A Methodology for Analyzing and Improving EVA Performance

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ABSTRACT

Future missions to the Moon, Mars, and beyond will result in an increase in extravehicular activity (EVA). In addition to a surge in number, planetary EVAs will be more complex than the current EVAs performed on the International Space Station because of required ambulation on the ground to move between mission locations. Gas-pressurized spacesuits, such as the current xEMU, are cumbersome and difficult to operate as a result of high pressure, improper fit, the weight of the spacesuit, and volume changes of the soft materials during movement. Poor performance from these factors may ultimately lead to suboptimal EVA performance and impact mission success. Thus, a robust metabolic model and path planning tool to minimize the effect of poor spacesuit performance would be beneficial. Metabolic modeling and prediction (both before the mission and in real-time) for planetary EVAs can provide invaluable information about the crewmember's health, path planning, and real-time re-planning, and ultimately inform operational decisions during EVA traverses.

There have been limited studies on modeling energy expenditure of ambulation in a spacesuit. Norcross and his colleagues at NASA's Johnson Space Center completed a series of tests where subjects walked both unsuited and suited in the Mark III (MKIII) spacesuit at varying speeds, suit pressures, inclines, and gravities to determine the effects each factor on metabolic cost [1]. From all the collected data, a multiple linear regression model was developed to predict metabolic rate of locomotion in the MKIII as a function of properties of the spacesuit, anthropometry of the subject, and speed of the subject. This linear model does not consider the complex interactions between the many variables that impact metabolic rate. In 2014, McFarland and Norcross evaluated the mobility of the MKIII and Z1 spacesuits, and later the Rear Entry I-Suit (REI), by conducting a set of 5 tasks. They concluded that metabolic testing continues to show great promise in characterizing spacesuit performance [2] but their simple model required further verification. Metabolic rate data and equations can be used to create a path planning tool such as SEXTANT (now a part of the NASA BASALT research project) to support planetary EVA and overall surface mobility. The currently implemented metabolic cost model for the tool was developed by Marquez [3] using extrapolations of the velocity and metabolic data from Apollo missions. This model is relatively simple and assumes constant walking velocities based on the terrain slope (i.e. for given slope, it is assumed that the astronaut would move at one specific velocity).

The goal of our research is to quantify and address the negative impacts of the spacesuit on human performance. Our first step is to better understand and quantify these spacesuits effects using biomechanical modeling approaches and tradeoff analyses. Variables of interest include spacesuit-induced joint torques, spacesuit pressure, mobility performance, and metabolic predictions. Next, we will supplement existing partial gravity walking data with additional ambulation data via two hypogravity analogs: body weight support systems (BWSS) and water immersion. Currently, we are performing experiments with a BWSS system at a range of gravity levels and velocities to gather kinematic, kinetic, and metabolic data. Following these studies, the goal is to create a novel metabolic model using the data we collected in addition to available data from suited and unsuited ambulation studies. This model will address the limitations of previous models and allow for real-time metabolic prediction. The model will also aid in measuring the impact of our new spacesuit technologies currently under development. Our final goal is to integrate our metabolic model into a path planning tool. This tool will be valuable for both mission planning and real-time operations during planetary missions.

[1] J. R. Norcross *et al.*, "Metabolic Costs and Biomechanics of Level Ambulation in a Planetary Suit," *NASA Tech. Rep.*, 2010, [Online]. Available: http://www.sti.nasa.gov.

[2] S. M. Mcfarland and J. R. Norcross, "Development Of An Objective Space Suit Mobility Performance Metric Using Metabolic Cost and Functional Tasks," *46th Int. Conf. Environ. Syst.*, no. July, 2016.

[3] J. J. Marquez and M. L. Cummings, "Design and evaluation of path planning decision support for planetary surface exploration," *J. Aerosp. Comput. Inf. Commun.*, vol. 5, no. 3, pp. 57–71, Mar. 2008, doi: 10.2514/1.26248.