.

Time into EVA: 6:39:36

Quality of Film: CDR's back is facing the camera throughout the incident. Also at the time of the fall his feet are not in view.

c. LMP's fall at Station 8. EVA 2.

Time: 06:03:32:30 - 32:56 GET

Terrain: Small and medium rocks scattered; mostly level. Station 8.

Carrying: Camera and sample bags are mounted.

Apparent Reason: He had hopped down to pick up the tongs; in doing so he stepped on the tongs so that when he tried to lift them he lost his balance.

Previous Activity: The CDR and LMP were sampling and the CDR had just stowed a sample in the LMP's sample collection bag (SCB). The CDR started to walk away and the LMP went to pick up the tongs.

Description - Fall: The LMP bent his knees and got down on his right knee to pick up the tongs. He missed the tongs and fell.

Description - Recovery: With his left hand the LMP held on to the CDR who assisted him in getting up.

Time into EVA: 4:53:05

Quality of Film: Most of the time the LMP was hidden by the CDR.

d. CDR's fall at Station 11. EVA 3.

Time: 06:22:58:37 - 58:59 GET

Terrain: Small rocks to large boulders; craters. Station 11.

Carrying: Camera and bags mounted. Carrying SCB.

Apparent Reason: When picking up the bag, the CDR leaned too far to the right and lost his balance.

Previous Activity: The CDR is sampling at Station 11. As he went to a new sampling site he dropped one of the sample bags so he returned to pick it up.

Description - Fall: The CDR returned to pick up the sample bag, approached it, took about five steps, bent his knees (right knee touched the ground), leaned right and reached out with his right hand to pick up the bag. After he grabbed the bag and his right arm was coming up, he lost his balance, was unable to regain his balance and fell on both hands.

Description - Recovery: The CDR backed up on his knees, raised the upper part of his body, rested on his left hand. (The sample bag is in his right hand and the SCB is in his left hand.) As he straightened up he moved his feet very rapidly until he was standing. (His method of recovery differs from the LMP who uses a rocking motion to get to his feet.)

Time into EVA: 1:31:19

Quality of Film: Generally good. The CDR's right side is to the camera; however, his legs are not distinct because of the shadows.

2. Penetrometer Falls

a. LMP's fall at Station 4. EVA 2.

Time: 06:00:35:48 - 35:55 GET

Terrain: Loose surface soil; small and medium rocks scattered; shallow craters. Station 4.

Carrying: Nothing.

Apparent Reason: He was in an unstable position to begin with and then when he tried to get up he slipped on the loose soil.

Previous Activity: LMP is walking around with the penetrometer, obtaining readings.

Description - Fall: The LMP pushed in the penetrometer by leaning on it. The penetrometer was located near the top of a small slope and the LMP's feet were down the slope. The penetrometer went in all the way and since the LMP was leaning on it, his body approached the surface. He paused and started to stand up but his feet slid on the loose soil and he ended up on his hands with his body and legs parallel to the surface.

Description - Recovery: He leaned forward some more and pushed back with his arms, obtaining enough momentum to get to his knees and then to his feet.

Time into EVA: 1:56:23

Quality of Film: The LMP was facing the camera; thus much of the detail was not clear.

b. LMP's fall at Station 10.

Time: 06:05:11:50 - 12:16 GET

Terrain: Many small rocks scattered; loose soil; shallow depressions. Station 10.

Carrying: Nothing.

Apparent Reason: He lost his balance when the penetrometer went in all the way.

Previous Activity: LMP was walking around with the penetrometer obtaining readings.

Description - Fall: The LMP pushed in the penetrometer by leaning on it. The penetrometer went in all the way (unexpectedly), and he lost balance. He fell to his right side and extended his right arm to break the fall while his left was still on the penetrometer. He fell forward and his feet went in the "air," then down. He adjusted the position of his body, released the penetrometer, and put both hands on the surface.

Description-Recovery: After adjusting his body and putting both hands on the surface, he leaned forward, pushed back, got to his knees but did not make it up. He leaned forward a second time, pushed back, got to his knees, tried to stand up but ended up back on the ground again. He leaned forward a third time, pushed back, got to his knees, went back on his feet and finally stood up.

Time into EVA: 6:32:25

Quality of Film: Good sequence. The LMP has his right side to the camera. The rocking sequence where he tries to get up is also good.

C. POSSIBLE CAUSAL FACTORS

A preliminary analysis suggested that loss of traction on loose soil caused crewmen to slip and fall. A more thorough analysis revealed that the crew's unique method of picking up objects with their hands instead of with tongs also contributed to loss of balance and subsequent falls.

The falls associated with the penetrometer were related to the method used by the LMP to push in the penetrometer and also to the penetration and plate-load-sinkage characteristics of the lunar soil. In each instance where a fall occurred, the penetrometer shaft was pushed into the soil to its maximum penetration depth. In order to push the penetrometer into the soil the LMP leaned on the instrument with his entire weight. As the penetrometer sank to its maximum depth, and occasionally this occurred rapidly when the soil offered little resistance, he either lost his balance and fell (Station 10), or else he ended up in an unstable position and fell trying to stand up (Station 4).

The pickup falls involved other reasons. The crewmen's method of picking up objects was to approach the object, hop, bend the knees, reach out, grab the object, and stand up. In two of the pickup falls the crewman went through the pickup procedure but reached out too far to grab the object. This caused the loss of balance and the fall. These were the LMP's fall at the ALSEP site and the CDR's fall at Station 8. At the ALSEP site, the LMP leaned over until he was only 15° from the horizontal in reaching out to pick up the rammer. This was so great a displacement of his center of gravity that when he started to bounce up again his feet slid and he fell. The CDR's fall at Station 8 was similar. In order to pick up the sample bag he leaned too far to the right and so when he tried to stand up, he also lost his balance and fell.

