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| **Fiscal Year:** | FY 2008 | **Task Last Updated:** | FY 10/07/2008 |
| **PI Name:** | Newman, Dava J. Ph.D. | | |
| **Project Title:** | Advanced EVA Biomedical & Energetics Performance and Space Suit Assessment | | |
| **Division Name:** | Human Research | | |
| **Program/Discipline:** | NSBRI Teams | | |
| **Program/Discipline--Element/Subdiscipline:** | NSBRI Teams--Technology Development Team | | |
| **Joint Agency Name:** | | **TechPort:** | No |
| **Human Research Program Elements:** | None | | |
| **Human Research Program Risks:** | (1) **EVA**:Risk of Injury and Compromised Performance Due to EVA Operations | | |
| **Space Biology Element:** | None | | |
| **Space Biology Cross-Element Discipline:** | None | | |
| **Space Biology Special Category:** | None | | |
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| **Zip Code:** | 02139-4301 | **Congressional District:** | 8 |
| **Comments:** | | | |
| **Project Type:** | GROUND | **Solicitation / Funding Source:** | Directed Research |
| **Start Date:** | 11/01/2006 | **End Date:** | 04/30/2008 |
| **No. of Post Docs:** | 1 | **No. of PhD Degrees:** | 2 |
| **No. of PhD Candidates:** | 2 | **No. of Master' Degrees:** | 0 |
| **No. of Master's Candidates:** | 3 | **No. of Bachelor's Degrees:** | 2 |
| **No. of Bachelor's Candidates:** | 2 | **Monitoring Center:** | NSBRI |
| **Contact Monitor:** | | **Contact Phone:** | |
| **Contact Email:** | | | |
| **Flight Program:** | | | |
| **Flight Assignment:** | | | |
| **Key Personnel Changes/Previous PI:** | | | |
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| **Performance Goal Text:** | | | |

To support NASA and NSBRI advanced EVA biomedical research, the MIT EVA research team provided robotic spacesuit testing of a spacesuit exoskeleton knee joint, developed a planetary EVA mission planning capability, and reviewed biomechanics and energetics results of partial gravity locomotion.
Human and robotic testing of a Space Suit Simulator (S3) was performed by Professor Newman and her team and MIT for NASA colleagues (Dr. Schaffner of Wyle Laboratories and Dr. Gernhardt of NASA Johnson Space Center). The S3 program involved testing a right knee joint brace, or joint suit simulator, on the Robotic Space Suit Tester (RSST) at MIT in the Man-Vehicle Laboratory. Testing requirements achieved included: characterization of the sensitivity of the joint torque versus angle relationship on joint displacement speed; hysteresis behavior of the joint; quantification of the adjustability of joint range of motion; and the adjustability of joint friction and stiffness. All knee results show hysteresis of the joint, which is a characteristic of both the robot and actual space suit joint torques. Adjusting trajectory speed has little effect on maximum joint torques. For range of motion, three configurations of the knee joint

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| Task Description: | were tested: one without any limitation (0º - 130º), and two smaller ranges (20º - 110º and 40º - 90º). Torques were higher only for the most highly constrained case. As expected, joint torque increases with friction, but we also found that the range of motion decreases with increasing friction. Preliminary testing of aerogel swatches for EVA thermal protection was also performed. The swatches were sewn into arm sections and tested over the RSST elbow. These garments were considerably stronger than expected, and allowed for 130 degrees of movement without failing.<br><br>Another research deliverable under this project included developing a 3D EVA mission planning tool. Applied to future planetary manned missions, an EVA mission planner will assist astronauts plan and navigate their traverses, and will also inform the crewmember of planetary terrain mapping (digital elevation maps, editing, waypoint automation and path planning, 3D viewing and zooming), sun illumination levels, life support status, metabolic costs, scientific timelines and emergency walkback calculations. This research effort investigated the appropriate balance between humans and automation for geospatial path problem solving within the high-risk domain of human planetary surface exploration, where decisions are time critical and humans must adapt to uncertainty.<br><br>As a human-machine interface, the planner should function efficiently and intuitively with the astronaut. Cognitive decision making tools were studied, which showed that the path planning process should include 3 steps: collecting external information, integrating the information together with reference to costs and goals, and generating the path iteratively using a sensitivity analysis. The EVA mission planner allows for the collection of all pertinent information, such as physiological factors, navigating waypoints, obstacle settings/angles etc, and then uses a geographical information system for terrain data. An optimization algorithm then determines the most efficient path to achieve the desired waypoints using an EVA metabolic rate model. The best path is shown on a map in 3D for clear guidance to the astronaut. Early trials of the planner have proven to be a success. Navigating system will be highly valuable to astronauts during EVA on planetary surfaces.<br><br>The final component of this research effort was to review and quantify space suit biomechanics and energetics for planetary locomotion EVAs. We developed a framework for comparison of energetics data across and between all published lunar EVA studies published in the literature. Major factors affecting the energetic cost of movement while wearing a space suit include: suit pressurization, gravity, velocity, surface slope, and space suit configuration. Apollo lunar surface EVA on-foot locomotion metabolic rates, while unexpectedly low, were higher than other activity categories. In a follow on publication, we hypothesized that space suit legs act as springs during running, thereby lowering cost of transport relative to space-suited walking. We transformed data from suited and unsuited energetics studies into a common format and developed a regression equation for specific resistance, S, (energy per weight per distance) based on the Froude number (a non-dimensional parameter associated with gait transitions), surface slope, gravity, and space suit pressure. A regression on S achieved an adjusted R2 of 0.83; all factors were significant ($P<0.0005$). No additional evaluated factors met the acceptance criteria. The categorical regression, but not the hypothesis test, suggested that the running group had reduced efficiency per unit time; both tests suggested that the running group had increased efficiency per unit distance. Findings suggest that gas-pressure space suit legs function as springs during running, including the finding of higher efficiency per unit distance during running, despite the presumed increased work against space suit joint torques at higher velocities. |
| Rationale for HRP Directed Research: | |
| Research Impact/Earth Benefits: | RSST testing allowed for characterization of knee joint and aerogel garment torques. Our study refines a protocol to allow for the quantitative improvement of garments worn on earth. Materials, designs and tailoring techniques can be tested in short time frames to allow for quick optimization of thick or stiff garments. For instance, fire fighter pants must protect the wearer from extremes of temperature and also injury from falling debris, and yet allow quick locomotion and ladder climbing. The RSST protocol provides a framework and hardware for measuring joint torques - and thereby resistance to free movement - over extended periods with repetitive and precise movements that would not be possible for human subjects. Other tight or restrictive garments, such as therapeutic and rehabilitation designs, could also be tested using the system and protocol so that appropriate skin compression is produced while minimizing movement constraints.<br>The EVA mission planner will aid in the safe and efficient planning of any earth traverse, particularly where the subject/group needs to manage navigation, physiologic- and mission-specific information, all in time-finite situations. Planning traversals for complex scientific or information-rich exploration can be dangerous and inefficient. Further, managing significant information becomes increasingly difficult when the task changes to real-time re-planning of a traversal, i.e., new discoveries or discrepancies between planned and observed conditions demanding immediate selection of a new path while not violating mission constraints. Applications for this mission planner includes basic hiking and exploring, various scientific missions - such as geologic surveys in desert conditions - and especially expeditions to any extreme environments, such polar expeditions and deep-sea diving. |
| Task Progress: | Significant progress was made in the research program in the last funded year of 2007. The RSST was used successfully for two separate testing protocols: testing of a space suit simulator (S3) knee joint revealed important properties of the S3 as well as properties of the robot (e.g. differences between commanded input for movement and actual joint movement, due to the high-torque S3). The S3 was characterized in terms of joint stiffness, friction, range of motion, and preload to assist in the knee simulator development. As a separate project, advanced concept thermal samples from Aspen Aerogels were tested for material properties and feasibility for spacesuit outer garment use. Torque-vs-angle curves were generated for the robot elbow wearing an Aerogel sleeve, which was shown to move through a full elbow deflection of 130 degrees with minimal torque penalty. The testing protocols used in 2007 can be extended to future materials or garments. The robot is functional and produces reliable results.<br>A planetary EVA mission planner was also developed and tested as part of the funded project. This study focused on improving planetary EVAs through human and automation collaboration by investigating the real-time task of traversal planning and re-planning, and creating a tool for such EVA mission planning. Cognitive decision making tools were studied, which showed that the path planning process should include 3 steps: collecting external information, integrating the information together with reference to costs and goals, and generating the path iteratively using a sensitivity analysis. The EVA mission planner allows for the collection of all pertinent information, such as physiological factors, navigating waypoints, obstacle settings/angles etc, and then uses a geographical information system for terrain data. An optimization algorithm then determines the most efficient and safe path to traverse the desired waypoints using an EVA metabolic rate model. The best path is shown on a map in 3D for clear guidance to the astronaut. Early trials of the |

planner around the MIT campus have proven to be a success.

As a further component to the research program, we quantified space suit biomechanics and energetics using a partial gravity simulator. Metabolic costs limit the duration and intensity of extravehicular activity (EVA), an essential component of future human missions to the Moon and Mars. We developed a framework for comparison of energetics data across and between published partial gravity EVA studies. We found that gas-pressure space suit legs function as springs during running, including the finding of higher efficiency per unit distance during running, despite the presumed increased work against space suit joint torques at higher velocities.

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| **Bibliography Type:** | Description: (Last Updated: 03/20/2019) |
| **Abstracts for Journals and Proceedings** | Newman DJ, Edmonds J, Waldie JM A, Hoffman J, Lindqvist L, Carr CE, Marquez J. "EVA biomechanics & energetics performance: space suit assessment." NASA Human Research Program Investigators' Workshop, League City, Texas, February 4-6, 2008.<br>NASA Human Research Program Investigators' Workshop, League City, Texas, February 4-6, 2008. , Feb-2008 |
| **Papers from Meeting Proceedings** | Marquez JM, Newman DJ. "Recommendations for real-time decision support systems for lunar and planetary EVAs." 37th International Conference on Environmental Systems, Chicago, IL, July 9-12, 2007.<br>SAE paper 2007-01-3089. Warrendale, PA : SAE, 2007. , Jul-2007 |
| **Papers from Meeting Proceedings** | Rader AR, Newman DJ, Carr CE. "Loping: A strategy for human locomotion?" 37th International Conference on Environmental Systems, Chicago, IL, July 9-12, 2007.<br>SAE paper 2007-01-3134. Warrendale, PA : SAE, 2007. , Jul-2007 |