Space Suit Performance: Methods for Changing the Quality of Quantitative Data

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Introduction: NASA is currently designing a new space suit capable of working in deep space and on Mars. Designing a suit is very difficult and often requires trade-offs between performance, cost, mass, and system complexity. To verify that new suits will enable astronauts to perform to their maximum capacity, prototype suits must be built and tested with human subjects. However, engineers and flight surgeons often have difficulty understanding and applying traditional representations of human data without training.

To overcome these challenges, NASA is developing modern simulation and analysis techniques that focus on 3D visualization. Early understanding of actual performance early on in the design cycle is extremely advantageous to increase performance capabilities, reduce the risk of injury, and reduce costs. The primary objective of this project was to test modern simulation and analysis techniques for evaluating the performance of a human operating in extra-vehicular space suits.

Methods: Subjects performed functional tasks and isolated motions to obtain a baseline for human performance in a suit. Nine subjects were used during testing, four in the Mark III planetary space suit demonstrator and five in the Z1 prototype suit. The hip joint of the Mark III suit was tested with four different joint configurations, while the Z1 was tested in a single hybrid configuration. Results were analyzed and displayed in 3D spherical coordinate plots or 3D CAD representations.

Human performance data was analyzed using customized analysis scripts in BodyBuilder (Vicon, Oxford, UK) and MATLAB (MathWorks, Natick, MA, USA). Simulations were created using the SolidWorks Simulation platform (Dassault Systems SolidWorks, Waltham, MA, USA).

Results: Results for the Mark III showed that traditional Euler angle data under-estimated hip flexion-extension by 12% due to an inability to account for out-of-plane motion. A reduction in the maximum hip abducted position was 60% for one hip joint condition when considered in 2D, but the 3D work envelope showed a volume reduction of over 90%. The volumetric data also showed there was only a 14% overlap between the desired hip joint work envelope for an unsuited subject and the suit's actual hip joint work envelope. Similar results for the Z1 showed that there were only minimal benefits with its hybrid design when analyzed in 3D.

Discussion: Results showed the large discrepancies in the data's possible interpretations when analyzing the data with different methods. Using 3D visualization techniques is a feasible tool for evaluating human performance, especially when analyzing out-of-plane motions. The suit simulation model was found to be advantageous in its ability to visually represent complex motions and volumetric work envelops in three dimensions.

Conclusion: Results demonstrated that 3D data representation provided a much more holistic look at functional performance and increased the ability to perform qualitative assessment of the quantitative data. This method was also found to be beneficial because of its ability to visually represent complex bearing rotations and volumetric ranges of motion in 3D. Visually quantifying these differences will give designers and flight surgeons a faster and deeper comprehension of suit performance, human performance, and injury risks and will help to optimize suit designs to match the needed human performance much more efficiently.