The Use of Human Factors Simulation to Conserve Operations Expense

H. Charles Dischinger, Jr.; George S. Hamilton; and *Hsin-I. Wu.
NASA/Marshall Space Flight Center and *Texas A&M University.

Abstract. In preparation for on-orbit operations, NASA performs experiments aboard a KC-135 which performs parabolic maneuvers, resulting in short periods of microgravity. While considerably less expensive than space operations, the use of this aircraft is costly. Simulation of tasks to be performed during the flight can allow the participants to optimize hardware configuration and crew interaction prior to flight. This presentation will demonstrate the utility of such simulation. The experiment simulated is the fluid dynamics of epoxy components which may be used in a patch kit in the event of meteoroid damage to the International Space Station. Improved configuration and operational efficiencies were reflected in early and increased data collection.

Introduction.

Need for simulation. In an era of reduced and reducing budgets, NASA is turning to technology to find new methods to develop flight hardware in ways that are "faster, better, and cheaper." The solutions are typically found in simulation software packages. Utilization of human and human task simulation affords the opportunity to evaluate a variety of design, operational, and teaming options prior to the integration of real humans into a real hardware system and even prior to the fabrication of the hardware.

While this is true for on-orbit task design, it also applies to preflight testing, operations preparation, and training. Human factors simulation has been used at Marshall Space Flight Center to prepare for neutral buoyancy testing, with significant increases in test efficiency (Etter, Dischinger, and Loughead, 1996; Dischinger and Loughead, 1998). This increase in efficiency was reflected both in test streamlining and in improvement of task success. These in turn result in shortening of costly test time and reduction in amount of retest required.

The flight of hardware on the NASA KC-135 airplane represents a sort of halfway-point in hardware development. This airplane provides short bursts of microgravity that afford experimenters the opportunity to study the response of their systems to the on-orbit gravity regime. The hardware utilized is developed specifically for the parabolic flight environment. Airplane use is expensive: the developer pays for plane usage by the week and by the amount of floorspace occupied. Optimization of inflight operations time and of floorspace utilization has direct impact on the development budget.

Space Station example. The International Space Station will operate in an orbital debris-laden environment. Experience with Mir and the U.S. Shuttle shows that most impacts from debris and micrometeoroids are not vehicle-threatening. However, contingency preparations must be made, in the event of a module puncture (debris and meteoroids in the range of 1 cm are able to create punctures). Among these preparations is the Marshall Space Flight Center development of a patch kit with the acronym KERMIt (for Kit for External Repair of Module Impacts). KERMIt Includes a metal or plexiglass disc patch which uses an epoxy sealant. This sealant would be injected by spacesuited astronauts under the patch after the latter is attached to the hole. Two hand-pumped injectors would be used to insert the epoxy components, which then must mix to form the sealant. The mixing characteristics of these substances in microgravity need to be understood before such a system can be rated acceptable for on-orbit use. The KC-135 offered the KERMIt developers the opportunity to conduct the requisite mixing studies.

Methods. Flight time and floorspace on the aircraft were purchased by the KERMIt project. In preparation for the reduced-gravity flights of the mixing experiment, a series of simulations was run to support the flight configuration and the team operations. Since this was primarily a fluid dynamics study, experimental hardware setup was developed to collect visual data from a mixing chamber. The mixing chamber was designed to reflect the flow and mixing environments that would be available on-orbit, but with the allowance that full camera viewing of the interior of the mixing chamber be provided. The epoxy resin injection system consisted of engineering prototypes of the flight injector units. Three or four cameras were to be placed around the mixing chamber to collect the mixing data.

KC-135 operations. The airplane typically flies about a half-hour out from its home base and begins climb and then dive, flying parabola patterns. As the top of a parabola is reached, the internal gravitational effects rapidly decline to very low levels (milligravity range). These levels are maintained for between twenty and twenty-five seconds, at which time the pilot must pull out and climb again to repeat the cycle. In the course of an experimental flight, the plane typically flies between thirty and forty parabolas. During each of these, an experiment team such as the KERMIt team has about twenty-two seconds to collect data. It is therefore important that every second of reduced gravity be available for data collection. That is, reconfiguration of hardware between experimental runs (during parabolic dives) should optimally be achieved during the pullout and ascent phase of the parabolas. In addition, the optimal use of flight time requires that all parabolas be utilized for data collection. In reality, this rarely happens. The typical flight week runs from Tuesday through Friday; Monday is a training day. Most experimental teams spend Tuesday, often Wednesday, and even Thursday developing the best working environment for collecting data. This includes decisions about hardware configuration and choreography of the team operations. The former results in laying out the hardware on the cabin floor in such a way as to place items within reach. The scripting (even if informal) of team member positions and movement flow allows the proper tools to be available at the appropriate time. The time invested in this effort is costly in several respects. The team may find they did not need to rent as much of the floorspace as they did. Given that the number of opportunities to collect data is limited from the outset, each opportunity (parabola) invested in test development means that the cost of each true data collection parabola is increased. Finally, while materials were not limiting for the KERMIt team (the epoxy used, while somewhat expensive, was available from industrial suppliers), in some experiments, the supply of experimental material is very short.