The unique pickup procedure involves a high degree of coordination among its components. If, for example, the approach-hop places the astronaut too far from the object he must necessarily reach out too far in order to get it. This, in turn, places the astronaut in an unstable position. Even if the approach-hop is "on target," the astronaut must have an accurate place-memory because the object is often not in view at the moment of pickup. (The limitations on visibility of the EVA suit are discussed in a later section entitled "Hammer Retrieval.")

The LMP's fall at Station 4 differed from the other pickup falls. In this instance the LMP went to pick up the tongs and in doing so he hopped and stepped on the tongs with his left foot. Then, when he grabbed the tongs and started to pull them up, he knocked himself off balance and fell. This fall can be partly attributed to limited visibility and/or inaccurate visual estimation.

The reasons for the CDR's fall at the LM during closeout were not too evident because he was not in full view of the camera. However, since he lost his balance after he had the brush, it was possible that he reached out too far and was in an unstable position and unable to attain traction on the loose soil.

D. METHOD OF RECOVERY

In one fall the LMP helped the CDR get up on his feet (at the LM), in another the CDR helped the LMP (Station 8). In the other falls the crewmen differed in their methods of recovery. The LMP was able to get up by using a rocking motion. This involved getting on all fours, leaning forward, pushing back with his hands to acquire enough momentum to get to his knees and then to his feet. The CDR, on the other hand, got to his feet by kneeling upright and then pushing up fast with his feet until he was standing and stable.

E. A SUCCESSFUL PICKUP AND A PICKUP FALL

In order to determine why pickup falls occurred, a detailed analysis was done on an unsuccessful pickup fall and a successful pickup. The pickup at 05:01:52:22 GET (ALSEP site) and the pickup fall at 05:01:53:10 GET were chosen for comparison because they involved the same crewman, EVA, terrain and time period. In addition, the camera angle was good so a detailed analysis was possible.

At the successful pickup, the LMP approached the HFE probe, started to pick it up, bounced back up and got in position to try again. On the second try he approached the probe, hopped and stepped on his right foot as he knelt on his left knee. He leaned forward and towards the left, reaching down along his left knee to pick up the probe with his left hand. After getting it he bounced back up.

At the unsuccessful pickup, the LMP approached the rammer, started to pick it up, bounced back up and got in position to try again. On the second attempt he approached the rammer, hopped and knelt on both knees, leaned forward and left and reached out to pick up the rammer with his left hand. But in order to get the rammer he had to reach out at least a foot beyond his left knee and in reaching so far he bent over until his body was almost parallel to the surface. When he attempted to bounce back up, his feet slid and he lost his balance and fell. He then used a rocking motion to get back to his feet.

The detailed analysis pointed out that when the LMP picked up the probe, he leaned forward approximately 25° from vertical and picked up the probe just in front of his left knee. However, when he picked up the rammer, he extended his left hand beyond his left knee and in doing so he leaned forward approximately 75° from vertical. This placed the LMP in an unstable position and when he started to bounce back up, his feet slid and he fell. The overextended lean was the major difference between the successful and the unsuccessful pickup.

F. FALLS IN APOLLO 15 AND APOLLO 16

The falls occurring on Apollo 15 resulted from the soil conditions, specifically tripping over rocks (uneven terrain) and tripping at the edge of craters (soil in near failure condition). The falls on Apollo 16 were mainly the result of the methods used by the crewmen to pick up objects and to deploy the penetrometer. On Apollo 16 there were no falls observed that were caused by tripping due to soil conditions.

G. SUMMARY

An analysis of the falls on Apollo 16 was undertaken to determine the circumstances associated with falling and the methods used in recovering from the falls. Six falls were analyzed: four of these were related to the crewmen's unique method of picking up objects while two occurred during the insertion of the penetrometer. The recovery operations were slightly different for the two astronauts.

Section VII
ADDITIONAL ANALYSES

A. HAMMER RETRIEVAL

Both crewmembers dropped the hammer (geology type) while driving double core tubes on EVA 2. (CDR at Station 10: core tubes #27 and #32; LMP at Station 8: core tubes #29 and #36). See Section V of this report for core tube driving analysis. The CDR was able to pick up the hammer (15 in. long, 3 lb. 1-g wt., 0.5 lb. lunar wt.) from the lunar surface at the first attempt, while the LMP was not able to achieve this in four attempts. The latter retrieved the hammer by use of the tongs, and successfully continued driving the core tubes.

1. Suit Restraints - Analysis of the methods used and other factors involved in these hammer retrieval attempts are revealing in the insight they provide into performance of a task at the threshold of pressure-suited capability. The suit is the principal restraining factor in this activity from at least three aspects:

a. Vision. The helmet allows downward vision to about 6 inches in front of the subject when he is standing in a normal "erect" position. If the helmet visor assembly is at maximum opening, peripheral vision is not obstructed. A more serious obstruction to downward vision is the Hasselblad camera mounted on the RCU which restricts the crewman from viewing anything closer than 2 feet directly in front of him. Other angles of vision for various positions assumed by the crewman are affected by his positional attitude in leaning forward or to the side.

The CDR, in picking up the hammer, leaned forward up to 35° and to the right up to 40° in order to retain sight of the hammer as long as possible. The LMP leaned forward 17-23°, and to the right 25-30° maximum. The latter also started his retrieval attempts farther away from the hammer, 40-60 inches vs. 36 inches for the CDR. The LMP appeared to have his visor partially closed which would hamper side, especially side and down, vision. The reduced visual range of the LMP due to visor position and not leaning as far forward and to the right undoubtedly lessened his chances.

b. Flexibility. The picking up of an object the size and shape of the hammer requires the crewman to flex the suit at the knees and hips to the maximum. Both crewmen used the method of "crouching" on the right knee while extending the left leg and leaning to the right to reach the hammer lying on the surface. To achieve maximum flexure requires considerable force which is difficult to maintain. The CDR was able to attain the flexed position and reach the surface, while the LMP did not in at least two of the attempts. (It was not possible to see the LMP's right hand in all attempts.) The LMP used a jumping motion to gain downward momentum and facilitate flexure. Apparently the restraint of the suit was such that sufficient flexing could not be achieved.

