NASA/TP–2011–216151

Apollo Extravehicular Activities Video and Data Archives: Stumbling, Locomotive Velocity, and Metabolic Rates

Melissa Scott-Pandorf, PhD
Wyle Integrated Science and Engineering Group
NASA Johnson Space Center, Houston, Texas

Lawrence Kuznetz, PhD
Universities Space Research Association, Houston, Texas

June 2010

THE NASA STI PROGRAM OFFICE . . . IN PROFILE

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and mission, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at http://www.sti.nasa.gov

- E-mail your question via the internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at (301) 621-0134

- Telephone the NASA Access Help Desk at (301) 621-0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7115 Standard
  Hanover, MD 21076-1320

NASA/TP–2011–216151

Apollo Extravehicular Activities Video and Data Archives: Stumbling, Locomotive Velocity, and Metabolic Rates

Melissa Scott-Pandorf, PhD
Wyle Integrated Science and Engineering Group
NASA Johnson Space Center, Houston, Texas

Lawrence Kuznetz, PhD
Universities Space Research Association, Houston, Texas

June 2010

Acknowledgements

We would like to thank Lindsay Marek, Jonathon Kay, and Drew Bateman for their help in collecting and analyzing data.

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
301-621-0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-605-6000

This report is also available in electronic form at http://ston.jsc.nasa.gov/collections/TRS/

Abstract

It is important to understand how well the astronauts are able to function while performing exploration responsibilities to improve the safety and efficiency of future lunar sortie missions. A wealth of knowledge may be gained by searching the video archives from the extravehicular activities (EVAs) performed during the Apollo missions. Metabolic and movement characteristics from these missions can be assessed to determine the effort required by astronauts when performing extravehicular tasks. Analysis results indicated that the Apollo astronauts fell 3% of their EVA time; walked, loped, or ran at speeds ranging from 1.3 to 5.5 kph (0.8 to 3.4 mph); and reached metabolic rates of more than 2 215 617.39 J/hour (2100 BTU/hour). These values can be used when considering future lunar sorties as well as to verify simulation studies conducted on the ground. These data also provide a quantitative estimate of the number of stumbles and falls the astronauts experienced during Apollo EVAs. Likely factors influencing stability, speed, and energy expenditure include environmental characteristics, suit characteristics, crew training, and overall crew health. Future research may be performed to further investigate these factors to properly prepare for space exploration beyond the International Space Station.

Contents

1 Introduction 1

2 Lunar Exploration Source Video Footage 1

3 Movement Characteristics and Metabolic Rates 2
3.1 Leaping on the moon 2
3.2 Loss of balance and falling 2
3.3 Limitations of video 4

4 Lunar Exploration Velocity 5
4.1 Methods by which to determine velocity 5
4.2 Velocity analysis results 6
4.3 Velocity discussion 6
4.4 Velocity limitations 7

5 Lunar Exploration Metabolic Rate 7
5.1 Calibration curves 7
5.2 Matching velocities 9
5.3 Metabolic curves results 9
5.4 Metabolic limitations 9

6 Future Work 10

7 References 10

Appendix A: Video Cataloging Data 12
Appendix B: Apollo 17 Stumbling and Falls 14
Appendix C: Calibration Curves 15

Figures

1 Video footage of an astronaut leaping during an Apollo mission. The height of the leap was estimated to be 0.45 m (18 in) 2
2 An example of the video tracking software used to determine the distance traveled during a video clip..... 5
3 Sample Apollo heart rate data..... 8
4 Sample Apollo calibration curve 8
5 Sample recreated calibration curve..... 9

Tables

1 Lunar Journal Times, Average Velocities, and Activity Descriptions for Apollo Missions..... 6
2 Summary of Metabolic Rates and Walking Speeds..... 10

Acronyms

ALSEP	Apollo Lunar Surface Experiment Package
ALSJ	Apollo Lunar Surface Journal
DVD	digital video disc
EVA	extravehicular activity
LM	lunar module
LRV	lunar roving vehicle
PLSS	Portable Life Support System

1 Introduction

Interest in lunar exploration has been revitalized by recent aspirations to return to the moon. The overall success of these missions will be characterized by the ability of astronauts to efficiently and safely perform tasks during lunar sortie missions.

In an effort to improve the safety and efficiency of future lunar sortie missions, it is therefore important to understand how well the astronauts are able to function while performing exploration responsibilities. A wealth of knowledge may be gained by searching the video archives of the extravehicular activities (EVAs) performed during the Apollo missions. Metabolic and movement characteristics from these missions were assessed to determine the effort required by the astronauts to do extravehicular tasks. Challenges in mobility that are a consequence of the environment and the suit can similarly be assessed. This information can potentially lead to improvements that may be made to the next generation of spacesuits to increase astronaut mobility and mission success.

This investigation is descriptive in nature and provides three important factors to consider regarding future lunar missions. First, the video archives of the Apollo missions are reviewed and key events are noted. Specifically, astronaut loss of balance and falls are documented. Second, the walking and running velocities of Apollo crew members are calculated from the Apollo video footage, which establishes an understanding of the movement speeds that will likely be seen in future lunar missions. Third, the velocities are synchronized with metabolic characteristics from the missions. The end result of this will be reaching a better understanding of how mobility in a lunar environment while wearing an EVA suit may be compromised, and how an astronaut's metabolic rate correlates to his locomotive velocity on the moon. This information can serve as building blocks to our understanding of other factors such as the cost of transport, the maximum distance that can be explored away from the lunar module (LM), and the need for alternate modes of transportation.

2 Lunar Exploration Source Video Footage

A review of the Apollo mission videos database can generate important knowledge for future lunar exploration. With the exception of the recordings made during the Apollo 11 flight, all video footage was analyzed from a camera mounted on the Apollo LM or lunar roving vehicle (LRV). As the missions progressed, camera technology advanced and the quality of the videos increased dramatically. Because of this, most of the analysis in this project was done on Apollo missions 15, 16, and 17. The camera used on these missions was an RCA J-Series (RCA Astro Division, Hightstown, NJ). After this camera was detached from the LM, the Apollo astronauts fixed it to the LRV to document nearly every move of their EVAs.

Commands from the ground allowed the camera to pan, tilt, and zoom as it followed the astronauts in its field of view. While this capability allowed for extensive and valuable video footage of the EVAs, it also created obstacles in analyzing the specific characteristics of interest in the Apollo missions.

Although this video footage was originally downlinked in analog, it is now preserved digitally on Betacam Sp cassettes. Each mission was broken down from these source cassettes, and select clips were ripped from the tapes and reorganized on digital video disc (DVD). The Apollo Lunar Surface Journal (ALSJ)[1] provided mission transcripts and allowed for the synchronization of mission times, EVA activities, metabolic rates, and heart rates. This information, combined with the DVD footage, served as the backbone for this study. A summary of the video clips used in this study, which includes mission time and a short description of the activities glimpsed in the videos, can be seen in Appendix A.

3 Movement Characteristics and Metabolic Rates

3.1 Leaping on the moon

Two brief clips of leaping were found during our analysis of the locomotive velocity of the astronauts on the lunar surface. Due to interest, the height of these leaps was determined using motion analysis software (Dartfish™, Fribourg, Switzerland). Dartfish™ software allows the user to establish a known distance within a video clip as a reference. Movement can thus be tracked to determine distance traveled. In this case, two leaps were assessed based on the known height of the Portable Life Support System (PLSS) (0.92 m [36.2 in]. The first leap was determined to be 0.45 m (18 in) (Figure 1) and the second leap (not shown) was 0.42 m (16 in).

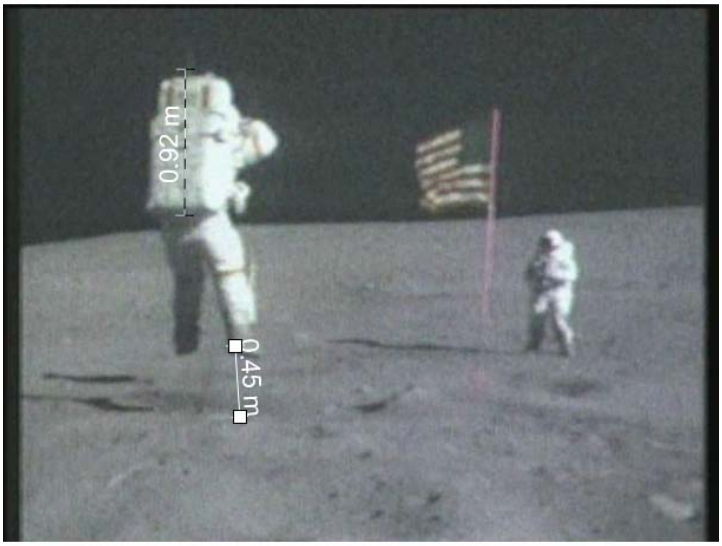


Figure 1. Video footage of an astronaut leaping during an Apollo mission. The height of the leap was estimated to be 0.45 m (18 in).

At first glance, a vertical leap of 0.45 and 0.42 m (18 and 16 in) does not seem impressive, even if one considers the excessive 167.0-kg (368.2-lb) mass of the astronaut and wearing a suit and life support system (~75.0 kg [165.3 lb] body weight + 92.0 kg [202.8 lb] suit and PLSS). This occurs because the effective weight in the 1/6*g* found on the lunar surface is only 28.0 kg (61.7 lb). The muscles must still develop an inertial force of 167.0 kg (368.2 lb) to move the suit at all, however, which makes leaps of 0.45 and 0.42 m (18 and 16 in) impressive nonetheless.