The value-added aspect of the simulation. It was the belief of the KERMIt team that simulation of hardware configurations, team size, and experimental operations would help reduce the amount of floorspace utilized and increase the amount of time spent collecting data. It was their desire to be sufficiently prepared for the flight that the optimal amount of floorspace could be rented and the flight experimental operations could begin much earlier than normal. The questions they asked us to address were: what is the best layout of the hardware to support the tasks; how many people will be required; and how can the tasks be choreographed?

The KERMIt experimental design. The KERMIt team required two operators of the epoxy injectors. These operators would need to be in place each time a dive began, and it was determined that the best way to accomplish this was to immobilize them with restraint straps fixing them to the cabin floor. They were thus rendered unavailable for climb-phase operations such as retrieval of new epoxy cartridges for their injectors and film changeout. The question about team structure then became: how many *more* than these two are needed? The other team member(s) would need to be able to check and adjust camera settings, reload film cartridges, and acquire epoxy cartridges for the injector operators. It was readily agreed that at least two additional team members would be preferred, one for each of the task classes (camera operations and injector operations). Was it possible that three would be needed? This decision was important, as all tasks must be accomplished in the climb phase. The ability of the team to complete them could be compromised if team members get in each other's way.

The optimal layout of the experimental hardware would allow a smooth flow of team member movement while minimizing the floorspace required. The hardware consisted of the mixing chamber, the two injectors, and three cameras in a fixed arrangement (Figure 1). In addition, supply and tool boxes needed to be placed around this assembly to support but not interfere with operations.

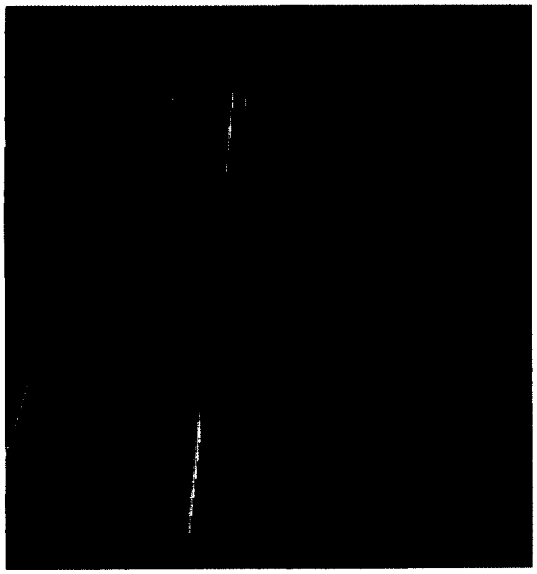

Figure 1. Hardware configuration in the "square" supply box layout. Three cameras, two epoxy injectors, a mixing chamber, and four stowage boxes are shown.

The simulation environment. ERGO, a module of the Deneb Robotics package IGRIP, was used to develop the simulations. CAD models of the injectors and mixing chamber were imported from the hardware developers. Models of the cameras, cartridges, and tool/supply boxes were developed using the CAD capabilities in ERGO. The hardware assemblies to be tested were placed on a model of the aircraft cabin floor (the cabin floor is represented in the simulations by the grayed area and constitutes a width spacing constraint). Simulations were run using different hardware configurations, different numbers of team members, and different choreography. Linear, square (Figure 1), and "L-shaped" arrangements of the support hardware containers were examined in simulations, each with four or five team members.

Results. One of the first configurations suggeste4d by the KERMIt team was the square arrangement of the tool/supply boxes illustrated in Figure 1. It was determined that this arrangement afforded the smoothest access to all necessary supplies. While four team members could be shown to easily accomplish the tasks (Figure 2), it was decided that five should fly. The fifth person would "float." He or she was to be available to jump in to support emergency situations, when either the camera- or the injector-support person ran into difficulty.