It is not known whether such factors as the respective heights (CDR - 5 ft. 9 in.; LMP - 5 ft. 11-1/2 in.), suit fit, or other physical characteristics of the crewmen and/or their suits contributed to the results. However, when such a threshold activity (as this apparently was) is attempted, minor differences show up as important contributors to performance.

c. Conditioning. In a threshold activity, as previously mentioned, small differences are magnified in the performance. While precise data are not available, it has been established that the CDR spent considerable time in testing suit mobility and operational limits, and also trained in the KC-135 at 1/6-g in picking up objects. Included in these conditioning and training exercises were numerous performances of a retrieval such as hammer pickup. This experience was a positive factor in the successful retrieval on the lunar surface.

2. Method Analysis - Given the suit restrictions and relative amount of training referred to above, the methods used by the crewmen are of interest.

a. CDR. The CDR got in position 3 feet from the hammer and down sun. He leaned forward 35° while making two quick hopping motions to move forward a few inches. Then he jumped forward so that his left foot was extended forward and to the left and his right knee touched the surface 5 inches from the hammer. At this point he was at maximum crouch, and leaned right about 40° to reach the hammer. The forward and side lean enabled him to keep the hammer in view the maximum length of time before the grasp. Having gained forward momentum through lean, jump, and crouch, this movement is continued after grasping the hammer. It appears that the forward motion was necessary to keep from falling, such was the extent of lean, both forward and to the side. Since mass governs momentum, this had a stronger effect on the recovery after grasp of hammer than weight, reduced to 1/6-g. The CDR went from 0.7 ft./sec. at point of grasp to 1.5 ft./sec. in 1.5 seconds, nearly straight forward, indicating the acceleration attained. The average velocity for the entire performance was 1.25 ft./sec., the 5 foot distance being covered in 4 seconds. Timing, coordination and adaptability to suit, lunar conditions, etc., must be considered as critical to success. The CDR used a continuous, "swooping" type of motion, with the grasp at the low point of the crouch, and accelerating to regain equilibrium and normal position.

b. LMP. The LMP positioned himself in a line and 40 inches away from the hammer, cross sun, and leaned forward 17°. He then took a short hop and a jump forward with his left foot forward and to the left, even with the hammer. The right knee touched the surface, even with the hammer. The LMP leaned 25° to the right, but there was no forward lean during the grasp attempt, which failed. He then boucned back, his left foot moving back 15 inches right, 12 inches back, then continued to move back about 30 inches for the second attempt. The three other attempts were in the same pattern, except the jump to attain grasp position was higher and more pronounced. On the last attempt, the LMP moved in the opposite direction and between the hammer and tube, then straightened vertically and proceeded on to the right.

It would appear that the LMP had difficulty keeping the hammer in view because he did not lean far enough forward or to the right. While he jumped to flex the suit, he did not "follow through" or continue forward to counteract a forward lean.

3. Conclusion - The methods used by the two crewmen to pick up a dropped hammer were different but the metabolic rates were similar (1098 BTU/hr. for CDR, 1128 for LMP). Analysis indicates that this activity requires maximum flexing of the suit, leaning forward and to the right to see the object, deep crouch on one knee with opposite foot extended, but particularly, continuous forward motion to counterbalance forward lean and facilitate return to normal standing position. The forward and side lean are essential to keep the object in view as long as possible as the move

is made toward it. This type of activity also requires sufficient experience and training to give the crewmen complete feel of the effort and coordination needed for the performance.

B. TWO MAN VERSUS ONE MAN PERFORMANCE OF A SIMILAR TASK (DOUBLE CORE TUBE SAMPLING)

1. Purpose

The purpose of this analysis is to determine if this representative activity, double core tube sampling, can be more efficiently accomplished by one man or by the combined efforts of two men.

2. Sources of Data

The double core tube sampling was performed two times on the Apollo 15 mission and four times on the Apollo 16 mission. On the Apollo 15 mission, the two astronauts on the lunar surface worked together to accomplish this task. On Apollo 16, however, the task was performed by the LMP alone. Of the four performances by the LMP, only two were analyzable.

In the analysis of this task, the part that required hammering was not included. Since hammering is a soil dependent activity, eliminating it made the double core tube sampling performances comparable.

3. Results

The data for this analysis appear in Table 10. On the average, the Apollo 16 performances of this task required 34% less time, in terms of total man-minutes, than the Apollo 15 performances. However, the clock time on Apollo 15 was 24% less (6.27 min. vs. 8.25 min.) because two crewmen were working simultaneously. Also, with two men, the individual energy expenditure rate (BTU/hr.) was about 10% less on the average for Apollo 15.

Table 10
DOUBLE CORE TUBE SAMPLING
APOLLO 15 (TWO MAN TASK) AND APOLLO 16 (ONE MAN TASK)

Trials	Clock Time (min.)	Man-Minutes (min.)	Avg. Tot. Energy Rate (BTU/hr.)	Energy Cost CDR (BTU)	Energy Cost LMP (BTU)	Energy Cost Total (BTU)
Apollo 15 (Two Men)						
#1	6.71	13.42	925	113.3	93.6	206.9
#2	5.83	11.66	803	78.2	77.6	155.8
Average	6.27	12.54	903[1]	95.7	85.6	181.3
Apollo 16 (One Man)						
#1	10.10	10.10	1089	[2]	183.1	183.1
#2	6.46	6.46	839	[2]	90.3	90.3
Average	8.28	8.28	991[1]	[2]	136.7	136.7

[1]Weighted Average

[2]This task was performed by the LMP. Therefore, the CDR has no energy cost charged to this activity.

However, the total energy cost (BTU) for the Apollo 16 performances of this task amounted to an average of 24% less energy required than did the Apollo 15 performances.

4. Conclusion

The single crewman performance during the double core tube sampling required fewer man-minutes and a lower energy cost than the two crewman performance of the same task.