3.2 Loss of balance and falling

We developed a metric to estimate how loss of balance and falling impacted the Apollo missions. This metric, known as the F/V ratio, is the ratio of fall time in minutes to total video time viewed in minutes. Although the F/V ratio is preliminary, and other ratios may prove more meaningful in future analyses, it represents the best available metric at the time of this study. A priori criteria for events that qualify as fall time include the time taken to fall on video footage; the time spent stumbling on video footage; a noticeable loss of balance on video footage; and a comment in the

ALSJ concerning loss of balance or a fall that was not documented on the video but occurred during the elapsed video time being assessed. The falls not seen on video but noted (based on the ALSJ) occur because occasionally no astronauts are in view of the camera but their communications with mission control remain. These communications eventually are recorded in the ALSJ. It is likely that more stumbles occurred throughout the lunar EVAs, but the ALSJ and videos did not catch them. Therefore, the actual fall time is likely greater, meaning that the F/V ratio predicted here is probably less than actually occurred.

$$\frac{\text{Time spent falling, stumbling, or recovering from a fall}}{\text{Total time of video viewed}} = \text{F/V}$$

Apollo 17 was selected as the most representative mission to determine F/V because there excellent ALSJ documentation was available along with the videos. Results from each of the 3 EVAs in Apollo 17 are summarized separately followed by a total F/V for all Apollo 17 EVAs combined. Mission times and the type of fall for each EVA are listed in Appendix B.

EVA 1

Based on video and journal archives from EVA 1 of Apollo 17, it was determined that 3.08 minutes of 173 minutes of viewed EVA activity included a stumble or fall.

F/V = 3.08 minutes/173 minutes viewed = 0.02 = 2%

Thus, It is estimated that 2% of EVA time was spent stumbling, falling, or recovering from a fall. Two falls and 6 stumbles were found in video footage from EVA 1 of Apollo 17.

EVA 2

Similar results were found during EVA 2. Although he video footage of the EVA was 101 minutes, much of this EVA was spent traveling on the LRV, which would have minimized the fall or stumbling occurrence during this activity.

F/V = 1.92 minutes/101 minutes = 0.02 = 2%

It is estimated that 2% of EVA time was spent stumbling, falling, or recovering from a fall. It is possible that if the astronauts were walking around more during EVA 2, more falls would have been noted. Three falls occurred during EVA 2. There was no documentation or video footage of stumbling during this EVA.

EVA 3

A slightly larger percentage of fall time was determined for EVA 3.

F/V = 3.08 minutes/116 minutes = 0.03 = 3%

It is estimated that 3% of EVA time was spent stumbling, falling, or recovering from a fall. Apollo 17 crew members can be heard within the ALSJ commenting on the difficulty they were having maintaining balance on the uneven terrain on which they were working during this particular EVA. Specifically, the crew stated that the PLSS was a source of imbalance for them while working on a slope. If the documented balance work (i.e., stabilizing effort) that was performed by the astronauts while working on the slope were included in the fall percentage time, it would be closer to 12% of EVA time as fall time. However, 3 falls, 2 stumbles, and 2 noted instances of balance issues occurred that fit within our predetermined criteria for fall time. This led to the estimated F/V ratio of 3% fall time during EVA 3.

Total Fall Time

F/V ratio for EVAs 1, 2, and 3 = 8.08 minutes = 0.02 = 2%

Overall, it is estimated that, during Apollo 17, astronauts spent 2% of their EVA time falling, stumbling, or recovering from a fall. In total, 8 falls and 10 stumbles were documented during Apollo 17.

Summary

Despite the uniqueness of the 3 EVAs for Apollo 17, the F/V ratios were surprisingly similar at 2% to 3%. Therefore, it is likely that the ratios are conservative but reasonable estimates. Although the ratio is not large, it still represents valuable time wasted (2 falls for every 100 steps taken is indeed a concern). Recovering from a fall was usually a strong contributor to the overall fall time, which indicates that the suit design appeared to hinder the astronauts' recovery. Recent research on PLSS design has shown that a shift in the center of gravity up and back would decrease the stability of the walking pattern.[2] The design of the Apollo PLSS biased the center of gravity upward and rearward from what an individual is normally accustomed to on Earth, which is likely to have contributed to some of the loss of balance during Apollo 17. Finally, multiple instances of falls raise concern for crew safety on longer-duration and more frequent EVAs such as are planned for future lunar explorations.

3.3 Limitations of video

Early Apollo missions had limited and less advanced camera technology. Apollo missions 11 through 14 had only a fixed camera to document the EVAs, so there is little downlinked footage of astronauts; most of the video sent back is of the lunar surface. Most importantly, there simply is not much quality video of astronauts performing EVA tasks to analyze throughout these early missions.

On the other hand, missions 15 through 17 had more advanced camera technology provided by the RCA J-Series cameras. The tilt-pan-zoom camera allowed mission controllers to watch the entirety of the EVA. Unfortunately, the ability to tilt-pan-zoom posed a significant limitation in our analysis of the astronauts' velocities. This is because, to get an accurate determination from the video, the camera cannot be in motion. If the camera tilts, pans, or zooms, velocity determination becomes difficult and error is introduced. Furthermore, the astronaut must be moving

parallel to the plane of the camera. These limitations required a careful selection of video clips from downlinked footage, especially for the velocity analysis study presented in the next section.

4 Lunar Exploration Velocity

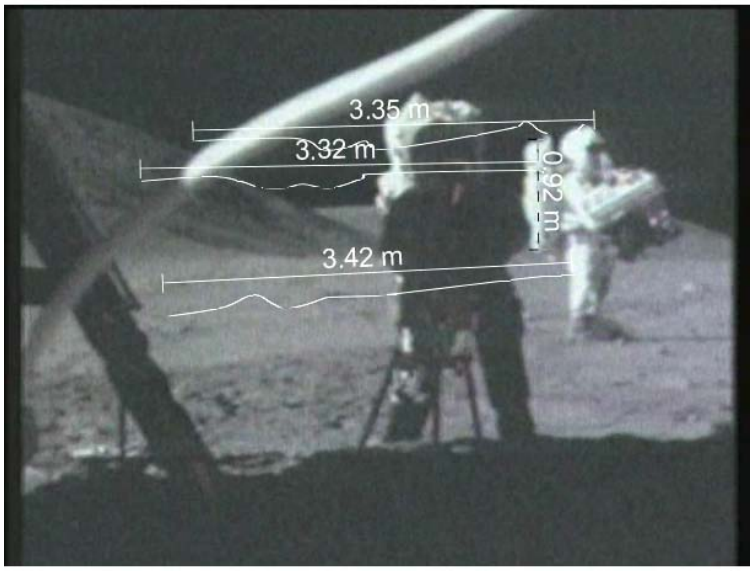


Figure 2. An example of the video tracking software used to determine the distance traveled during a video clip.

Establishing a good estimate for the velocity astronauts can use to traverse the lunar surface will be useful in future mission planning. This velocity will be an important factor in considering (1) the distance an astronaut may travel from base or rover on foot, (2) the need for a back-up means of transportation, (3) the estimated energy expenditure for specific EVA tasks, and (4) the margin of error for life support consumables.

Figure 2 provides an example of the video tracking software that is used to determine the distance traveled by an astronaut during a video clip.

4.1 Methods for determining velocity

Fourteen video clips were selected for velocity determinations using motion analysis software (Dartfish™). Two methods were used for verification in most cases: (1) The first tracked the astronaut for each frame of video before Dartfish™ provided the horizontal distance; (2) The second employed a distance-drawing tool in the motion tracking software to mark a start and an end point. This tool allowed the user to connect the 2 points to determine a distance value. Both methods required a known distance within the field of view of the camera. The height and depth of the PLSS was used as the known distance parameter, from which all subsequent distances were determined. Distance was calculated by using both the height and the depth of the PLSS to ensure that both factors resulted in similar distance values. To enhance accuracy, multiple trials were performed and velocity was determined using the mean distance over these multiple trials divided by the time of the video clip. Final velocities reported are the average of at least 5 trials.

Three previously recorded speeds of the Apollo 17 video clips were in the ALSJ; these were determined using lunar surface maps. In these cases, the time for an astronaut to go from one landmark to another was recorded. Then, knowing the distance between landmarks, velocity was calculated. However, deviations due to the astronaut's translation within the path were not known, bringing into question the accuracy of the speed calculations within the ALSJ.

In some cases, video clips that contained some panning, zooming, or astronaut motion out of plane were still used. Basic geometry helped provide a corrected velocity in these cases.

4.2 Velocity analysis results

Running speeds varied between 3.2 and 5.5 kph (2.0 and 3.4 mph). Slower speeds were reported when the astronauts were performing work activities in a localized area with a gait style more akin to walking than running (also determined from visual analysis). These localized speeds ranged from 1.3 to 3.1 kph (0.8 to 1.9 mph). Two video clips also included the astronaut carrying the Apollo Lunar Surface Experiment Package (ALSEP), which accounted for 54.5 kg (120.2 lb) of added mass. The velocity for these activities was determined to be between 2.3 and 2.9 kph (1.4 and 1.8 mph).

Two additional video clips were found that included, beyond basic locomotion, backpedaling and jumping. Activity descriptions are listed beside the calculated results in Table 1.

