

RESULTS AND LESSONS LEARNED FROM PERFORMANCE TESTING OF HUMANS IN SPACESUITS IN SIMULATED REDUCED GRAVITY. Steven P. Chappell¹, Jason R. Norcross¹, and Michael L. Gernhardt²; ¹Wyle Integrated Science and Engineering Group, NASA Johnson Space Center, 2101 NASA Parkway, Mail Code Wyle/HAC/37C, Houston, TX, 77058, steven.p.chappell@nasa.gov and jason.norcross-1@nasa.gov; ²NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX, 77058, michael.l.gernhardt@nasa.gov.

Introduction: NASA's Constellation Program has plans to return to the Moon within the next 10 years. Although reaching the Moon during the Apollo Program was a remarkable human engineering achievement, fewer than 20 extravehicular activities (EVAs) were performed. Current projections indicate that the next lunar exploration program will require thousands of EVAs, which will require spacesuits that are better optimized for human performance. Limited mobility and dexterity, and the position of the center of gravity (CG) are a few of many features of the Apollo suit that required significant crew compensation to accomplish the objectives. Development of a new EVA suit system will ideally result in performance close to or better than that in shirtsleeves at 1 G, i.e., in "a suit that is a pleasure to work in, one that you would want to go out and explore in on your day off." [1] Unlike the Shuttle program, in which only a fraction of the crew perform EVA, the Constellation program will require that all crewmembers be able to perform EVA. As a result, suits must be built to accommodate and optimize performance for a larger range of crew anthropometry, strength, and endurance. To address these concerns, NASA has begun a series of tests to better understand the factors affecting human performance and how to utilize various lunar gravity simulation environments available for testing.

Objectives: To collect performance data from suited humans during parabolic flight, to compare to and validate ground-based testing results using 2 other lunar-gravity analogs: 1) overhead suspension and 2) underwater buoyancy.

Methods: A custom weight support structure interfaced with a prototype lunar surface spacesuit, allowing manipulation of both suit mass and CG. Three series of tests were completed to either directly compare results with ground-based tests already completed, or to populate gaps in that data due to limitations of the respective analog environments used for those tests (e.g., insufficient lift capacity in the overhead suspension system; limited degrees of freedom). The 3 parabolic flight series were varied mass (VM), varied weight (VW), and varied center of gravity (VC). In the VW series, suit mass (120 kg) was constant at 0.1, 0.17, and 0.3 G for a total gravity adjusted weight (TGAW) of 196, 333, and 588 N, assuming an 80-kg

subject. In the VM series, gravity level was constant at 0.17 G and suit mass was 89, 120, and 181 kg, for TGAWs of 282, 333, and 435 N. The 333 N condition was common to both the VW and VM series. Point-by-point comparison of the VW and VM series was not possible due to limited adjustability of suit mass and parabolic profile options. In the VC series, gravity level and suit mass were held constant at 0.17 G and 181 kg, and system CG was varied among 3 locations (B=4.8/1.0, C=7.6/14.4, and P=11.2/20.1 cm, aft/above the reference subject's CG). The CG of the system was defined as the combined CG of the subject, the spacesuit, and the equipment required to change the CG. Weight locations to alter CG were based on a reference subject (81.6 kg, 182.9 cm). Suited testing was performed with the suit pressurized at 29.6 kPa. Six subjects (80.0±10.6 kg, 182.3±6.2 cm) completed 4 tasks (walking, kneel/stand, rock pickup, and shoveling). The kneel/stand task was identical to ground-based testing. For rock pickup and shoveling, fabric bags filled with lead shot were used in lieu of weights and rocks. Walking during parabolic flight was overground across a short distance because the treadmill used during ground-based testing could not be accommodated in the available plane volume. In all conditions, upon completion of each task subjects provided ratings of perceived exertion (RPE) [2] and scores using the gravity compensation and performance scale (GCPS) [3]. GCPS ratings are based on the level of operator compensation required in partial gravity compared to performing the same task, unsuited, in 1 G. On this scale, a rating of 2 is equal to 1-G performance and larger numbers indicate perceived increases in the amount of subject compensation required to achieve desired performance. Motion-capture cameras were used to capture kinematic data, and force plates were used to record ground reaction forces for all tasks except kneel/stand.

Results: RPE and GCPS trends were similar for VW and VM where trends could be directly compared. Extrapolations of the VM data seem to indicate that as TGAW increased beyond 333 N, VM would lead to higher RPE and GCPS ratings than VW, but as TGAW decreased below 333 N, trends for VM and VW were similar (Figure 1).