Section VIII
CONCLUDING STATEMENTS

The research presented in this report represents a varied approach to the evaluation of astronaut lunar performance. This was an inevitable outcome of our basic approach -- non-intrusive acquisition of data. The basic source was TV kinescopes. Our data consisted of those elements of astronaut activity which we could see, or document by voice record. Of particular interest were those activities which were repeated either in a single EVA or over several EVAs. Repeated activities enabled us to evaluate both the consistencies and variations in performance. Natural changes in conditions provided an analogue to the experimental intrusion planned by an investigator. This report, then, represents essentially, applied natural research.

Astronaut mobility was evaluated both qualitatively and quantitatively. The two astronauts of Apollo 16 exhibited two sharply divergent methods of locomotion: one a traditional walking mode, the other a skipping, "cantering" activity with one foot always preceding the other. Of significant interest was the fact that both modes were performed at equivalent metabolic expenditure rates (BTU/hr.).

When lunar performance was compared with the last 1-g training performance of the same task, a number of significant results were obtained. Lunar performance took longer but was done at a reduced metabolic rate with the result that the metabolic cost in BTU was only slightly lower for task performance on the moon.

Metabolic adaptation over EVAs and performance trials was clearly exhibited for three different types of tasks ranging from sedentary (Riding the LRV) to very energetic (Hammering).

As on Apollo 15, there were several falls on Apollo 16. On Apollo 15 such falls were strongly associated with the lunar terrain. Falls on Apollo 16, on the other hand, seemed to be related to the unique method of object retrieval and to penetrometer operation.

Additional analyses confirmed the soundness of the decision to utilize one man rather than two (as on Apollo 15) in double core tube sampling. The single crewman required fewer man-minutes and a lower energy expenditure (BTU) than the two-crewman performance of the same task.

The results obtained seem particularly relevant to future mission planning, especially for missions in which astronauts would have to operate under reduced gravity conditions.

Section IX
RECOMMENDATIONS

A. Since the method the astronauts utilized for object retrieval seems promising, a training program (KC-135) should be initiated for those astronauts of Apollo 17 who might be inclined to use it.

B. The slipping of the hammer (or any other object used extensively by the astronauts) could be eliminated by the application of Velcro to glove and hammer. In addition a lanyard attached to the hammer, encircled about the glove, would prevent the fall of the hammer to the lunar surface.

APPENDIX A

EVA TIMELINES - CDR & LMP

CDR - EVA #1

Event	GET[1]	ΔT[2]	GET[1]	ΔT[2]
Start EVA Watch			04:22:52:56	
Pre-Egress			04:23:00:34	7.63
Egress			04:23:03:54	3.33
Familiarization			04:23:05:38	1.73
Deploy TV Camera			04:23:15:03	9.42
Offload LRV			04:23:27:25	12.37
Set Up LRV			04:23:33:18	5.88
Checkout LRV			04:23:40:12	6.90
Offload Far U.V. Camera			04:23:58:34	18.37
Load LRV			05:00:19:15	20.68
Flag Deploy			05:00:26:23	7.13
ALSEP Prep.			05:00:31:05	4.70
Reset Far U.V. Camera			05:00:38:10	7.08
Deploy Cosmic Ray Exp.			05:00:39:11	1.02
Trav. Prep.			05:00:40:56	1.75
Trav. to ALSEP Site[3]			05:00:52:38	11.70
ALSEP Station Tasks:				
ALSEP Site Prep.	05:00:55:12	2.57		
Connect RTG	05:01:07:43	12.52		
Deploy PSE	05:01:20:12	12.48		
Offload Mortar Package	05:01:24:53	4.68		
Remove LSM	05:01:27:00	2.12		
Erect C/S & Assemble & Align Antenna	05:01:43:47	16.78		
Deploy LSM	05:01:52:40	8.88		
Deploy Geophones	05:02:05:40	13.00		
Thumper Geophone Experiment	05:02:22:40	17.00		
Setup Mortar Package	05:02:43:24	20.73		
Doc. Samples	05:02:47:13	3.82		
Trav. Prep.	05:02:56:30	9.28	05:02:56:30	123.87
Trav. to Station #1			05:03:23:54	27.40
Station #1 Tasks:				
Geol. Prep.	05:03:28:28	4.57		
Rake Samples	05:03:36:45	8.28		
Doc. Samples	05:04:09:07	32.37		
Trav. Prep.	05:04:14:05	4.96	05:04:14:05	50.18

[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.

Event	GET	ΔT	GET	ΔT
Trav. to Station #2			05:04:21:10	7.08
Station #2 Tasks:				
Geol. Prep.	05:04:24:38	3.47		
LPM Measurement	05:04:45:50	21.20		
Trav. Prep.	05:04:48:07	2.28	05:04:48:07	26.95
Trav. to Station #3			05:04:54:14	6.12
Station #3 Tasks:				
Photo Prep.	05:04:56:28	2.23		
LRV "Grand Prix" Driving	05:04:59:24	2.93		
Mortar Pack Activation	05:05:06:01	6.62		
Trav. Prep.	05:05:08:00	1.98	05:05:08:00	13.77
Trav. to LM			05:05:10:41	2.68
EVA Closeout:				
Station Prep.	05:05:13:41	3.00		
Closeout Activities	05:05:16:04	2.38		
Reset Far U.V. Camera	05:05:18:20	2.27		
Redeploy CRE	05:05:22:18	3.97		
Closeout Activities	05:05:53:14	30.93		
Reset Far U.V. Camera	05:05:58:14	5.00	05:05:58:14	47.55
EVA Termination			05:06:05:04	6.83

Total EVA #1 - 7 hr. 12.13 min.

