Multipurpose Crew Restraint Development for Long-Duration Space Flights

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Humans will be living and working in microgravity for increasingly longer periods during the planned missions to the Moon and Mars. Given the challenges of weightlessness and the confinement of a relatively small spacecraft, these crewmembers will be faced with ergonomic challenges involving limitations on space, stability, and visibility within their work areas. These challenges can result in prolonged periods of unnatural postures of the crew, ultimately causing pain, injury, and loss of productivity.

While a number of general-purpose restraints, such as handrails and foot loops, have been used on the Space Station, experience has shown that these general-purpose restraints may not be optimal, or even acceptable, for some tasks that have unique requirements. Activities, such as teleoperation of a robot, will require a restraint with the flexibility to allow for torso movement. Tasks such as microsurgery or slide preparation will require a great deal of stability. The Usability Testing and Analysis Facility (UTAF) at Johnson Space Center (JSC) has recently completed a series of evaluations of three basic types of restraints onboard NASA's reduced gravity aircraft (KC-135): general-purpose restraints, teleoperation restraints, and restraints for glovebox operations. During the flight tests, participants performed representative onboard tasks while in each type of restraint. The flight sessions were videotaped, and participants completed a questionnaire, which included ratings and free response questions, at the end of each flight day. The primary goal of these evaluations was not to evaluate/approve a final design, but rather to identify restraint components/concepts that work well in microgravity and to develop human factors design requirements based on the results.

For the purpose of this project, general purpose restraints were defined as very simple pieces of hardware that could provide minimal restraint for a number of different types of tasks. The following general purpose restraint concepts were developed for testing: padded and unpadded handrail, padded socks, and web restraint.

The UTAF partnered with the Robot Systems Technology Branch at JSC to develop and test a restraint for teleoperation of the Robonaut, a robot astronaut. An astronaut located inside the Space Station will remotely operate Robonaut through a telepresence control system. Essentially, Robonaut mimics every move the operator makes. This requires the operator to be stable enough to prevent inadvertent movements while allowing the flexibility to accomplish the controlled movements of the robot. The restraint developed uses padded roller bars to pin comfortably the thigh and shin, allowing the operator's torso, arms, and feet to move freely for teleoperation.

Six types of restraint components—foot plates, foot roller bars, thigh bar, shin bar, bungee cord, and lumbar support—were evaluated to address the high degree of stability required for glovebox operations. A tripod structure was used as a support base for the reconfigurable restraint components.

The restraints were developed using a human factors engineering design process, which included requirements gathering, graphical modeling for the range of crewmember

Type of Restraint	Good Results/ High Preference	Needs More Research	Poor Results/ Low Preference
Unpadded Handrail			X (uncomfortable)
Padded Handrail	X		
Padded Socks			X (less comfort, more hassle)
Web			X (too flexible)
Robonaut Restraint	X		
Foot plates	X		
Foot Roller Bars		X (mixed results)	
Thigh Bar		X (mixed comments)	
Shin Bar			X (unnecessary with foot plates)
Bungee Cord		X (need more data, lowest gloveport loads)	
Lumbar Support			X (unnecessary)

sizes, and fabrication and testing. All of the restraint designs were evaluated across three KC-135 flight evaluations. This airplane flies a parabolic flight path to generate approximately 23 seconds of microgravity. Each flight evaluation consisted of approximately 40 parabolas. Multiple participants, who were simultaneously performing representative onboard tasks while in the various restraints, were involved in each flight evaluation. General-purpose restraints were evaluated while participants performed some technology studies; the Robonaut restraint was evaluated while operating the Robonaut optical tracking system; and glovebox restraints were evaluated while participants worked inside a medium-fidelity Life Sciences glovebox mockup. Participants were JSC employees, including a few astronauts and contractor personnel certified to fly on the KC-135. The flight sessions were videotaped, and participants completed a questionnaire, which included ratings and free response questions, at the end of each flight day. Load cells were placed on the glove ports for the last flight evaluation to serve as a potential measure of restraint adequacy.

The table, which represents a high-level summary of the results found, indicates which components had positive results, which need more research, and which did not work well in microgravity.

No forces greater than 10 lbs were applied to the glove ports. For tasks such as filter changeout, a deep reach activity, higher forces were applied as expected. Overall, the least amount of force was applied when the participants used the bungee cord restraint.

We have learned much about crew restraints in microgravity, but these evaluations are only a beginning. As we complete additional concept work, we will need to emphasize methods and ease of attachment, adjustability, stowage, and setup. One crewmember who participated in the flight evaluations observed that the best overall solution would be to give the crewmember options. Some crewmembers will prefer more restraint and some less; some tasks will require more stability than other tasks, and crewmembers already well-adapted to the microgravity environment will need less restraint than those new to microgravity. We should factor this valuable observation into further development efforts.