# METABOLIC COST OF EXTRAVEHICULAR ACTIVITIES

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## ABSTRACT

The data on metabolic rates during Skylab extravehicular activities are presented and compared with prior experience during Gemini and Apollo. Difficulties experienced with Gemini extravehicular activities are reviewed. The effect of a pressure suit on metabolic rate is discussed and the life support equipment capabilities of each life support system are reviewed. The methods used to measure metabolic rate, utilizing bioinstrumentation and operational data on the life support system, are described. Metabolic rates are correlated with different activities. Metabolic rates in Skylab were found to be within the capacities of the life support systems and to be similar to the metabolic rates experienced during Apollo lunar 1/6-g extravehicular activities. They were found to range from 100 kcal/h to 500 kcal/h, during both 1/6-g and zero-g extravehicular activities. The average metabolic rates measured during long extravehicular activities were remarkably consistent and appeared to be a function of crew pacing of activity rather than to the effort involved in individual tasks.

## INTRODUCTION

The prospect of pressure suit operations outside of space vehicles and on the lunar surface was the source of much speculation prior to Gemini. Prediction varied from the prospect of almost effortless activity to the fear that without the stabilization provided by Earth gravity useful activity would be very difficult. The Skylab zero-g extravehicular activity data is of particular interest when it is considered in combination with the Apollo and Gemini data. This paper covers the energy cost of extravehicular activity from Gemini through Skylab.

### Gemini

A summary of the Gemini extravehicular activities, their length, the difficulties experienced by the crewmen, and the average and peak heart rates, is presented in table I. There was no attempt to measure metabolic rates. It was apparent that on several occasions, the metabolic rates were above the capacity of the life support systems, both for thermal control and carbon dioxide washout.

TABLE I. GEMINI EXTRAVEHICULAR ACTIVITY EXPERIENCE

5 Gemini extravehicular activity missions - 6 hours total extravehicular activity time

| Flight | Experience | Duration (hours) | Heart Rates (beats per minute) $\bar{x}$ | Peak |
|---|---|---|---|---|
| Gemini 4 | Overheating during hatch closing - objectives completed | 0.60 | 155 | 175 |
| Gemini 9 | Visor fogging - hot at ingress - objectives incompleted | 2.11 | 155 | 180 |
| Gemini 10 | No problem with heat or work rate - objectives completed | 0.65 | 125 | 165 |
| Gemini 11 | Exhausting work - no specific mention of heat - objectives incompleted | 0.55 | 140 | 170 |
| Gemini 12 | Good restraints - no problems - objectives completed | 2.10 | 110 | 155* 130 |

Metabolic rates - not determined but in excess of life support system capability at times

*Voicing a message to Houston

The energy cost of extravehicular activities is dependent to a large extent on the pressure suit and life support system. The Gemini pressure suit had a fixed resting position and had minimum mobility for extravehicular activity. Considerable energy was expended working against the suit. The heat removal capacity of the life support system was limited physically to about 225 kcal/h in Gemini 4. The gas cooling life support system used on the later Gemini units had an increased physical capacity, but at acceptable body temperatures the system was limited to about 250 kcal/h. The emphasis in the earlier Gemini extravehicular activities was in the use and evaluation of propulsive maneuvering units. Beginning with Gemini 12 increased emphasis was placed on extravehicular activity technology and improved restraint and systems. In summary, the Gemini Program indicated that extravehicular activities could be much more difficult and physically taxing than had been anticipated and that more emphasis should be placed in crew training and restraint technology.

## Apollo

The lunar portion of the Apollo Program presented entirely different extravehicular activity problems, *i.e.,* 1/6-g and an unknown terrain. The effect of 1/6-g on the cost of work in a pressure suit had been investigated by several researchers using 1/6-g simulators (1, 2, 3). Indications were that the cost of walking would be reduced while the cost of other activities would be increased; however, the results and conclusions were by no means uniform. An additional factor of uncertainty was the terrain and surface composition of the moon and its effect on the metabolic cost of walking. In response to these uncertainties, conservative biomedical estimates of the life support requirements were defined based on the available data, and methods to measure metabolic rate during the extravehicular activities were developed utilizing operational data from the life support system and bioinstrumentation.

To handle high workloads during Apollo extravehicular activities and the resulting high heat production in the suit, a liquid cooling system was used. The liquid cooled garment used in this system could suppress sweating at work rates up to 400 kcal/h and allow sustained operations at rates as high as 500 kcal/h without thermal stress.