Table 1. Lunar Journal Times, Average Velocities, and Activity Descriptions for Apollo Missions

Mission	Lunar Journal Time	Calculated Speed kph(mph)	Journal Speed kph(mph)	Description
11	--	4.7(2.9)	--	Running behind LM
15	148:55:33	1.3(0.8)	--	Pictures with the flag
	148:56:00	2.3(1.4)	--	Pictures with the flag
	148:56:30	1.3(0.8)	--	Pictures with the flag
*	167:22:28	3.1(1.9)	--	Walking in front of LM
	147:55:06	1.6(1.0)	--	Walk during work
16	120:25:42	--	--	Jump 1 – 0.46 cm (0.18 in); Jump 2 – 38.1 cm (15 in)
	120:32:26	2.3(1.4)	--	Carrying ALSEP
	120:37:20	2.9(1.8)	--	Carrying ALSEP
	122:28:34	1.4(0.9)	--	Backpedal
	123:55:44	4.5(2.8)	--	Running
17	120:18:52	3.7(2.3)	--	Running. EVA 1 Deep Core
	120:27:01	--	5.3(3.3)	Running
	141:19:07	--	4.3(2.7)	Running
*	165:36:41	5.5(3.4)	--	Running (Maximum calculated velocity of 5.3 to 6.1 kph [3.3 to 3.8 mph] from distance trials.)
*	170:27:16	3.2(2.0)	4.5(2.8)	Running to LM

*Video clips in which geometry was required.

4.3 Velocity discussion

Speeds of 3.2 to 5.4 kph (2.0 to 3.4 mph) would not be considered running on Earth. However, visual observation of the locomotion style of astronauts traversing the moon clearly shows a flight phase between steps that is more indicative of a run than a walk. Additionally, previous work with simulated reduced gravity has shown a positive relationship between gravity and preferred transition speed from a walk to a run. For example, an astronaut walking in Earth gravity (1*g*) will select a higher transition speed than in lunar gravity.[3]

In addition, from remarks recorded in the ALSJ and from viewing locomotion on the Apollo videos, it would appear that the astronauts were running at higher speeds than computed. As the distance traveled and the time it took to travel that distance were carefully calculated for the

select samples above, it is possible that the flight phase of lunar locomotion creates the perception of greater speed. However, the flight phase may be generating more vertical excursion and very little horizontal excursion, which could lead to lower overall speeds.

4.4 Velocity limitations

The use of archival data often introduces analysis limitations. Camera panning and zooming made most video unusable. Whenever possible, however, velocity was calculated. Most often, the qualifying video clips had the astronaut walking in the sagittal plane across the entire viewing screen. These were ideal conditions. On the other hand, some clips included movement on an incline, toward the camera, or small intervals of zooming (see * items in Table 1). basic geometry was used to overcome this issue by adding in lost distance due to the bad camera angle or zoom. Although it was possible to calculate a factor that could scale the distance, the velocities calculated for these clips should be considered with caution. When a combination of video resolution and angle of locomotion were too difficult to delineate precisely, we approximated the velocities. In these cases (shown in Table 1 with a *), there were greater deviations between trials, which equated to a standard deviation of approximately ±1.1 kph (0.7 mph). The starred (*) items were not the only video clips that required approximation. Due to video resolution, the Apollo 11 video clip was difficult to distinguish and, therefore, included estimations. Locomotion clips that were not starred (*) items resulted in a standard deviation of ±0.3 kph (0.2 mph). These values encourage us to believe that the velocity findings presented herein are reasonably accurate. The velocity of 4.5 to 4.7 kph (2.8 to 2.9 mph) was also found repeatedly in these missions. This led us to conclude that a common velocity selection for an astronaut traversing on the moon is approximately 4.5 kph (2.8 mph).

5 Lunar Exploration Metabolic Rate

The metabolic expenditures of the astronauts on the lunar surface can be explored by using the data obtained from prior sections. This involves synchronizing heart rates and metabolic rates to the mission activities and velocities of the prior section.

5.1 Calibration curves

EVA flight controllers were able to determine continuous real-time estimates of crew metabolic rate, total energy expenditure, and specific task energy expenditure from PLSS telemetry data during the Apollo Program. These data included the decay of the oxygen bottle pressure, the inlet and change in water temperature (delta T) across the astronaut's liquid cooling garment (LCG), and heart rate data (Figure 3). While the heart rate data were judged unreliable at the time due to degradations in the calibration curve that had been taken several days preflight (from microgravity and other effects), it is possible to construct a new "tethered" calibration curve by superimposing the real-time metabolic rates from the other parameters on the same timeline as the heart rate data (Figure 4). This allows estimates of metabolic rate and task expenditure to be made in much tighter time scales than the other methods, which, by nature, ranged from 15 to 30 minutes. A calibration curve constructed as such permits estimates of crew metabolic rate and energy cost on a minute-to minute-basis; see Figure 5.

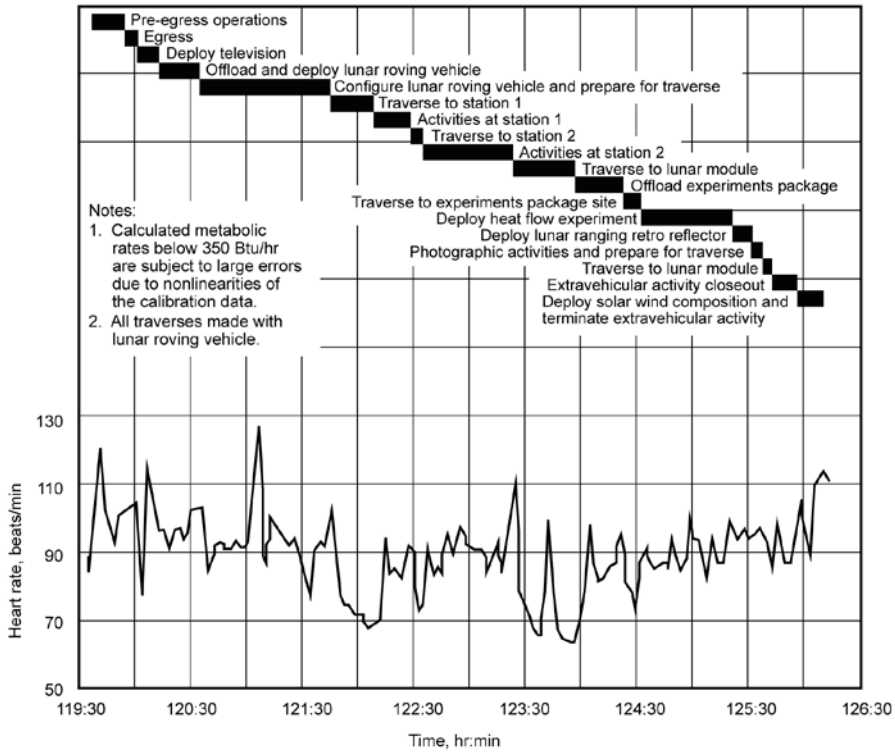


Figure 3. Sample Apollo heart rate data.[4]

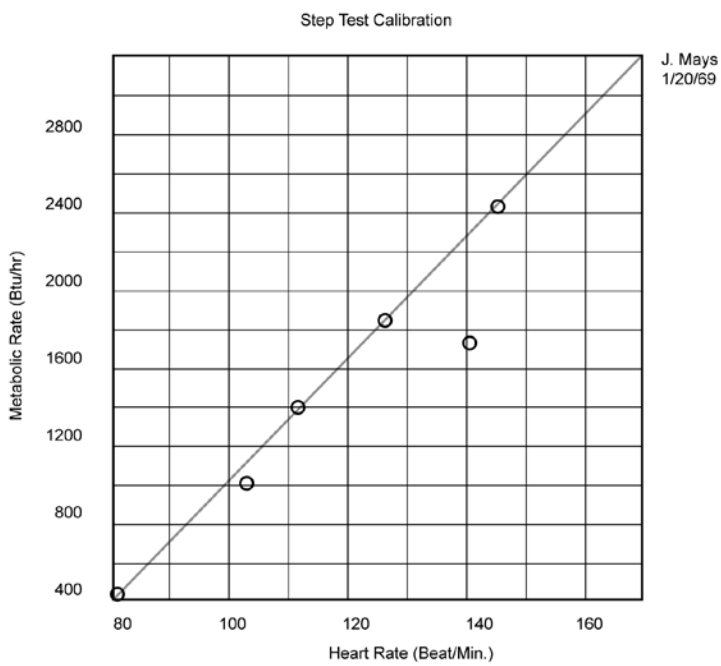


Figure 3. Sample Apollo calibration curve.[5,6]

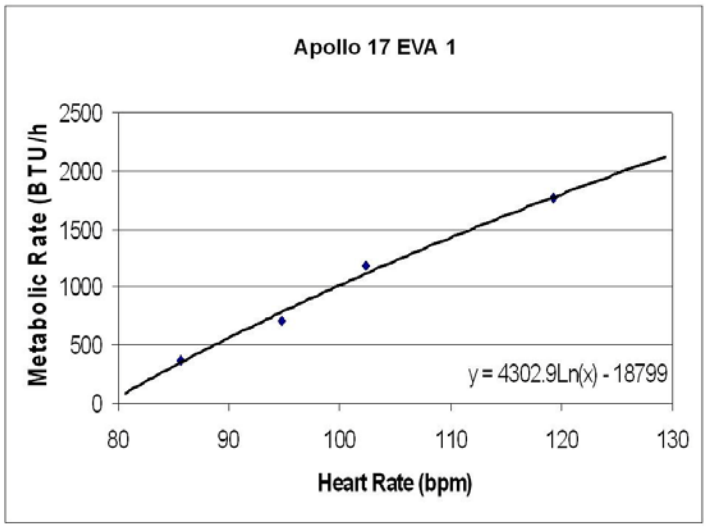


Figure 4. Sample recreated calibration curve.

No fewer than four data points were taken to create the calibration curve for each crew member on each EVA. The heart rate was averaged over the corresponding mission time for every metabolic rate data point to create a data set for each calibration curve. A logarithmic curve was then fit to each of the data sets to obtain a calibration curve that estimated the metabolic rate for a specified heart rate (Figure 5).