For the VC series, mean RPE and GCPS were highest at CG location P for all tasks (Figure 2 & Figure 3). Variability was greatest at B and lowest at C, and large variations between subjects at the same CG existed for both RPE and GCPS. These trends were not consistent with results from unsuited CG studies performed in the underwater and overhead suspension lunar gravity simulations.

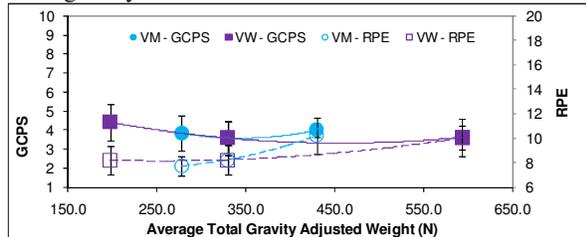


Figure 1. GCPS & RPE comparison of VW & VM series

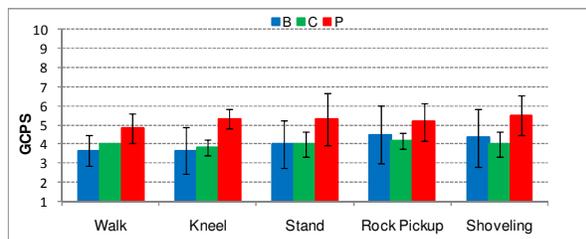


Figure 2. GCPS comparison from VC series

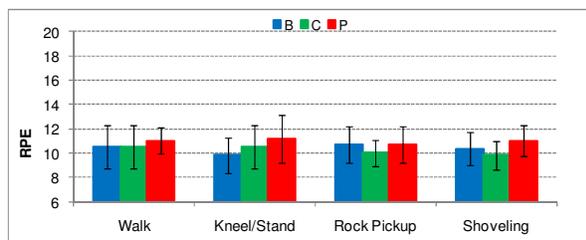


Figure 3. RPE comparison from VC series

Discussion: Modeling a change in suit mass by altering weight alone may be an adequate simulation through a limited range when looking at gross metrics of subjective performance of suited humans, but whether it would be sufficient for more precise metrics of human performance still needs further study. Modifying CG during suited testing at lunar gravity seems to affect subjective performance ratings. However, intersubject variation in subjective ratings at a given CG indicates that further study is needed to evaluate interactions among lunar-gravity simulation, system CG, system mass, and subject characteristics such as anthropometry, strength, and fitness.

The ability to compare results from parabolic flight with those from ground-based tests was limited. Subtle differences in experiment setup, lack of direct crossover test points, and subject population differences may have contributed to the comparability of the results.

Kinematic and ground reaction force data were highly variable due to volumetric limitations and the variability of the acceleration levels during a parabola. Volumetric constraints affected the ability of the subjects to attain a stable gait during walking due to the need to stop, turn, and start in the confined area compared to an uninterrupted treadmill gait on the ground. Acceleration variations during parabolas limited the ability to allocate differences in ground reaction forces to condition changes versus aircraft-induced disturbances.

Conclusions: Suited human performance testing during parabolic flight can provide the most realistic simulation of reduced gravity because the human, suit, and all associated equipment are in the reduced-gravity field. However, limitations of the test environment can affect the quality of the data collected. The short duration of each parabola (15-30 s) precludes assessment of metabolic rate. Airplane cabin dimensions limit data collection capabilities and the tasks that can be performed, and may cause subjects to adjust their gait style. Aircraft acceleration variability can affect the ability to discern condition-related changes. Even with these limitations, much can be done to improve the utility of data collected during parabolic flight and its applicability across other lunar-gravity analogs. Utilization of aircraft and aircrews that can provide maximum-duration parabolas with the required acceleration accuracy will provide the best environment for research. Maximizing the length of the cabin available for tasks such as ambulation or increasing cabin height to allow use of a force plate-fitted treadmill will allow suited subjects to attain a stable gait. To maximize the ability to compare data from parabolic flight with that from other simulated reduced-gravity analogs, tests performed in other analogs should be designed with identical constraints regarding equipment, task duration, methods, and subjects. Finally, the costs associated with performing experiments using parabolic flight must be kept within reach of available research budgets that provide sufficient numbers of subjects and task repetitions. These improvements would maximize the ability to achieve meaningful significant differences and to make the most informed recommendations for future lunar spacesuit designs to optimize human performance.

References: [1] Gernhardt, M. L. (2009) Personal Communication. [2] Borg G. A. (1996) Borg's Perceived Exertion and Pain Scales. Champaign, IL: Human Kinetics. [3] Norcross J.R. et al. (2009), Feasibility of Performing a Suited 10-km Ambulation on the Moon - Final Report of the EVA Walkback Test (EWT). NAST TP-2009-214796.