Real-time estimates of metabolic rate were made during the lunar surface extravehicular activities using three parameters: oxygen bottle pressure, the heat removal by the liquid cooled garment, and heart rate. The noise experienced in the telemetered oxygen-bottle-pressure data made it difficult to obtain reliable oxygen utilization rates for time periods of less than 30 minutes, particularly at low metabolic rates. The oxygen utilization rates included the suit leakage which had to be estimated. The maximum leakage rate of oxygen allowed by the pressure suit specification was equivalent to a metabolic rate of approximately 50 kcal/h.

Because of the limitations of the oxygen-bottle-pressure method, correlation of liquid cooled garment data to metabolic rate was also used during the mission. Using a thermoregulatory mathematical model and empirical data on the liquid cooled garment, a relationship was defined between liquid cooled garment heat removal and metabolic rate for each liquid cooled garment inlet temperature. This method was verified with test data obtained during altitude chamber training.

Correlations between heart rate and metabolic rate were obtained for each individual from a series of preflight exercise response tests on the ergometer. The heart rate method was used only as a relative measurement because of its known sensitivity to psychological and environmental factors. The heart rate method, however, when related to total energy expenditure as determined by oxygen and liquid cooled garment methods, permitted an estimate of the cost of specific activities on a minute-by-minute basis.

The average metabolic rates experienced during these extravehicular activities, as shown in table II, were lower than had been predicted prior to Apollo, and the crewmen were able to move easily and confidently on the lunar surface. Within the operational classification of activities the most energy consuming were those classified as overhead. These activities included egress, offloading and setup of equipment around the lunar module vehicle, and ingress and stowage of lunar samples. The highest metabolic rates experienced during the performance of discrete activities (350-450 kcal/h) were associated with steep uphill walking traverses, transporting of the Apollo Lunar Scientific Experiment Package pallet, ingressing the lunar module with lunar samples, drilling, and removing of drill bits. The Apollo Lunar Scientific Experiment Package deployment and geologic survey activities resulted in lower metabolic rates than the overhead activity. These activities as a group were less predictable and required more time for judgment and in some cases for precise manual manipulation. The lowest metabolic rates and the most clearly defined operation activity was observed while riding the Lunar Rover. The metabolic rates for this activity approached rates reported for shirtsleeve riding in an automobile.

The highest average rate of 300 kcal/h was experienced by the Lunar Module Pilot on Apollo 11. This crewman had been assigned to the task of evaluating modes of locomotion during what was the shortest extravehicular activity, and he was quite active in performing this task. Several crewmen experienced the minimum average metabolic rates of approximately 200 kcal/h on different missions.

TABLE II. APOLLO LUNAR SURFACE EXTRAVEHICULAR ACTIVITIES

| Flight | EVA | Crewman | Scientific Package Deployment | Geological Station Activity | Overhead | Lunar Rover Vehicle Operations | All Activities | EVA Duration (hours) |
|---|---|---|---|---|---|---|---|---|
| Apollo 11 | 1 | Armstrong | 195 | 244 | 214 | --- | 227 | |
| | | Aldrin | 302 | 351 | 303 | --- | 302 | 2.43 |
| Apollo 12 | 1 | Conrad | 206 | 243 | 294 | --- | 246 | |
| | | Bean | 240 | 245 | 267 | --- | 252 | 3.90 |
| | 2 | Conrad | --- | 218 | 215 | --- | 221 | |
| | | Bean | --- | 253 | 248 | --- | 252 | 3.78 |
| Apollo 14 | 1 | Shepard | 182 | 294 | 220 | --- | 202 | |
| | | Mitchell | 226 | 174 | 259 | --- | 234 | 4.80 |
| | 2 | Shepard | 118 | 238 | 214 | --- | 229 | |
| | | Mitchell | 203 | 267 | 213 | --- | 252 | 3.58 |
| Apollo 15 | 1 | Scott | 282 | 275 | 338 | 152 | 276 | |
| | | Irwin | 327 | 186 | 293 | 104 | 246 | 6.53 |
| | 2 | Scott | 243 | 293 | 287 | 149 | 253 | |
| | | Irwin | 265 | 189 | 266 | 99 | 204 | 7.22 |
| | 3 | Scott | 261 | 242 | 311 | 138 | 260 | |
| | | Irwin | 230 | 188 | 234 | 107 | 204 | 4.83 |
| Apollo 16 | 1 | Young | 207 | 216 | 273 | 173 | 220 | |
| | | Duke | 258 | 268 | 275 | 159 | 255 | 7.18 |
| | 2 | Young | --- | 223 | 249 | 112 | 198 | |
| | | Duke | --- | 244 | 236 | 105 | 208 | 7.38 |
| | 3 | Young | --- | 231 | 235 | 124 | 205 | |
| | | Duke | --- | 242 | 264 | 103 | 208 | 5.67 |
| Apollo 17 | 1 | Cernan | 285 | 261 | 302 | 121 | 275 | |
| | | Schmitt | 278 | 300 | 285 | 113 | 272 | 7.20 |
| | 2 | Cernan | --- | 261 | 302 | 121 | 207 | |
| | | Schmitt | --- | 300 | 285 | 113 | 210 | 7.62 |
| | 3 | Cernan | --- | 261 | 302 | 121 | 234 | |
| | | Schmitt | --- | 300 | 285 | 113 | 237 | 7.25 |
| | Average | | 244 | 244 | 270 | 123 | 234 | |
| Total Time (hours) | | | 28.18 | 52.47 | 52.82 | 25.28 | 158.74 | |