5.2 Matching velocities

After the calibration curves from the heart rate data were created, they were used to determine the metabolic rate for times in which the walking or running speeds of the crew member during a mission could be established. The effort required to complete a task could be analyzed by matching the velocity with a metabolic rate.

For each velocity calculated, the corresponding mission time was used to determine the heart rate recorded while walking or running. The calibration curve for that crew member during the subsequent EVA was then used to calculate the metabolic rate of the crew member during the activity.

5.3 Metabolic curves results

Calibration curves were created for each crew member on each mission on which a walking or running velocity was determined. A sample calibration curve can be seen in Figure 5, and all of the calibration curves can be seen in Appendix C.

The metabolic rates for each of the walking and running velocities were determined from these calibration curves. Table 2 provides a summary of these metabolic rates and their corresponding heart rates and velocities.

5.4 Metabolic limitations

Due to the age and poor quality of the graphs displaying the instantaneous crew member heart rate, some human error in the averaged heart rate is used in the calibration curves. The time interval between heart rate recordings was unknown, which may have also caused inaccuracies in calculating average heart rate.

Complications arose during the creation of the calibration curves when there was no match among the mission times from the ALSJ, the averaged metabolic rate data, and the heart rate data. This lack of a match caused difficulty in correlating an averaged heart rate to an averaged metabolic rate, as well as difficulty with matching heart rates to supplied velocities. Inconsistencies

in the correlation between metabolic rate and velocities may be attributed to a misalignment in the mission times reported from different sources.

Table 2. Summary of Metabolic Rates and Walking Speeds

Mission	Journal Time	Speed kph(mph)	Heart Rate (bpm)	Metabolic Rate (BTU/hr)	Description
11	--	4.2(2.9)	149	1556	Running behind LM
15	147:55:06	1.6(1.0)	123	1201	Walk during work
	148:56:00	2.3(1.4)	124	1218	Pictures with the flag
	148:56:30	1.3(0.8)	124	1218	Pictures with the flag
	167:22:28	3.1(1.9)	98	1505	Walking in front of LM
16	120:25:42	N/A	97	1002	Jump 1 – 0.46 cm (0.18 in); Jump 2 – 38.1 cm (15 in)
	120:32:26	2.3(1.4)	118	1488	Carrying ALSEP
	120:37:20	2.9(1.8)	144	2150	Carrying ALSEP
	123:55:44	4.5(2.8)	95	767	Running
17	120:18:52	3.7(2.3)	100	1016	Running. EVA 1 Deep Core
	120:27:01	5.3(3.3)	114	1542	Running
	141:19:07	4.3(2.7)	102	971	Running
	165:36:41	5.3(3.3)	106	1135	Running
	170:27:16	4.5(2.8)	124	1581	Running to LM

6 Future Work

To continue work in this study, the calibration curves and the metabolic rate data should be used to create the energy-velocity plots for each crew member and determine the transport cost of EVAs during the Apollo missions. Once these data have been generated, we can make a direct comparison between the transport costs of the Apollo crew members and those recorded in ground lunar gravity simulation studies that have already been conducted. This would give us insight into the validity and accuracy of these ground studies performed in an Earth gravity environment, as well as provide information on the effort required to perform tasks while wearing a spacesuit. Finally, this report indicated that falling during lunar EVAs is a potential safety issue. Likely factors influencing stability, speed, and energy expenditure include: environmental characteristics, suit characteristics, crew training, and overall crew health. Future research may further investigate these factors to properly prepare for space exploration beyond the International Space Station.

7 References

[1]Jones, E. M., and Glover, K. (eds.). *Apollo Lunar Surface Journal*, 1995. Accessed at http://www.hq.nasa.gov/alsj/frame.html.

[2]Scott-Pandorf, M., O'Connor, D. P., Layne, C. S., Josic, K., and Kurz, M. J. "Walking in simulated martian gravity: Influence of the portable life support system's design on dynamic stability." *J Biomech Eng*, 2009 Sep;131(9):091005.

[3]Donelan, J. M., and Kram, R. "Exploring dynamic similarity in human running using simulated reduced gravity." *J Exp Biol*. 2000;203:2405-2415.

[4]Johnston, R. S., Dietlein, L. F., and Berry, C. A. *Biomedical Results of Apollo*. SP-2006-368. NASA Johnson Space Center, Houston, Texas, 1 Oct 2006, p. 580. Previously published under JSC-12856, 1975.

[5]Kuznetz, L. H. *Control of Human Thermal Balance by a Liquid Circulating Garment Based on a Mathematical Model of the Human Thermoregulatory System*. NASA TM-58190, NASA Johnson Space Center, Houston, Texas. Previously published under JSC-11579, Oct 1976.

[6]Waligora, J. W., Hawkins, W. R., Humbert, G. F., Nelson, L. J. Vogel, S. J., and Kuznetz, L. H. *Apollo Experience Report: Assessment of Metabolic Expenditures*. NASA TN D-7883, Washington, DC, March 1975.

APPENDIX A:
Video Cataloging Data

Apollo 15

Reference Master Number	SMPTE Start Time	SMPTE Stop Time	Mission time	EVA #	Scene Description	Mission Task
718382	03:35:37:26	03:35:51:12	124:47:53	1	Throw	Between ALSEP Off-load and Work at Station 6
718314	04:04:13:00	04:04:23:00	125:16:27	1	Walk	Between ALSEP Off-load and Work at Station 6
718381	02:38:05:26	02:38:58:17	144:19:21	2	Walk	Work at Station 6
718381	02:47:22:00	02:47:37:00	144:28:04	2	Trips	Work at Station 6
718312	01:49:40:11	01:49:59:15	148:55:33	2	Walk	Closeout
718312	03:32:40:00	03:32:05:16	165:32:01	3	Trips 2	After Station 9
718333	02:59:25:08	02:59:40:08	167:22:28	3	Walk 2	Hammer and Feather
718306	28:54:20:28	28:54:30:23	147:55:06	2	Walk 2	Heat Flow Reprise/Station 8

Apollo 16

Reference Master Number	SMPTE Start Time	SMPTE Stop Time	Mission time	EVA #	Scene Description	Mission Task
718326	02:28:34:00	02:29:01:00	145:30:34	2	Walking	Geology Station 5
718303	22:27:43:25	22:27:50:00	147:32:26	2	Fall	Geology Station 8
718332	03:50:56:04	03:51:33:13	149:11:46	2	Fall 2	Geology Station 10 Near ALSEP Site
718332	03:53:24:13	03:53:37:17	149:14:13	2	Skip	Geology Station 10 Near ALSEP Site
718332	03:59:51:09	04:00:36:00	149:19:06	2	Rover-LM 4.4 kph (2.7 mph)	Geology Station 10 Near ALSEP Site
718380	03:44:48:26	03:45:10:26	166:58:35	3	Fall	Geology Station 11 at North Ray Crater
718317	01:13:49:18	01:16:31:15	167:55:31	3	Long Walk	House Rock (Before Station 13)
718373	22:53:20:11	22:53:37:08	169:43:51	3	Pass LM	Station 10 Prime
718373	23:25:22:21	23:25:37:03	170:21:33	3	Jump	EVA 3 Closeout
718373	23:25:40:04	23:25:55:02	170:22:01	3	Jump	EVA 3 Closeout

Reference Master Number	SMPTE Start Time	SMPTE Stop Time	Mission time	EVA #	Scene Description	Mission Task
718307	22:04:57:00	22:05:06:09	120:25:42	1	Jump	ALSEP Off-load
718307	22:05:31:22	22:05:58:05	120:26:21	1	Walk	ALSEP Off-load
718307	22:12:59:17	22:13:40:05	120:32:28	1	Encumbered	ALSEP Off-load
718307	22:16:35:18	22:16:37:29	120:37:20	1	Hop	ALSEP Off-load
718307	22:16:38:00	22:17:34:06	120:37:20	1	Walk	ALSEP Off-load
718307	22:30:04:11	22:30:35:27	121:04:51	1	Walk 2	Losing Heat Flow Experiment
718334	02:34:21:00	02:34:28:00	126:09:28	1	Hop 2	Losing Heat Flow Experiment
718334	02:50:39:05	02:50:46:13	122:25:26	1	R-1 Run	Thumper/Geophone Experiment
718334	02:53:42:00	02:53:51:12	122:28:34	1	Backpedal	Thumper/Geophone Experiment
718300	03:48:25:00	03:49:12:11	123:55:41	1	Long Traverse	Station 1 at Plum Crater
718326	02:54:30:00	02:54:35:00	145:56:37	2	Jump in Rover	Geology Station 5
718303	21:39:49:23	21:39:55:15	146:24:50	2	Walk	Geology Station 6

Apollo 17

Reference Master Number	SMPTE Start Time	SMPTE Stop Time	Mission time	EVA #	Scene Description	Mission Task
718302	18:20:40:05	18:20:47:07	120:18:52	1	Running	Deep Core/ALSEP Completion
718302	18:24:42:27	18:29:24:28	120:27:01	1	5.4 kph (3.4 mph)	Deep Core/ALSEP Completion
718319	10:21:24:19	10:23:19:20	141:19:07	2	4.5 kph (2.8 mph)	1st Half Traverse to Geo Station 2
718330	02:28:54:20	02:29:48:28	144:50:52	2	Slip	Geology Station 3 at Ballet Crater
718330	02:34:40:02	02:35:05:20	144:56:34	2	Ballet	Geology Station 3 at Ballet Crater
718330	02:41:23:12	02:41:36:09	145:03:40	2	LRV	Geology Station 3 at Ballet Crater
718374	02:00:35:28	02:00:56:11	165:36:41	3	Fall	Geology Station 6
718315	00:20:14:07	00:20:27:24	166:51:14	3	Run 2	Geology Station 8
718314	21:16:08:00	21:57:39:00	170:27:16	3	4.6 kph (2.9 mph)	EVA 3 Closeout