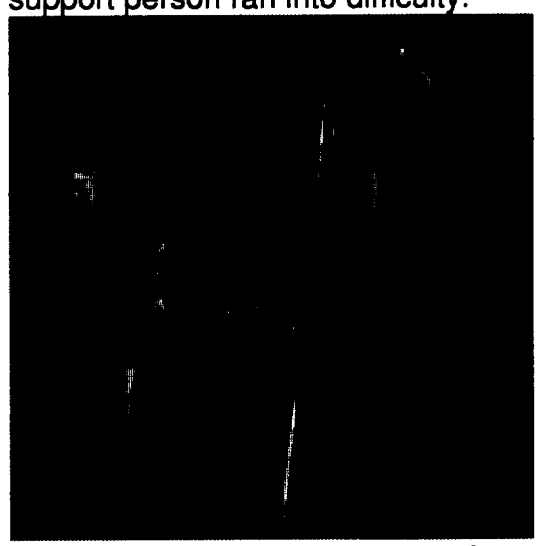

Figure 2. Teamwork simulation among four workers in the optimal hardware configuration.

The KERMIt team members wanted to explore the possibilities of using different numbers of experimental crewmembers and different hardware arrangements in order to either utilize reduced crew manpower or increase data collected. The first question to be explored was whether two people could operate the system. The need to conduct experiments with only two test crew could result from unavailability of team members during the flight week or, more likely, from illness during flight. Motion sickness is a common phenomenon among KC-135 test crews.

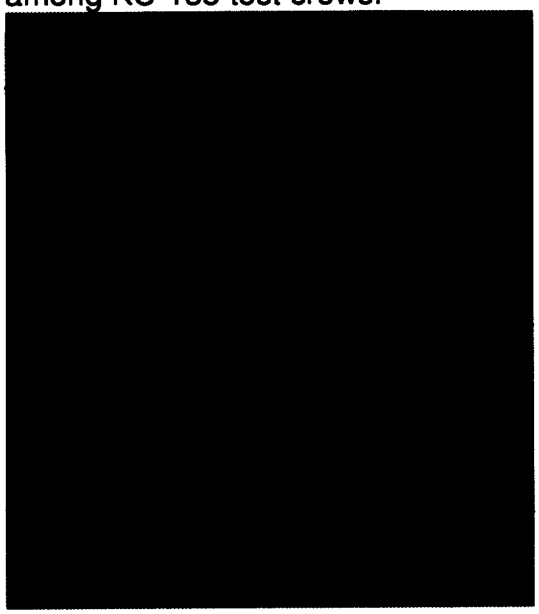

Figure 3. Arrangement of hardware that might support operations by two experimenters.

Figure 3 illustrates the limitations to this approach. Operation of the injectors is a two-handed task, making the configuration illustrated unfeasible. If both operators are dedicated to the injectors, there is not enough time to perform the camera and injector resupply tasks during ascent. In this circumstance, the KERMIt team recognized there would be a decline in data collection.

At the other extreme, we tried to address the questions of how much hardware and how many people could be crammed into a small amount of floorspace. Figure 4 is an example of a conceivable but unworkable solution.

Figure 4. An extra mixing chamber assembly and more people have been added to the work environment, in an attempt to increase data collection.

The attempt to add hardware (another mixing chamber and cameras) without purchasing additional length of floorspace results in interference between the camera attendant and the supply box or another worker trying to access the box (upper right of image). The available space for additional support personnel to move around in is also constrained. This option is clearly not optimal and may even result in decline in data collection.

Use of the simulations as trainers. After the simulations were developed, they were shown to the KERMIt team members who would participate in the experiment. This allowed them to help the simulator to refine the operations. At the same time, the team members studied the simulations to learn their flight tasks. They could observe the task flow from a variety of perspectives, including the "interior view, " in which they see through the eyes of the human model that simulated the tasks they would perform in flight. The experiment team reported that they were able to collect data the very first day of flight (Tuesday), a very unusual situation for the first flight of an experiment. They found the recommended hardware layout to be very efficient. They attribute the efficiency improvements in their experiment to planning aided by the simulation.

The presentation will include video showing representative simulations.

References

Dischinger, H. C., Jr. and T.E. Loughead. 1998. Comparison of human modelling tools for efficiency of prediction of EVA tasks. In NASA University Research Centers Technical Advances in Aeronautics, Space Sciences and Technology, Earth Systems Sciences, Global Hydrology, and Education, v. II.Coleman, T.L., B. White, S. Goodman, P. Sakimoto, L. Randolph, and D. Rickman, eds. TSI Press, Albuquerque; 160-164.

Etter B.D., H. C. Dischinger, Jr., and T. E. Loughead. 1996. Evaluation of an anthropometric human body model for simulated EVA task assessment. Proc. Southeastern Simulation Conference '96. 7,8 Oct., 1996. Huntsville, AL.