Particular efforts were made to relate walking speed to metabolic rate during Apollo 14 which included the most extensive walking traverses. The data are presented in figure 1.

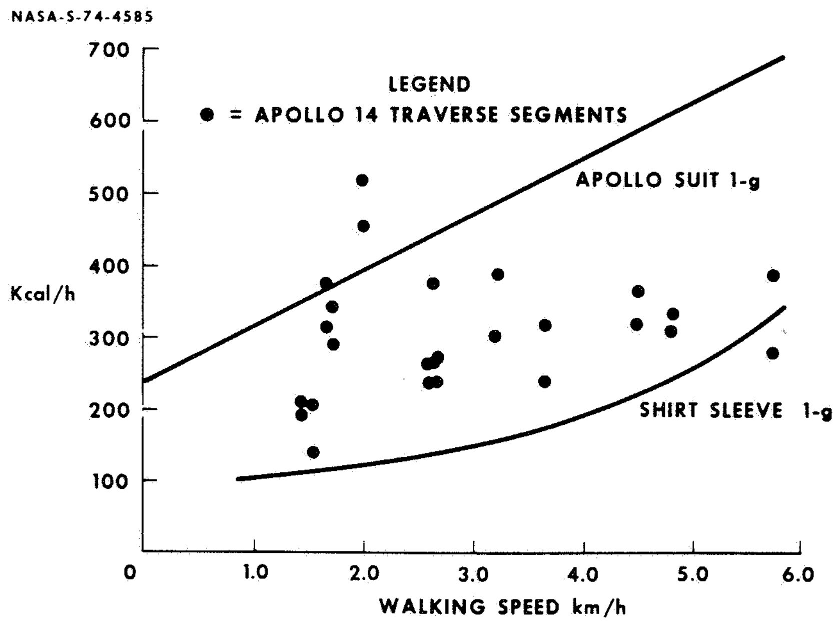


Figure 1. - Metabolic cost of lunar walking.

The data exhibited a very poor correlation between traverse rate and metabolic rate. During these operational traverses it appeared that the crewman maintained a comfortable walking effort and to a large extent the rate of travel at this level of effort varied with the terrain and the requirements of each traverse. The average speed for the 2.9 kilometers covered was 2.4 km/h at a metabolic rate of 300 kcal/h. The speed and efficiency of lunar walking were both greater than could be achieved wearing a pressure suit at one-g while neither speed nor efficiency was the equivalent of shirtsleeve operation at one-g.

A time and motion study (4 and 5 ) was carried out on Apollo 15 and 16 utilizing operation motion picture film and kinescope. This study compared the facility and energy cost of performing several specific activities at one-g during suited training and at 1/6-g on the lunar surface. One of the observations of this study was that manipulative tasks were completed more rapidly at one-g than at 1/6-g, but at greater metabolic cost.

In addition to the 14 lunar surface extravehicular activities, there were 4 zero-g extravehicular activities. The first was a standup extravehicular activity on Apollo 9 utilizing a portable life support system and on this extravehicular activity we have data (table III) similar to that obtained during the lunar surface extravehicular activities. During the Command Module extravehicular activities of Apollo 15, 16, and 17 the only data available were the heart rates. The metabolic rates estimated from heart rate were not used to constrain these extravehicular activities and it appears that in some cases the heart rates were elevated due to psychogenic causes.