LMP - EVA #1

Event	GET	ΔT	GET	ΔT
Start EVA Watch			04:22:52:56	
Pre-Egress			04:23:04:34	11.63
Egress			04:23:05:43	1.15
Familiarization			04:23:15:47	10.07
Offload LRV			04:23:27:17	11.50
Set Up LRV			04:23:32:44	5.45
LM Inspection and Pans			04:23:42:45	10.02
Load LRV			05:00:15:21	32.60
ALSEP Prep.			05:00:23:52	8.52
Flag Deploy			05:00:26:50	2.97
ALSEP Prep.			05:00:33:48	6.97
ALSEP Trav. (Walking Carrying ALSEP Barbell)			05:00:42:45	8.95
ALSEP Tasks:				
HFE Deploy	05:01:21:23	38.63		
Drill Core Sample	05:01:54:12	32.82		
Assist in Geophone Deploy	05:02:00:57	6.75		
ALSEP Photos	05:02:23:38	22.68		
Drill Core Disassemble	05:02:31:28	7.83		
Trav. Prep. and Doc. Samples	05:02:56:30	25.03	05:02:56:30	133.75
Trav. to Station #1			05:03:23:54	27.40
Station #1 Tasks:				
Geol. Prep.	05:03:30:35	6.68		
Rake Samples	05:03:36:59	6.40		
Doc. Samples	05:04:09:07	32.13		
Trav. Prep.	05:04:12:21	3.23	05:04:12:21	48.45
Trav. to Station #2			05:04:21:20	8.98
Station #2 Tasks:				
Geol. Prep.	05:04:24:04	2.73		
Photo Pan and 500mm Photos	05:04:29:54	5.83		
Doc. Samples	05:04:45:56	16.03		
Trav. Prep.	05:04:48:07	2.18	05:04:48:07	26.78
Trav. to Station #3			05:04:54:14	6.12
Station #3 Tasks:				
Photo Prep. and Photo CDR/ LRV "Grand Prix"	05:04:59:24	5.17		
Trav. Prep.	05:05:01:20	1.93	05:05:01:20	7.10
Trav. to LM (Walking)			05:05:02:59	1.65
EVA Closeout			05:05:39:47	36.80
EVA Termination			05:06:05:04	25.28

Total EVA #1 - 7 hr. 12.13 min.

CDR - EVA #2

Event	GET	ΔT	GET	ΔT
Start EVA Watch			05:22:39:25	
Pre-Egress			05:22:44:33	5.14
Egress			05:22:47:05	2.53
Reset Far U.V. Camera			05:23:03:06	16.02
Trav. Prep.			05:23:09:02	5.93
Doc. Samples			05:23:16:22	7.33
Trav. Prep.			05:23:22:33	6.18
Reset Far U.V. Camera			05:23:24:03	1.50
Trav. Prep.			05:23:25:24	1.35
Trav. to Station #4			06:00:09:14	43.83
Station #4 Tasks:				
Geol. Prep.	06:00:13:39	4.42		
Geol. Description	06:00:16:51	3.20		
Rake Samples	06:00:24:06	7.25		
Doc. Samples	06:00:35:31	11.42		
Trenching	06:00:38:01	2.50		
Doc. Samples	06:00:51:37	13.60		
Rake Samples	06:00:56:36	4.98		
Trav. Prep.	06:01:02:20	5.73	06:01:02:20	53.10
Trav. to Station #5			06:01:10:58	8.63
Station #5 Tasks:				
Geol. Prep.	06:01:16:21	5.38		
Rake Samples	06:01:41:27	25.10		
LPM Measurement & Samples	06:01 53:42	12.25		
Trav. Prep.	06:01:57:42	4.00	06:01:57:42	46.73
Trav. to Station #6			06:02:08:16	10.57
Station #6 Tasks:				
Geol. Prep.	06:02:12:18	4.03		
Doc. Samples	06:02:24:27	12.15		
Trav. Prep.	06:02:26:15	1.80	06:02:26:15	17.98
Trav. to Station #8			06:02:41:15	15.00
Station #8 Tasks:				
Geol. Prep.	06:02:44:42	3.45		
Rake Samples	06:02:53:16	8.57		
Doc. Samples	06:02:59:43	6.45		
LRV Troubleshooting and Repositioning	06:03:07:54	8.18		
Doc. Samples	06:03:33:34	25.67		
Trav. Prep.	06:03:47:05	13.52	06:03:47:05	65.84
Trav. to Station #9			06:03:53:48	6.72
Station #9 Tasks:				
Geol. Prep.	06:03:58:24	4.60		
Doc. Samples	06:04:19:56	21.53		
Trav. Prep.	06:04:28:11	8.25	06:04:28:11	34.38

Event	GET	ΔT	GET	ΔT
Trav. to Station #10			06:04:54:51	26.67
Station #10 Tasks:				
Geol. Prep.	06:05:00:26	5.58		
Double Core	06:05:10:11	9.75		
Doc. Samples and Photo Pan	06:05:21:08	10.95		
Trav. Prep.	06:05:21:50	.70	06:05:21:50	26.98
Trav. to LM			06:05:24:08	2.30
EVA Closeout:				
Reset Far U.V. Camera	06:05:27:36	3.47		
Closeout Activities	06:05:49:43	22.12		
Reset Far U.V. Camera	06:05:51:19	1.60		
Closeout Activities	06:05:58:38	7.32	06:05:58:38	36.81
EVA Termination			06:06:02:34	3.93

Total EVA #2 - 7 hr. 23.15 min.