APPENDIX B:
Apollo 17 Stumbling and Falls

EVA 1

Journal Time	**Loss of Balance Type**
118:25	Stumble
119:49	Stumble
121:00	Fall
121:01	Fall and Recovery
122:13	Stumble
122:15	Stumble and Recovery
123:01	Stumble
123:09	Stumble

EVA 2

Journal Time	**Loss of Balance Type**
144:02	Fall
144:51	Fall
144:56	Fall

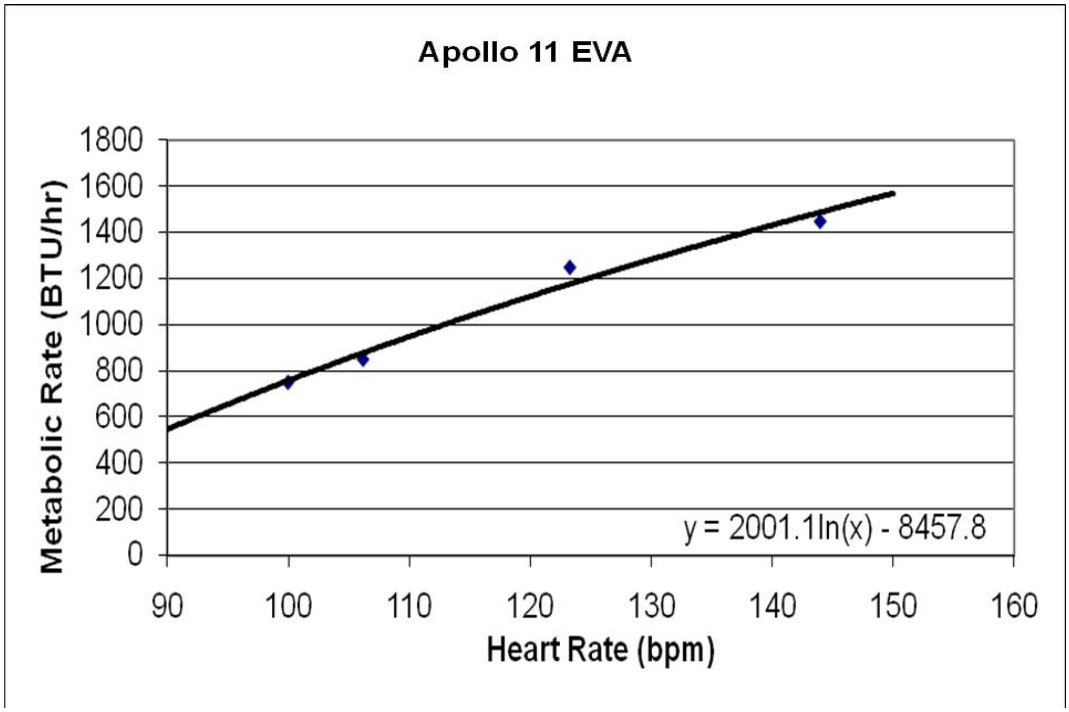
EVA 3

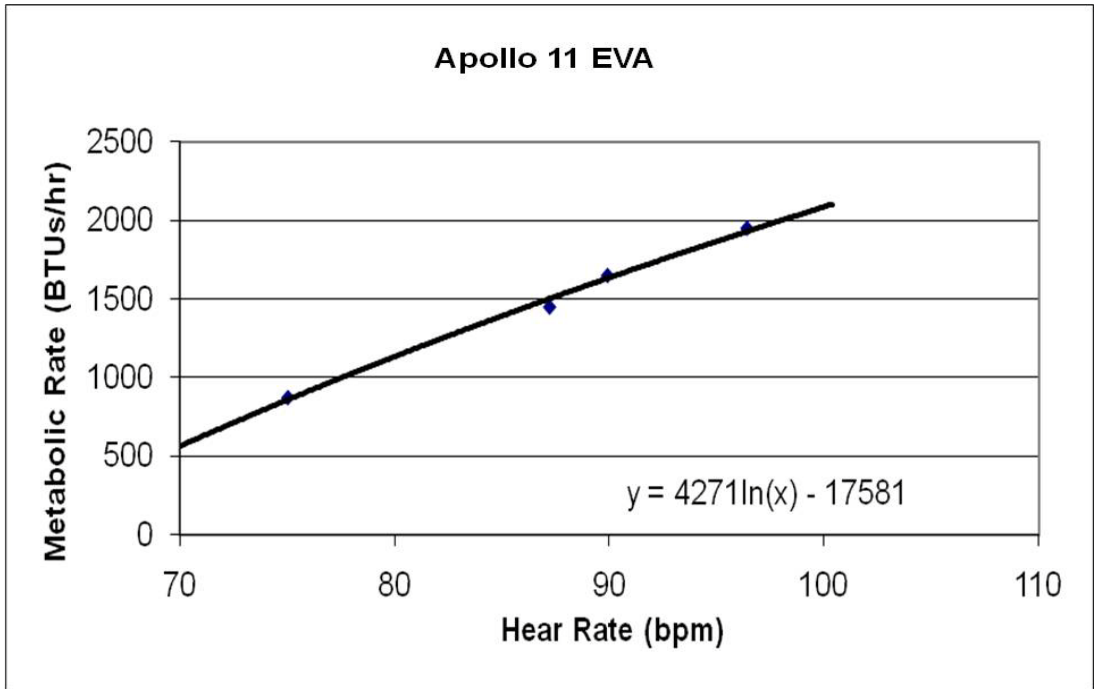
Journal Time	**Loss of Balance Type**
163:22	Stumble
165:24	Fall
165:36	Fall and Recovery
165:14	Balance Trouble
165:26	Balance Trouble
167:33	Fall
168:26	Stumble

APPENDIX C:
Calibration Curves

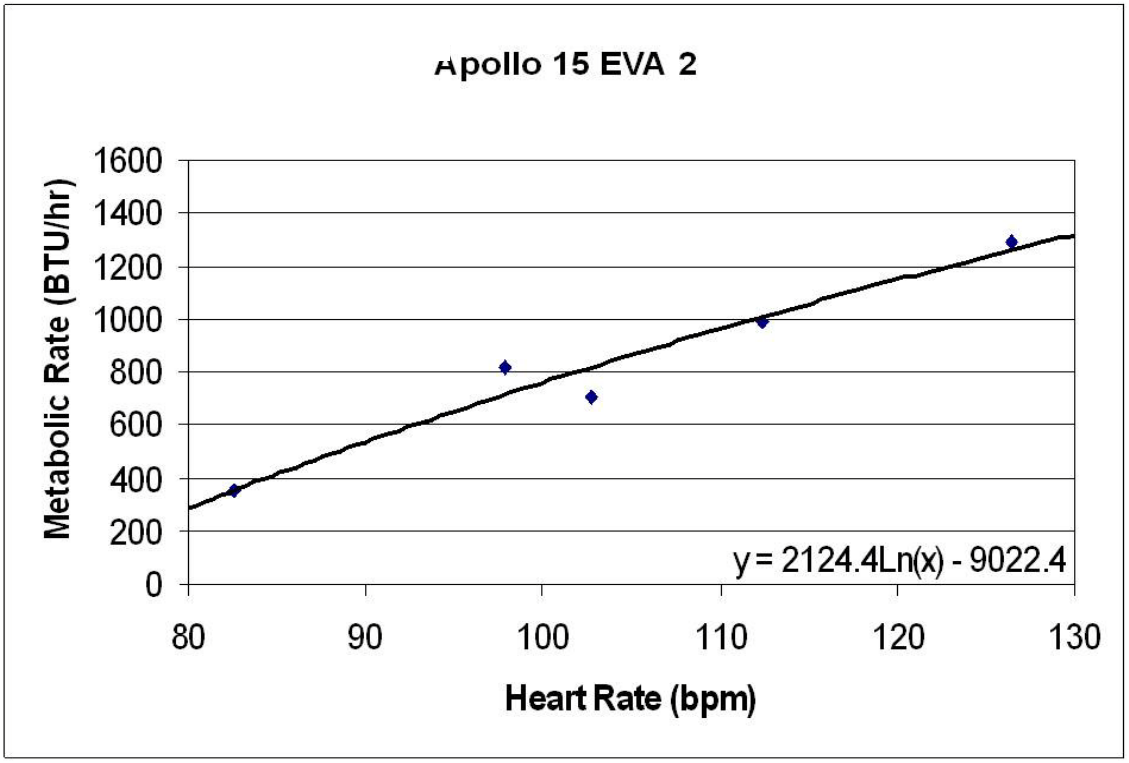
(Note: A calibration curve was made on only those EVAs for which a speed was calculated.)