TABLE III. APOLLO ZERO-G EXTRAVEHICULAR ACTIVITIES

| Flight | Crewman | Metabolic Rate (kcal/h) | Duration-hours |
|---|---|---|---|
| Apollo 9 | Schewickart | 151 | 0.98 |
| Apollo 15 | Worden | <237 | 0.66 |
| | Irwin* | <117 | 0.66 |
| Apollo 16 | Mattingly | <504 | 1.41 |
| | Duke* | not measured | 1.41 |
| Apollo 17 | Evans | <302 | 1.11 |
| | Schmitt* | <143 | 1.11 |
| | | Total Time (hours) | 7.38 |

*Standup extravehicular activities

## Skylab

Despite the large quantity of 1/6-g extravehicular activity data collected during Apollo, when the Skylab Program began, the experience with zero-g was limited to six hours of Gemini experience during which considerable difficulty was encountered and four hours of Apollo Command Module extravehicular activity consisting of a standup extravehicular activity and three repetitions of a comparatively simple film retrieval task. The original extravehicular activities planned for Skylab were six 3- to 4-hour extravehicular activities primarily to replace film in the ATM cameras. The umbilical life support system of Skylab had a heat removal capability equivalent to the Apollo portable life support system. The metabolic rate data were limited to the liquid cooled garment data and the heart rate data because of the different life support system. The correlation of heart rate and metabolic rate was based on the most recent in-flight experiment M171 bicycle ergometer test. The Skylab data are presented in table IV.

TABLE IV. SKYLAB EXTRAVEHICULAR ACTIVITIES

Metabolic Rates

| Mission | Duration (hours) | Metabolic Rate (kcal/h) CDR | PLT | SPT |
|---|---|---|---|---|
| SL2 EVA-1 (Gas cooling only) | 0.61 | | 330 | 260 |
| SL2 EVA-2 | 3.38 | 315 | | 265 |
| SL2 EVA-3 | 1.56 | 280 | | |
| SL3 EVA-1 | 6.51 | | 265 | 240 |
| SL3 EVA-2 | 4.51 | | 310 | 250 |
| SL3 EVA-3 (Gas cooling only) | 2.68 | 225 | | 180 |
| SL4 EVA-1 | 6.56 | | 230 | 250 |
| SL4 EVA-2 | 6.90 | 155 | 205 | |
| SL4 EVA-3 | 3.46 | 145 | | 220 |
| SL4 EVA-4 | 5.31 | 220 | | 185 |
| Total Time | 83.6 h | $\bar{x}$ 230 kcal/h | | |

The first Skylab extravehicular activities were done to deploy the solar panels. After success was achieved, and a considerable capability to perform work in zero-g was demonstrated, the number of extravehicular activities was increased to 10 and the duration of these extravehicular activities was lengthened. These additions included the deployment of the solar panels, erection of a solar canopy, repair of an Earth resource antenna, replacement of a gyro six-pack and other vehicle and experiment repairs. An additional extravehicular activity was done to make observations on the Comet Kohoutek. Because of problems with one of the vehicle coolant loops all three crewmen operated from a single coolant supply but the comfort cooling capacity at the loops remained at about 400 kcal/h steady-state. No problems were experienced from overheating. Because of the problem with the vehicle coolant system, the last extravehicular activity on Skylab 3 was conducted with gas cooling only. It was of limited scope and duration and no problems were experienced.

The metabolic rates were similar to those on the Apollo 1/6-g extravehicular activities. The highest metabolic rate, 500 kcal/h, was reached while the Commander on Skylab 2 was trying to cut a strap that was keeping the solar panels from deployment. The lowest rates were resting rates and these were reached several times during the extravehicular activities, particularly at the times when there was not enough light to continue an ongoing activity during a night pass. Crew comments during extravehicular activities indicated that it was easier to maneuver themselves and their equipment in zero-g than in water tank simulations, but that adequate restraints were even more important.

## CONCLUSIONS

° With adequate life support equipment and adequate restraints the capability was demonstrated to perform varied and extensive extravehicular activity tasks both in zero-g and 1/6-g with considerable real-time flexibility.

° The capability to work at relatively high levels, up to 500 kcal/h, when required was demonstrated without physiologic problems provided the life support capability is adequate.

° The average energy cost of long extravehicular activities was remarkably consistent at about 200 to 250 kcal/h, and appears to be a function of the crew pacing its activity rather than to the effort involved in performing individual tasks.

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