EVA Performance Prediction

Brian Peacock, Sudhakar Rajulu, James Maida
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Abstract

Astronaut physical performance capabilities in microgravity EVA or on planetary surfaces when encumbered by a life support suit and debilitated by a long exposure to microgravity will be less than unencumbered pre flight capabilities. The big question addressed by human factors engineers is: what can the astronaut be expected to do on EVA or when we arrive at a planetary surface? A second question is: what aids to performance will be needed to enhance the human physical capability?

These questions are important for a number of reasons. First it is necessary to carry out accurate planning of human physical demands to ensure that time and energy critical tasks can be carried out with confidence. Second it is important that the crew members (and their ground or planetary base monitors) have a realistic picture of their own capabilities, as excessive fatigue can lead to catastrophic failure. Third it is important to design appropriate equipment to enhance human sensory capabilities, locomotion, materials handling and manipulation.

The evidence from physiological research points to musculoskeletal, cardiovascular and neurovestibular degradation during long duration exposure to microgravity. The evidence from the biomechanics laboratory (and the Neutral Buoyancy Laboratory) points to a reduction in range of motion, strength and stamina when encumbered by a pressurized suit. The evidence from a long history of EVAs is that crewmembers are indeed restricted in their physical capabilities. There is a wealth of evidence in the literature on the causes and effects of degraded human performance in the laboratory, in sports and athletics, in industry and in other physically demanding jobs.

One approach to this challenge is through biomechanical and performance modeling. Such models must be based on thorough task analysis, reliable human performance data from controlled studies, and functional extrapolations validated in analog contexts. The task analyses currently carried out for EVA activities are based more on extensive domain experience than any formal analytic structure. Conversely, physical task analysis for industrial and uniformed services tasks on earth are much more formalized. Human performance data in the space context has two sources: first there is the micro analysis of performance in structured tasks by the space physiology community and second there is the less structured evidence from training and EVA contexts. Again on earth there is considerable evidence of human performance degradation due to encumbrance and fatigue. These industrial models generally take the form of a discounting equation. The development of performance estimates for space operations, such as timeline predictions for EVA is generally based on specific input from training activity, for example in the NBL or KC135.

Industrial operations models have been around for many years and aspire to varying levels of precision. For example Rohmert (1973) and Rose (2000) developed endurance decay curves for overhead muscular work and recently Gonzalez et al (2002) developed similar curves for the effects of pressurized suits. Crowden (1932) developed physiological fatigue and recovery curves for manual work. Waters et al (1993) developed a discounting model for manual materials handling that accounted for a variety of task parameters. The general industrial ergonomics literature (Konz and Johnson, 2000) describes various approaches to task planning allowances for such things as fatigue, environmental factors, restrictive clothing and other task related factors. In practice industrial task planners often use less elaborate rules of thumb such as the "one third rule" (Peacock, 2001) to design the physical content of repetitive work. There is also extensive evidence from the athletics literature, specifically from endurance events, on the relationship between chosen pacing strategy and performance. Recently (Peacock, 2004) has proposed a discounting model that accounts for individual, time, environmental and task effects on performance.

The purpose of this paper is to propose a physical performance model for space operations – specifically, microgravity EVA and planetary surface – that accounts for individual, environmental, clothing, task and time variables. The initial model is based on physical activities on earth, with data from the published literature. This model is then extended to the space context, particularly by observation of performance during training in pressurized suits. Evidence on physical capacity deterioration following extended space flight will be included where available. Finally the model will be validated by comparison with quantitative evidence from past EVAs. The result of this research will be an activity planning model that reliably predicts what can be expected of crew members during long duration space exploration missions.

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