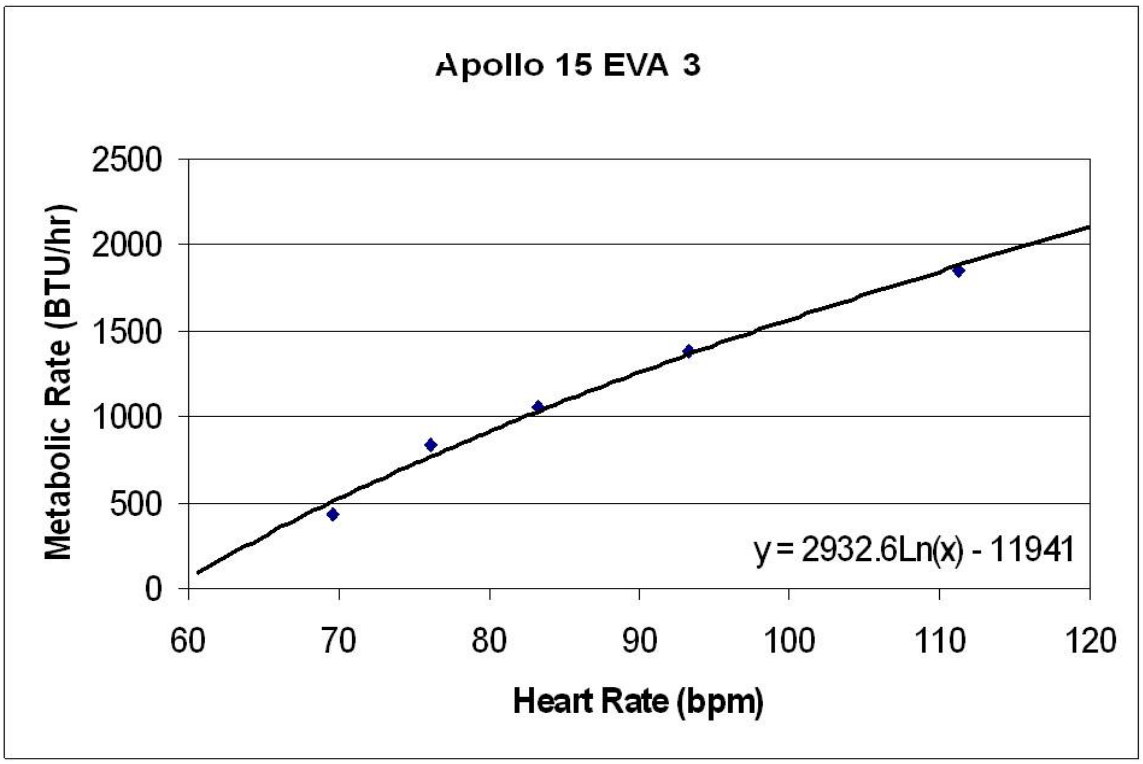
Apollo 11



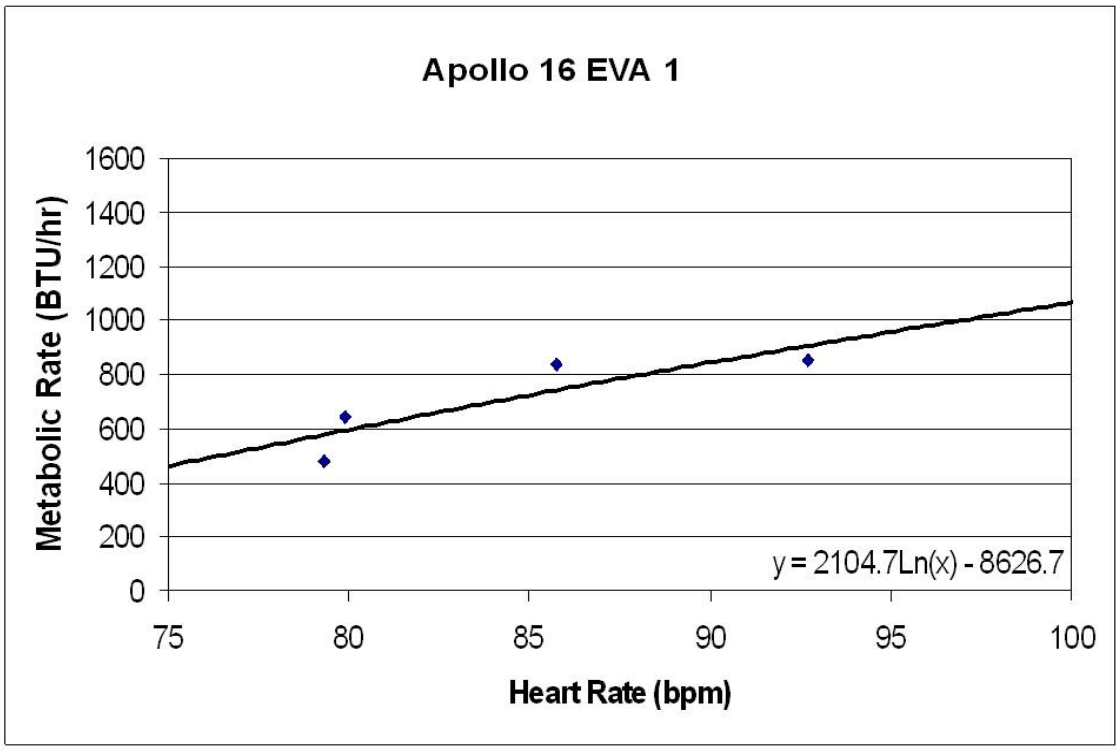


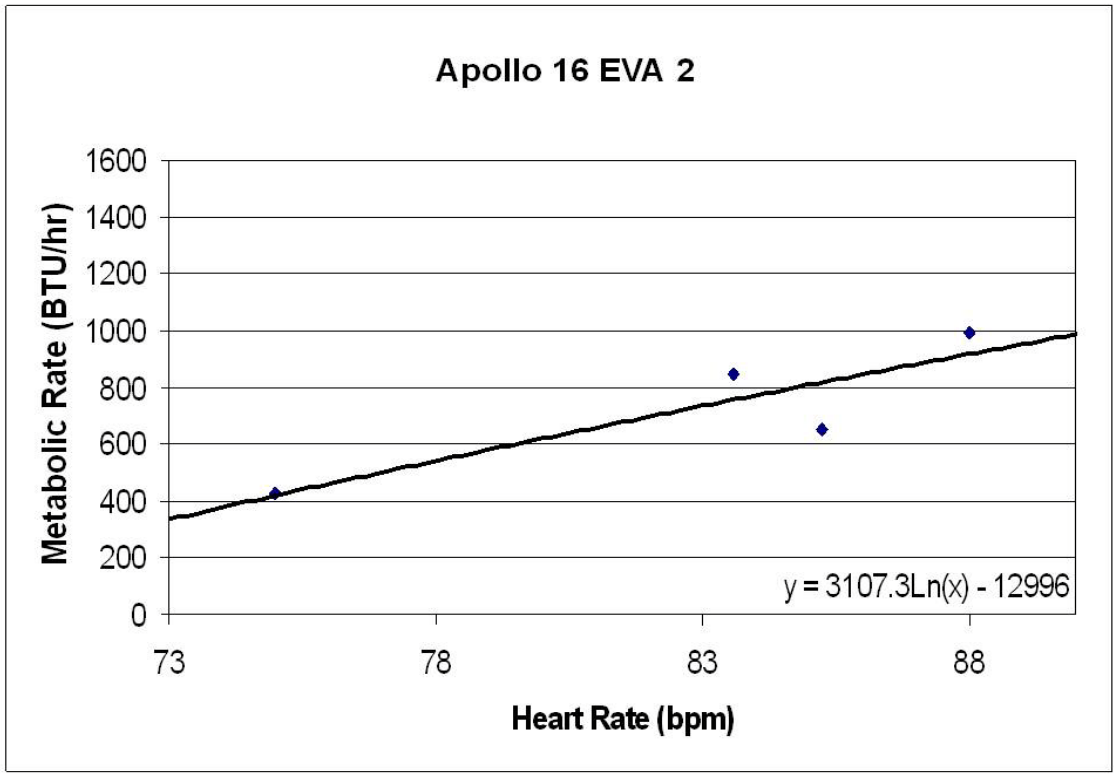
Apollo 15

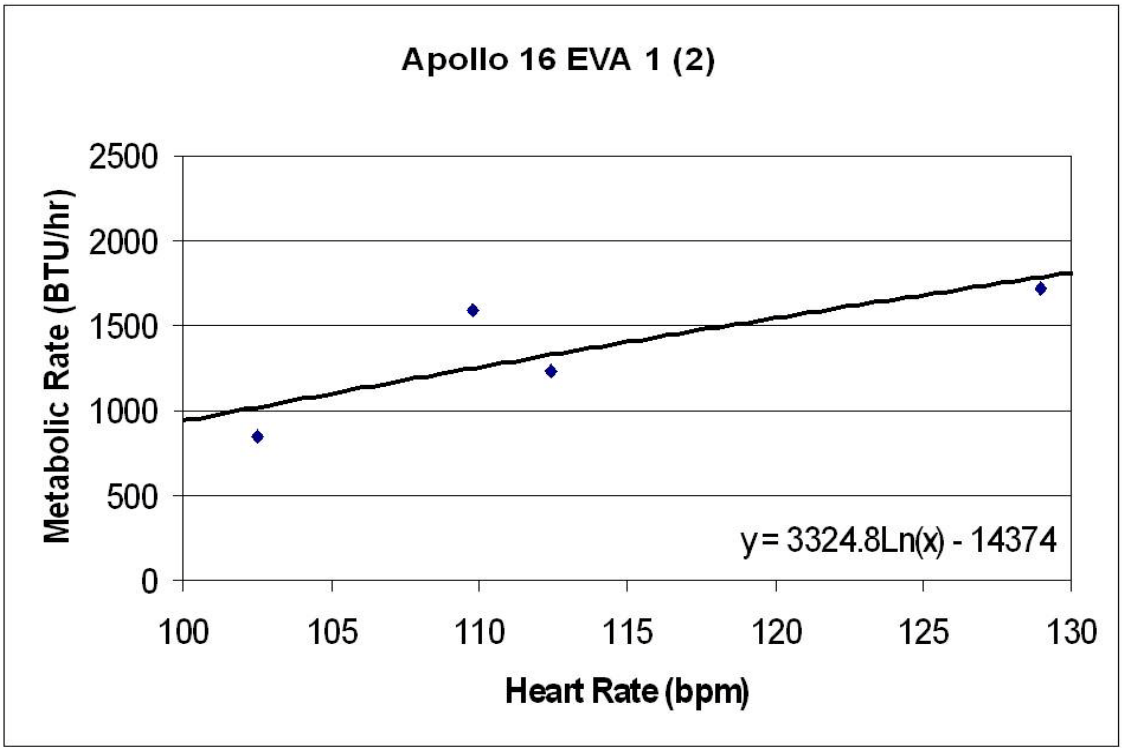

Apollo 15 EVA 2
Metabolic Rate (BTU/hr)
1600
1400
1200
1000
800
600
400
200
0
80
90
100
110
120
130
Heart Rate (bpm)
y = 2124.4Ln(x) - 9022.4

