ASSESSING THE RISK OF CREW INJURY DUE TO DYNAMIC LOADS DURING SPACEFLIGHT

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Spaceflight requires tremendous amounts of energy to achieve Earth orbit and to attain escape velocity for interplanetary missions. Although the majority of the energy is managed in such a way as to limit the accelerations on the crew, several mission phases may result in crew exposure to dynamic loads. In the automotive industry, risk of serious injury can be tolerated because the probability of a crash is remote each time a person enters a vehicle, resulting in a low total risk of injury. For spaceflight, the level of acceptable injury risk must be lower to achieve a low total risk of injury because the dynamic loads are expected on each flight. To mitigate the risk of injury due to dynamic loads, the NASA Human Research Program has developed a research plan to inform the knowledge gaps and develop relevant tools for assessing injury risk.

The risk of injury due to dynamic loads can be further subdivided into extrinsic and intrinsic risk factors. Extrinsic risk factors include the vehicle dynamic profile, seat and restraint design, and spacesuit design. Human tolerance to loads varies considerably depending on the direction, amplitude, and rise-time of acceleration therefore the orientation of the body to the dynamic vector is critical to determining crew risk of injury. Although a particular vehicle dynamic profile may be safe for a particular design, the seat, restraint, and suit designs can affect the risk of injury due to localized effects. In addition, characteristics intrinsic to the crewmember may also contribute to the risk of injury, such as crewmember sex, age, anthropometry, and deconditioning due to spaceflight, and each astronaut may have a different risk profile because of these factors. The purpose of the research plan is to address any knowledge gaps in the risk factors to mitigate injury risk.

Methods for assessing injury risk have been well documented in other analogous industries and include human volunteer testing, human exposure to dynamic environments, post-mortem human subject (PMHS) testing, animal testing, anthropomorphic test devices (ATD), dynamic models of the human, numerical models of ATDs, and numerical models of the human. Each has inherent strengths and limitations. For example, human volunteer testing is advantageous because a population can be selected that is similar to the astronaut corps; however, because of the inherent ethical limitations, only sub-injurious conditions can be tested. PMHSs can be tested in a variety of conditions including injurious levels, but the responses are not completely analogous to living human subjects. In addition, it is exceedingly difficult to select a PMHS population that is similar to the astronaut corps. ATDs are currently widely used in the automotive industry and military because they are highly repeatable and durable. Unfortunately, because they are mechanical models of the human body, the biofidelity of the responses are limited to dynamic conditions used to validate the ATD. Numerical models of the ATD, in addition to the strengths and limitations for ATDs, are easy to use for a variety of designs before a design is fabricated, but also have additional uncertainty. Dynamic models are simple and easy to use, but do not account for localized effects of the seat and suit. Finally, numerical models of the human have the potential to have the most advantages; however, the current models are not validated for the conditions expected during spaceflight. To properly assess spaceflight conditions with numerical human models, human data would be needed to optimize the model responses for those conditions.

Using the appropriate assessment method with the knowledge gained for each risk factor, an appropriate approach for mitigating the risk of injury due to dynamic loads can be developed ensuring crew safety in future NASA vehicles.