LMP - EVA #2

Event	GET	ΔT	GET	ΔT
Start EVA Watch			05:22:39:25	
Pre-Egress			05:22:48:03	8.63
Egress			05:22:49:29	1.43
Trav. Prep.			05:23:26:32	37.05
Trav. to Station #4			06:00:09:14	42.70
Station #4 Tasks:				
Geol. Prep.	06:00:12:56	3.70		
500mm Photos	06:00:16:49	3.88		
Rake Samples	06:00:24:06	7.28		
Penetrometer	06:00:37:09	13.05		
Double Core	06:00:48:51	11.70		
Rake Samples	06:00:56:25	7.57		
Photo Pan	06:00:58:09	1.74		
Trav. Prep.	06:01:01:29	3.33	06:01:01:29	52.25
Trav. to Station #5			06:01:11:16	9.78
Station #5 Tasks:				
Geol. Prep.	06:01:17:02	5.77		
Rake Samples	06:01:41:18	24.27		
Doc. Samples	06:01:50:46	9.47		
Trav. Prep.	06:01:56:47	6.02	06:01:56:47	45.53
Trav. to Station #6			06:02:08:13	11.43
Station #6 Tasks:				
Geol. Prep.	06:02:12:07	3.90		
Doc. Samples	06:02:24:27	12.33		
Trav. Prep.	06:02:25:58	1.52	06:02:25:58	17.75
Trav. to Station #8			06:02:41:15	15.28
Station #8 Tasks:				
Geol. Prep.	06:02:43:23	2.14		
Double Core	06:03:02:01	18.63		
LRV Troubleshooting & Walk to a New Sampling Site	06:03:06:48	4.78		
Doc. Samples	06:03:33:34	26.77		
Trav. Prep.	06:03:45:45	12.18	06:03:45:45	64.50
Trav. to Station #9			06:03:53:48	8.05
Station #9 Tasks:				
Geol. Prep.	06:03:55:21	1.55		
500mm Photos	06:03:56:45	1.40		
Single Core	06:04:14:31	17.77		
Doc. Samples	06:04:19:43	5.20		
Trav. Prep.	06:04:27:30	7.78	06:04:27:30	33.70

Event	GET	ΔT	GET	ΔT
Trav. to Station #10			06:04:54:51	27.35
Station #10 Tasks:				
Geol. Prep.	06:05:02:21	7.50		
Penetrometer	06:05:18:15	15.90		
Trav. Prep.	06:05:20:40	2.42	06:05:20:40	25.82
Trav. to LM (Walking)			06:05:21:28	.80
EVA Closeout			06:05:47:50	26.37
EVA Termination			06:06:02:34	14.73

Total EVA #2 - 7 hr. 23.15 min.

CDR - EVA #3

Event	GET	ΔT	GET	ΔT
Start EVA Watch			06:21:27:18	
Pre-Egress			06:21:36:03	8.75
Egress			06:21:39:45	3.70
LRV Load Trav. Prep.			06:22:00:34	20.82
Reset Far U.V. Camera			06:22:03:44	3.17
Trav. Prep.			06:22:04:35	.85
Trav. to Station #11			06:22:45:09	40.57
Station #11 Tasks:				
Geol. Prep.	06:22:48:41	3.53		
Geol. Description & Samples	06:22:56:27	7.77		
Doc. Samples	06:23:19:17	22.83		
Rake Samples	06:23:40:59	21.70		
Doc. Samples at "House Rock"	06:23:55:36	14.62		
Samples and Trav. Prep.	07:00:08:58	13.37	07:00:08:58	83.82
Trav. to Station #13			07:00:17:39	8.68
Station #13 Tasks:				
Geol. Prep.	07:00:21:43	4.06		
Rake Samples	07:00:27:31	5.80		
LPM Measurements	07:00:42:53	15.37		
Trav. Prep.	07:00:46:33	3.67	07:00:46:33	28.90
Trav. to Station #10'			07:01:15:38	29.08
Station #10' Tasks:				
Geol. Prep.	07:01:22:02	6.40		
Rake Samples	07:01:35:51	13.82		
Double Core	07:01:38:27	2.60		
Doc. Samples	07:01:42:43	4.27		
Trav. Prep.	07:01:48:39	5.93	07:01:48:39	33.02
Trav. to LM			07:01:51:05	2.43
EVA Closeout:				
Closeout Activities	07:01:55:16	4.18		
Reset Far U.V. Camera	07:01:57:03	1.78		
Closeout Activities	07:02:03:16	6.22		
Retrieve Cosmic Ray Exp.	07:02:14:11	10.92		
Closeout Activities	07:02:22:43	8.53		
Park LRV	07:02:27:09	4.43		
Closeout Activities	07:02:37:27	10.30		
LPM Measurements	07:02:48:20	10.88		
Closeout Activities	07:03:01:23	13.05		
Remove Far U.V. Camera Film Mag.	07:03:02:11	.80		
Closeout Activities	07:03:07:40	5.48	07:03:07:40	76.58
EVA Termination			07:03:11:20	3.67

Total EVA #3 - 5 hr. 44.03 min.

LMP - EVA #3

Event	GET	ΔT	GET	ΔT
Start EVA Watch			06:21:27:18	
Pre-Egress			06:21:39:22	12.07
Egress			06:21:39:55	.55
LRV Load and Trav. Prep.			06:22:04:28	24.55
Trav. to Station #11			06:22:45:09	40.68
Station #11 Tasks:				
Geol. Prep.	06:22:48:52	3.72		
Photo Pan and Geol. Description	06:23:07:24	18.53		
Doc. Samples	06:23:12:42	5.30		
500mm Photos	06:23:16:01	3.32		
Doc. Samples	06:23:29:56	13.92		
Rake Samples	06:23:40:59	11.05		
Doc. Samples at "House Rock"	06:23:55:36	14.62		
Samples and Trav. Prep.	07:00:08:58	13.37	07:00:08:58	83.82
Trav. to Station #13			07:00:17:39	8.68
Station #13 Tasks:				
Geol. Prep.	07:00:18:56	1.28		
Photo Pan and Geol. Description	07:00:22:55	3.98		
Rake Samples	07:00:27:31	4.60		
Doc. Samples	07:00:42:04	14.56		
Trav. Prep.	07:00:46:33	4.48	07:00:46:33	28.90
Trav. to Station #10'			07:01:15:38	29.08
Station #10' Tasks:				
Geol. Prep.	07:01:20:52	5.23		
Rake Samples	07:01:34:43	13.85		
Double Core	07:01:42:43	8.00		
Trav. Prep.	07:01:43:49	1.10	07:01:43:49	28.18
Trav. to LM (Walking)			07:01:44:41	.87
EVA Closeout			07:02:59:37	74.93
EVA Termination			07:03:11:20	11.72

Total EVA #3 - 5 hr. 44.03 min.