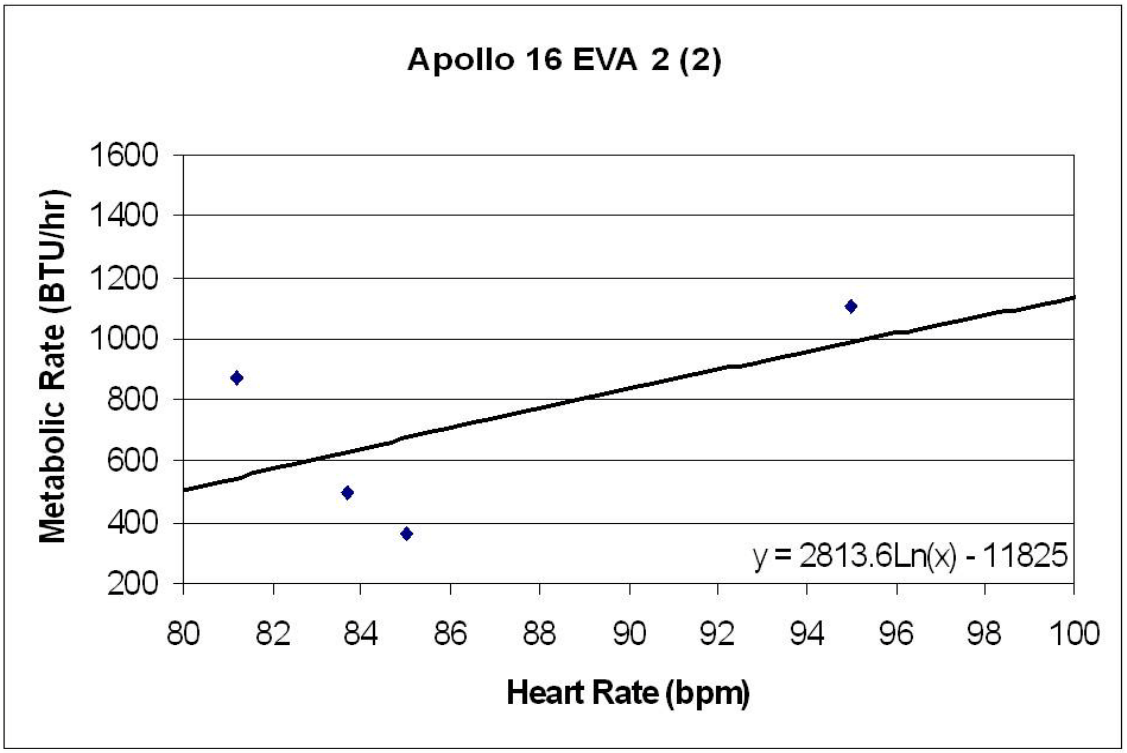

Apollo 15 EVA 3
Metabolic Rate (BTU/hr)
2500
2000
1500
1000
500
0
60
70
80
90
100
110
120
Heart Rate (bpm)
y = 2932.6Ln(x) - 11941

Apollo 16

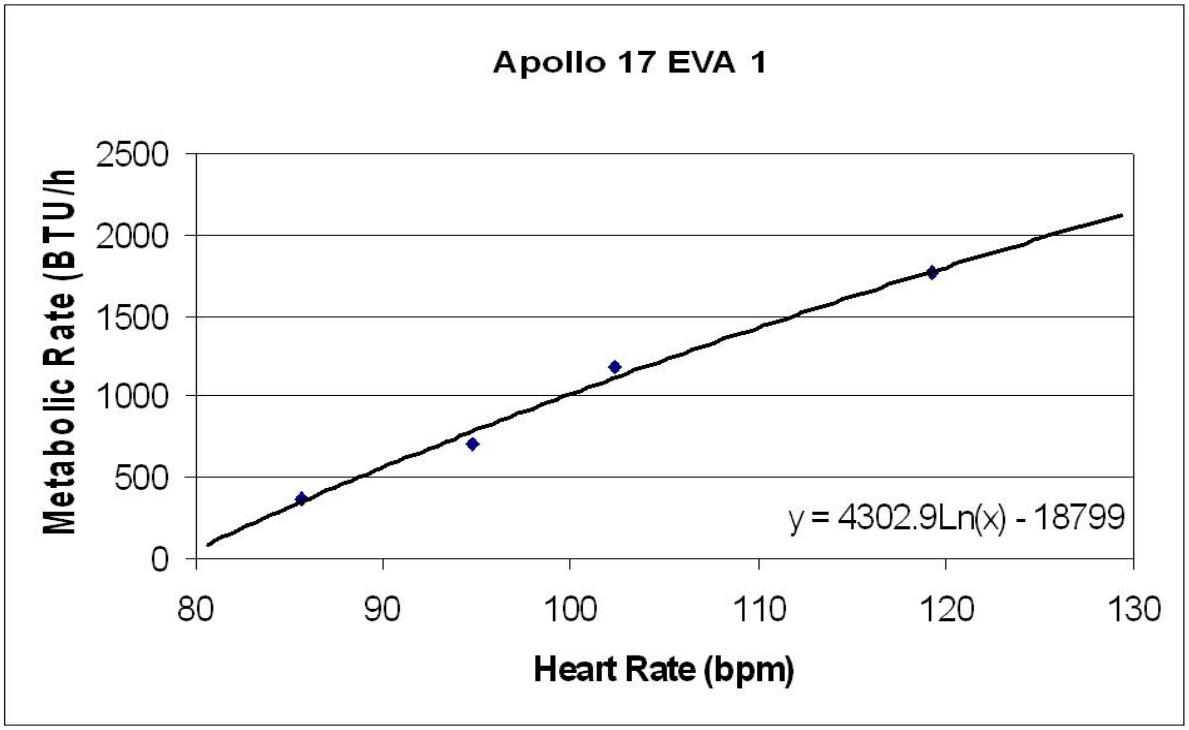

Apollo 16 EVA 1
Metabolic Rate (BTU/hr)
1600
1400
1200
1000
800
600
400
200
0
75
80
85
90
95
100
Heart Rate (bpm)
y = 2104.7Ln(x) - 8626.7

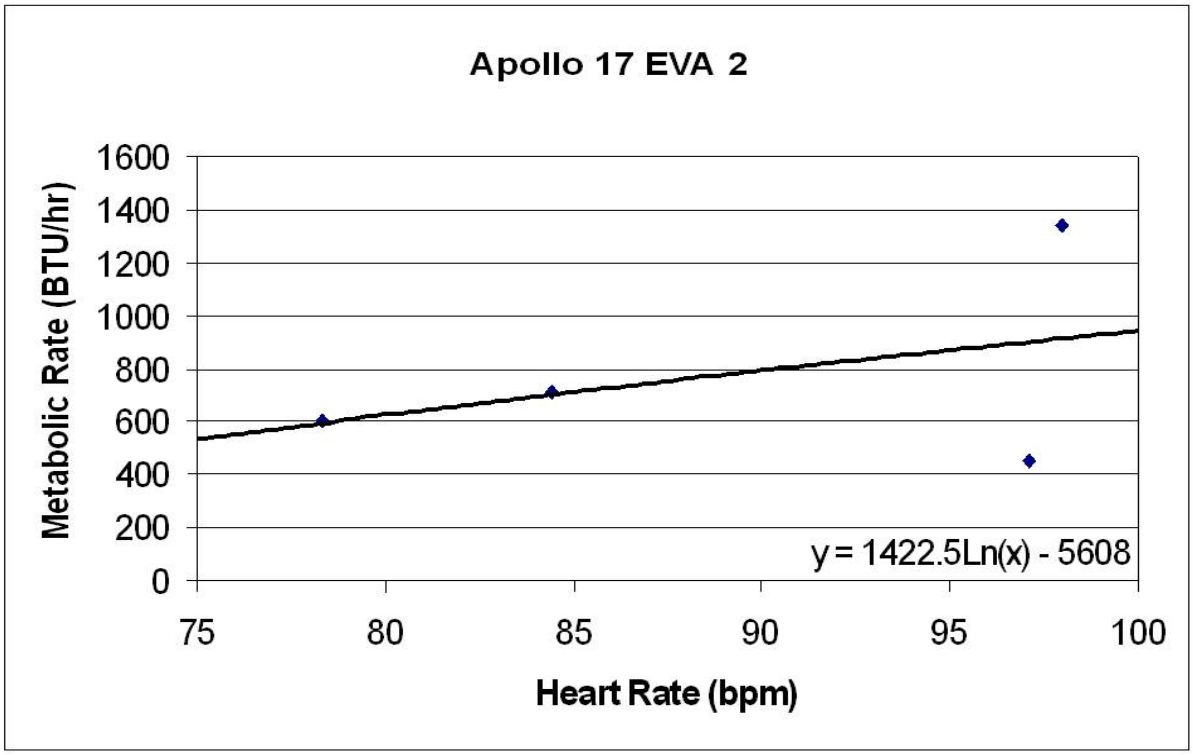

Apollo 16 EVA 2
Metabolic Rate (BTU/hr)
1600
1400
1200
1000
800
600
400
200
0
73
78
83
88
Heart Rate (bpm)
y = 3107.3Ln(x) - 12996

