Computational Modeling of Astronaut Kinematics and Injury Risks in a Standing Posture During Lunar Launch and Landing

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Introduction

For the Artemis missions to the lunar surface, NASA is planning to use the Gateway, a rendezvous point located in a lunar orbit. Astronauts will employ a transfer vehicle to travel from the Gateway to low lunar orbit, a descent vehicle to land on the surface of the Moon, and an ascent vehicle to return to the Gateway. Since the Moon's gravity is 6 times lower than Earth's gravity, astronauts may pilot a lunar transfer vehicle in the standing posture (similar to the Apollo missions), rather than a conventional seated posture. This study aims to quantify and understand injury risks and body kinematics for astronauts in a standing posture during vehicle launch, abort, and landing scenarios encountered in space missions using finite element human body modeling.

Methodology

Dynamic loading conditions during lunar missions were computationally simulated using the simplified Global Human Body Models Consortium (GHBMC) 50th percentile male pedestrian model (M50-PS v. 1.5.2 Elemance, Clemmons, NC). The model was repositioned and gravity settled in a neutral standing stance using dynamic simulations to represent the standing posture of an astronaut. The model was constrained to the ground by modeling a foot harness using feet straps. Dynamic loading conditions were simulated by applying a half-sinusoidal acceleration pulse with varied peak acceleration and rise time to the ground in the vertical and 10˚ offsets in the lateral and anterior-posterior directions relative to the vertical axis. Simulations were carried out using three different acceleration pulses – 49 m/s^2 (5g) peak acceleration with 10 ms rise time, 19.6 m/s^2 (2g) peak acceleration with 50 ms rise time, and 26.5 m/s^2 (2.7g) peak acceleration with 150 ms rise time. Effects of lunar gravity were simulated by applying gravitational acceleration of 1.63 m/s^2 in the vertical direction. A total of 30 simulations (10 directions×3 pulses) were carried out to simulate different launch, landing and abort scenarios during lunar missions.

Results and Conclusion

From each simulation, different injury metrics– head acceleration, head injury criterion (HIC), neck injury criteria (Nij), vertebral forces at C2 and L1 levels, femur and tibia forces and moments, revised tibia index (RTI), knee ligament forces, and ground reaction forces were extracted and compared against injury assessment reference values (IARVs) available from literature to compute injury risks. Also, kinematic responses – head displacement and arms motion corridor were extracted. Simulations showed that all the injury metrics were within the injury tolerance limit, except the upper RTI for 2.7g acceleration. Statistical regression analysis showed that of total variation in injury metrics, 94% was related to pulse magnitude and rise time and only 1.8% was explained by the direction of loading. Kinematic responses showed the range of motion for head and arms, which could inform the design of the lunar transport vehicle, spacesuits, and spacesuit helmet to minimize the injury risk due to interaction between astronaut body parts and surrounding hardware.

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