APPENDIX B

DETAILED ANALYSES OF THREE MOBILITY SEGMENTS

EVA 1 - ALSEP Traverse

Detailed analysis of certain segments of this traverse are given below. Reference time refers to the cumulative time in Table 1, Section II.

Segment 1- Move from LM toward ALSEP site with ALSEP package. Stopped to adjust package. Left foot leading, kicked up soil.

Distance - 10.2 ft.

Time - 4.75 sec.

Rate - 2.15 ft./sec.

Segment 2 - LMP started, after stop to adjust package.

Initial stride, with right foot first. Leaned forward.

Distance - 1.6 ft.

Time - 2.1 sec.

Rate - .76 ft./sec.

Continue to move with ALSEP package.

Distance - 8.7 ft.

Time - 5.3 sec.

Avg. Rate - 1.64 ft./sec.

Max. Rate - 2.08 ft./sec.

Segment 3 - LMP entered field of view while carrying ALSEP package to site location. This was a continuation of segments 1 and 2 above, but portions were lost due to TV camera not following in synchronization. This segment ends with ALSEP Package #2 coming loose and dropping to the surface.

A significant feature of this Segment 3 is that the left foot frequently trailed the right in a "canter" type of motion. Column 5 in the following table shows the respective right and left foot distances as each was placed in advance of the other. Note the generally shorter step distance for the left foot.

Successive stride[1] lengths, times, and rates, plus the foot advance distances, are as shown.

Col. 1 Step	Col. 2 Stride Distance (ft.)	Col. 3 Time (sec.)	Col. 4 Rate (ft./sec.)	Col. 5 Step Distance (ft.)
1. Right	1.60	.67	2.4	1.60
2. Left	2.73	1.46	1.9	1.13
3. Right	3.15	1.50	2.1	1.92
4. Left	2.12	1.34	1.6	0.20
5. Right	2.18	1.38	1.6	1.98
	(ALSEP RTG package starts to fall.)			
6. Left	2.18	1.36	1.6	0.18
7. Right	.87	1.09	0.8	0.69
8. Left	.80	1.17	0.7	0.11
9. Right	1.28	1.28	1.0	1.17
10. Left (stop)	2.75	1.16	2.4	1.58
	(ALSEP RTG package hits surface.)			

Summary of Segment 3 data:

Distance - 10.58 ft. (based on left foot)

Time - 6.49 sec.

Rate - 1.63 ft./sec.

LMP stops with left foot on surface.

Right leg reacts, does kicking type motion to about a 35-40° angle to front and side, and comes back to surface in about one (1) sec. LMP continues to react to RTG package falling at this point with the left foot moving out to his left, and by a bouncing type motion. LMP returned

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[1] Stride: Distance moved by one foot from one stopped position to the next.

both feet to surface at about the same position they were in just before "stop" (#10) shown above. This reaction took about 1.5 seconds. Another 3.5 seconds were used by LMP to regain balance, make a 90° turn to his right to face package, and prepare to approach it.

The last three or four steps (#7-10 incl.) reflect the effect of the RTG package dropping off. The pace up to this point was averaging between 1.6 and 2.0 ft./sec., but considerable bouncing, and kicking of soil, was evident. The load of 41.5 pounds moon weight (ALSEP packages of approximately 21 lbs. each) evidently reduced the velocity and mobility of the LMP. This event (package dropping), however, demonstrates the ability of crewmen to react promptly, and without disability, to anomalies in load.

EVA 2 - <u>CDR Traverse Down Rim of Cinco B Crater</u>

At 2.25 hours into EVA 2 (start at 06:00:55:12 GET) both crewmen were at Station 4, Cinco B, at a location approximately 135 feet south (at 7 o'clock) of the LRV which is inside of the crater. The crewmen had just completed sample collection, and started for the LRV, when this mobility segment began. Detail data are as follows:

1. <u>General</u> - CDR moves toward LRV (and camera) from just over ridge of crater, making a curving path which increased the straight-line distance by an estimated 15%. The path was down a slope of approximately 10° with the surface also sloping to the CDR's left about 10°. The area was covered with rocks of various sizes up to 3 feet across.

2. <u>Location</u> - Station 4, Cinco B Crater, traverse from a point approximately 135 feet to the south (7 o'clock) of the LRV to the LRV, sloping downhill, 10°.

3. Mode - Walk, generally even steps, with characteristic widespread stance and a bouncing motion. Carrying rake and gnomon, one in each hand. These tools, about 32 and 38 inches long respectively, had to be held by the CDR with his arms extended almost horizontally in front of him.

4. Rate - Distance traveled was 169 feet in 76 seconds at 2.22 ft./sec. Took 81 steps for an average distance of 2.09 ft./step, or an average stride of 4.18 feet.

5. Comment - The average rate is consistent with other traverses of longer distances. CDR used a more conventional walk pace, rather than the hopping-type pace used by most astronauts. The fact that the CDR had to carry the rake and gnomon, both fairly long, held out in front of him, probably slowed the rate of traverse. It is apparent that this and the rocky downhill slopes caused the CDR to exercise a greater degree of caution in this traverse than over a nominal, level, uncluttered area, while not carrying anything. Under the latter conditions, a 15% to 20% increase might be attained. The LMP came toward the camera at the same time (both were in the picture), and used a distinct hop or canter-type motion, with one foot always in front. The latter kicked up more soil than the CDR, who used the 1/6-g to advantage by using a "bounce" with many of his steps. It is apparent that both modes of traverse may be used effectively, depending on the individual crewmember.

EVA 3 - CDR on Traverse to House Rock at Station 11

At 2 hours and 20 minutes into EVA 3, while at Station 11, the crewmen traversed from the site of sample collection #388 to a large rock known as House Rock. The GET was 06:23:41:00 at start of traverse. The distance traveled was 258 feet in a northeast direction, across relatively smooth, level terrain, which contained scattered large rocks. There was a gradual downward slope near the rock. The CDR followed a "wandering" route which added about 15% to the straight-line distance. The nature of this terrain presented no mobility difficulty and the CDR was able to move in a walking-type gait at about 3.0 ft./sec.

1. Location - Station 11, approaching House Rock, located about 475-500 feet to the northeast of the LRV. The path followed by the CDR (and LMP) was from the site of sample #388, located about 220 feet northeast of the LRV.

2. Mode - CDR used walk, with generally even steps, widespread stance, and bouncing motion. This mode resulted in a minimum of soil kicking and breaking of stride. The CDR also was not carrying any tools or other equipment.

3. Rate - Distance traveled was 297 feet in 99 seconds for an average rate of 3.0 ft./sec. Average length of step was 2.28 feet. The average length of stride was 4.56 feet. Metabolic rate for CDR during this traverse was 1112 BTU. The LMP accomplished essentially the same traverse (distance, rate, etc.), but used more of the "hop" or "canter" type of motion, which resulted in more dirt kicking. His metabolic rate for this segment was 1185 BTU/hr.

4. Comment - This traverse represented the highest mobility rate yet maintained for any significant distance. Here the conditions were favorable to such a traverse, and the incentive to reach one of the most significant geological sites of any EVA, also influenced the successful accomplishment. It is noteworthy that the BTU rates are just about normal for walking activity.

APPENDIX C

TIME COMPARISONS OF SUB-TASKS

TIME COMPARISONS OF SUB-TASKS

Sub-task (Commander)	1-G Training 2/24 (A)	3/29 (B)	4/11 (C)	EVA 1 4/21 (D)	Ratio (D/C)	EVA Data Source
Checkout LRV						
Mount and test drive LRV	N/D	3.37	3.20	6.54[1]	2.04	V
Offload Far U.V. Camera						
1. Remove camera from LM and carry to deployment site	3.90	3.20	2.60	4.80	1.85	V
2. Deploy camera & battery on surface	1.75	1.40	1.90	2.68	1.41	V
3. Level and aim camera	4.15	3.80	4.25	9.67[2]	2.30	V
Flag Deploy						
1. Unstow and assemble flag	2.10	2.00	1.80	3.58	1.99	TV
2. Deploy flag on surface	.55	.35	.55	.92	1.67	V
3. Photography at flag	1.36	1.55	.85	1.12	1.32	TV
Connect RTG						
1. Connect RTG cable to central station (C/S).	2.90	2.20	2.30	5.93[3]	2.58	V
2. Remove subpallet and PSE stool from Package 2.	3.70	4.95	3.60	5.21	1.45	VTV

[1]CDR did considerably more driving inflight than during training.

[2]Inflight aiming procedures were different and more time-consuming than the aiming procedures used in training.

[3]CDR commented that he had considerable difficulty connecting the RTG cable to the C/S.

N/D - No Data

V - Voice

TV - Television

NOTE: All times are in decimal minutes.

TIME COMPARISONS OF SUB-TASKS (continued)

Sub-task (Commander)	1-G Training 2/24 (A)	3/29 (B)	4/11 (C)	EVA 1 4/21 (D)	Ratio (D/C)	EVA Data Source
Deploy PSE						
1. Deploy and level PSE	6.40	4.45	4.00	8.47	2.12	V
2. Remove & deploy thumper geophone (T/G)	1.90	1.45	.90	2.23[4]	2.48	VTV
Offload Mortar Package						
Remove and deploy mortar package (M/P)	2.40	2.45	2.00	2.38	1.19	TV
Assemble and Align Antenna						
Activate C/S	.50	N/D	.45	.98	2.18	V
Deploy LSM						
1. Carry LSM to deploy site	N/D	1.85	1.55	1.80	1.16	TV
2. Deploy and align LSM	N/D	3.55	2.50	4.72	1.89	VTV
Active Seismic Experiment						
T/G firing	N/D	11.10	12.00	14.95[5]	1.24	VTV
Set Up Mortar Package						
1. Carry M/P to deploy site & set on surface	N/D	1.40	1.10	6.27[6]	5.70	VTV
2. Deploy M/P	N/D	1.60	.95	1.76	1.85	VTV
3. Place M/P in base	N/D	1.05	1.75	3.75	2.14	VTV

[4]CDR had difficulty with the T/G cable reel tension. (The tension was so great that it caused the C/S to move when the CDR pulled on the T/G.)

[5]Inflight the CDR had to wait for the LMP to stop moving before every thumper firing. During training this procedure was not rigorously followed.

[6]CDR had considerable problems deploying the M/P base legs.

TIME COMPARISONS OF SUB-TASKS (continued)

Sub-task (Lunar Module Pilot)	1-G Training 2/24 (A)	3/29 (B)	4/11 (C)	EVA 1 4/21 (D)	Ratio (D/C)	EVA Data Source
<u>LM Inspection & Pans</u>						
Photo LM	5.52	5.15	3.15	10.02[1]	3.24	V
<u>Load LRV</u>						
1. Load LCRU & HGA on LRV	9.83	11.93	13.10	12.83[2]	.98	V
2. Load & configure TV camera on LRV	N/D	4.52	4.55	5.62[3]	1.24	V
<u>Deploy HFE</u>						
Obtain & configure ALSD	3.65	N/D	3.68	5.27	1.43	TV
<u>Bore Hole 1 Drilling</u>						
1. Assemble bore stems onto drill	N/D	N/D	.95	3.44[4]	3.63	TV
2. Drill 1st bore stem into surface	N/D	3.88	2.34	1.20[5]	.51	TV
3. Assemble 2nd bore stem onto drill	N/D	N/D	1.37	3.20[4,5]	2.34	TV

[1] LMP was required to take many more photographs than was planned and practiced in training.

[2] LMP had difficulty locking the HGA dish.

[3] In training the TV camera was on a tripod at 12:00/50'. Inflight the TV camera was obtained from the MESA.

[4] LMP had considerable difficulty inserting the bore stem into the drill chuck.

[5] The differences in soil characteristics between the training site and the lunar surface make these activities noncomparable.