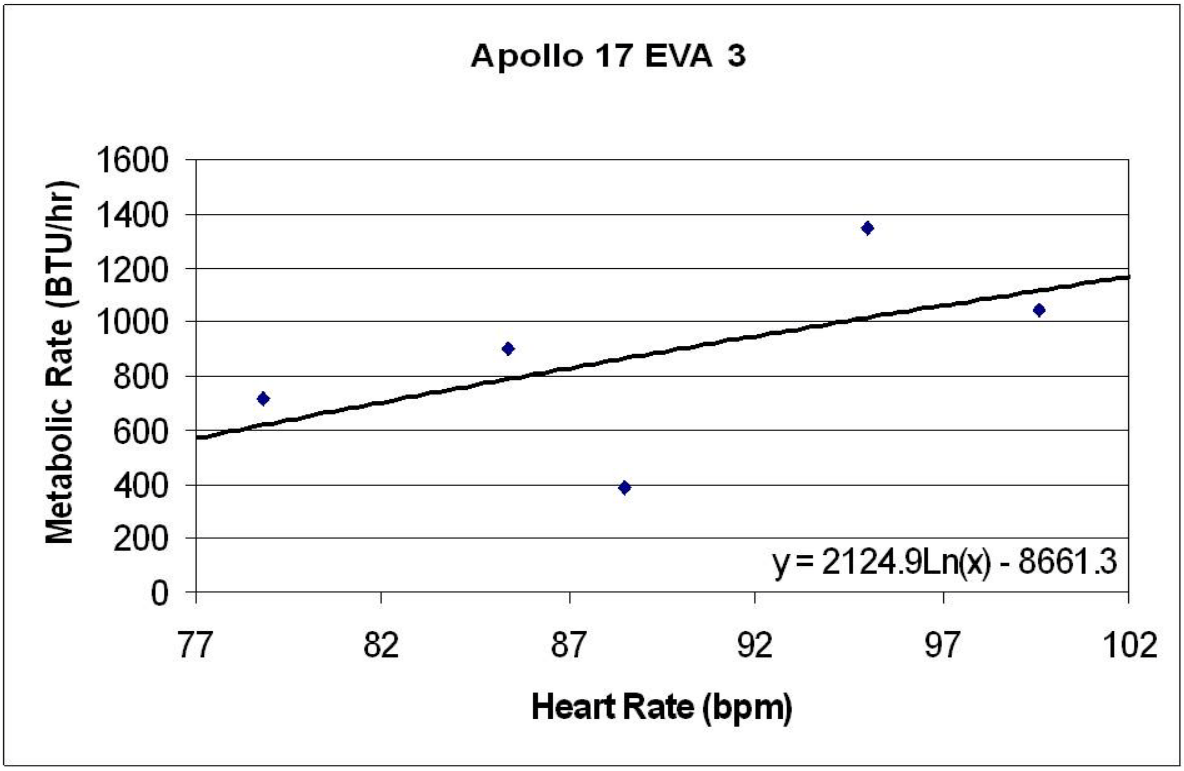

Apollo 16 EVA 1 (2)
Metabolic Rate (BTU/hr)
2500
2000
1500
1000
500
0
100
105
110
115
120
125
130
Heart Rate (bpm)
y = 3324.8Ln(x) - 14374

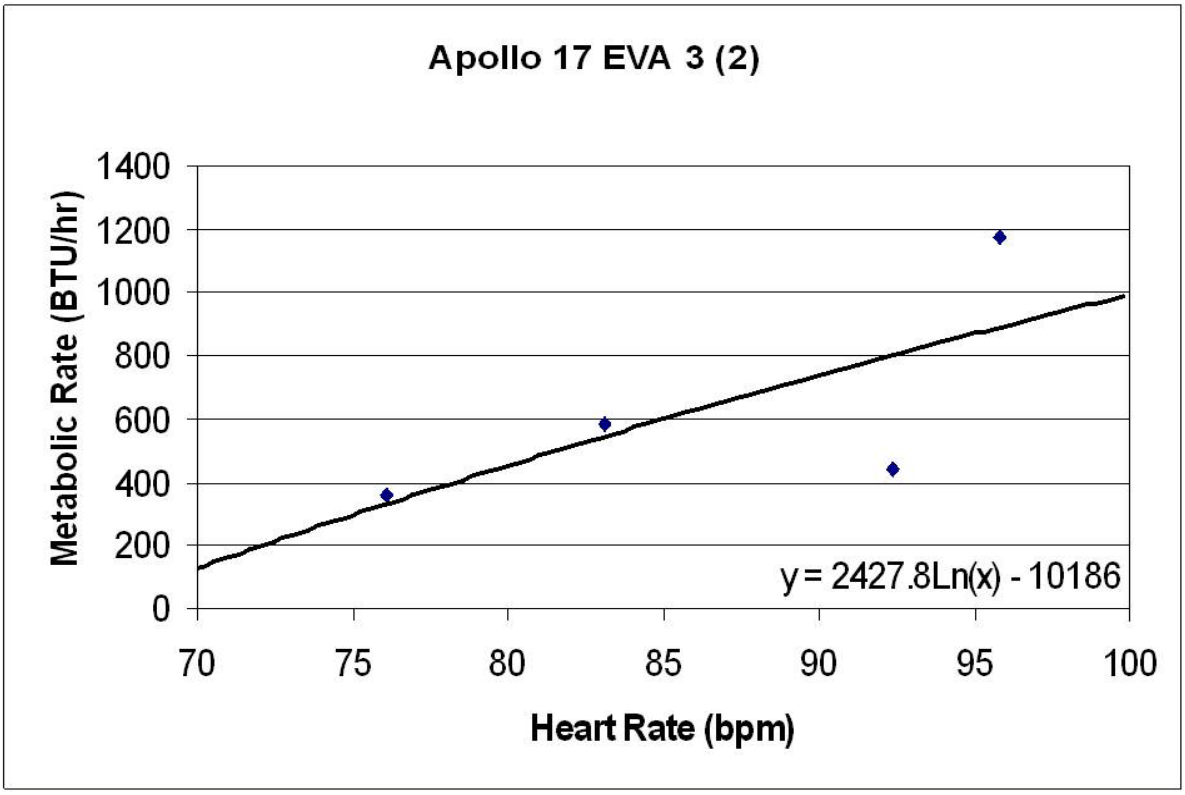

Apollo 16 EVA 2 (2)
Metabolic Rate (BTU/hr)
1600
1400
1200
1000
800
600
400
200
80
82
84
86
88
90
92
94
96
98
100
Heart Rate (bpm)
y = 2813.6Ln(x) - 11825

Apollo 17


Apollo 17 EVA 1
Metabolic Rate (BTU/h
2500
2000
1500
1000
500
0
80
90
100
110
120
130
Heart Rate (bpm)
y = 4302.9Ln(x) - 18799


Apollo 17 EVA 2
Metabolic Rate (BTU/hr)
1600
1400
1200
1000
800
600
400
200
0
75
80
85
90
95
100
Heart Rate (bpm)
y = 1422.5Ln(x) - 5608


Apollo 17 EVA 3
Metabolic Rate (BTU/hr)
1600
1400
1200
1000
800
600
400
200
0
77
82
87
92
97
102
Heart Rate (bpm)
y = 2124.9Ln(x) - 8661.3


Apollo 17 EVA 3 (2)
Metabolic Rate (BTU/hr)
1400
1200
1000
800
600
400
200
0
70
75
80
85
90
95
100
Heart Rate (bpm)
y = 2427.8Ln(x) - 10186

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 2011	Technical Publication

4. TITLE AND SUBTITLE
Apollo Extravehicular Activities Video and Data Archives: Stumbling, Locomotive Velocity, and Metabolic Rates

5. FUNDING NUMBERS

6. AUTHOR(S)
Melissa Scott-Pandorf, PhD,* Lawrence Kuznetz, PhD**

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Lyndon B. Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBERS
S-1098

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
TP-2011-216151

11. SUPPLEMENTARY NOTES
*Wyle Integrated Science and Engineering Group, NASA Johnson Space Center, Houston, **Universities Space Research Association, Houston

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified/Unlimited
Available from the NASA Center for AeroSpace Information (CASI)
7115 Standard
Hanover, MD 21076-1320 Category: 52

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

It is important to understand how well the astronauts are able to function while performing exploration responsibilities to improve the safety and efficiency of future lunar sortie missions. A wealth of knowledge may be gained by searching the video archives from the extravehicular activities (EVAs) performed during the Apollo missions. Metabolic and movement characteristics from these missions can be assessed to determine the effort required by astronauts when performing extravehicular tasks. Analysis results indicated that the Apollo astronauts fell 3% of their EVA time; walked, loped, or ran at speeds ranging from 1.3 to 5.5 kph (0.8 to 3.4 mph); and reached metabolic rates of more than 2 215 617.39 J/hour (2100 BTU/hour). These values can be used when considering future lunar sorties as well as to verify simulation studies conducted on the ground. These data also provide a quantitative estimate of the number of stumbles and falls the astronauts experienced during Apollo EVAs. Likely factors influencing stability, speed, and energy expenditure include environmental characteristics, suit characteristics, crew training, and overall crew health. Future research may be performed to further investigate these factors to properly prepare for space exploration beyond the International Space Station.

14. SUBJECT TERMS	15. NUMBER OF PAGES	16. PRICE CODE
extravehicular activity; astronaut locomotion; weightlessness; Apollo extension system; intravehicular activity; cislunar space; aerospace environments; space suits	32	

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited