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Evaluation of the Rear Entry I-Suit during Desert RATS Testing

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ABSTRACT

ILC Dover, LP designed and manufactured a rear entry upper torso prototype for the I-Suit advanced spacesuit. In September 2005 ILC Dover participated in the Desert Research and Technology Study (RATS) led by the Advanced Extravehicular Activity (EVA) team from National Aeronautics and Space Administration (NASA) Johnson Space Center (JSC). Desert RATS is a two-week remote field test at Meteor Crater, Arizona. Team members are from NASA, several universities, and a number of industry partners. These groups come together to gain hands-on experience with advanced spacesuit systems and to develop realistic requirements for future Moon and Mars exploration. Desert RATS gave ILC Dover the opportunity to put the rear entry I-Suit through many rigorous tests. The lessons learned there will be valuable for determining basic requirements for future lunar and Mars missions.

Desert RATS utilizes a ‘learn-by-doing’ approach for understanding what future requirements should be developed. This approach allows people to experience first hand how a spacesuit will interface with various elements of lunar and martian exploration. Lessons learned with regard to donning and doffing the rear entry I-Suit, ingressing and egressing the rover, driving and controlling the rover, collecting biological samples, collecting rock samples and following a checklist through a helmet mounted display (HMD) will be reviewed in this paper.

BACKGROUND

The 2005 Desert RATS was the seventh remote field test organized by the Advanced EVA team at NASA-JSC. This year, like each trip before it, brought new challenges to all the participants. One of the major challenges for the 2005 team involved having two pressurized suits conducting test activities together, which had not been achieved since Apollo.

For each day a morning and afternoon pressurized suit run was scheduled. Because there were only two weeks of testing it was important to maximize the amount of pressurized suit time as much as possible. A pressurized suit run lasts between forty-five to fifty-five minutes, due to the limitations of the liquid air backpack. The Advanced EVA team was able to double the amount of pressurized time by performing on-back recharges of the liquid air backpacks. By successfully accomplishing these recharges the 2005 Desert RATS team was able to perform many more beneficial tests than before.

In preparation for the 2005 Desert RATS, ILC Dover began in late 2004 designing and manufacturing a rear entry soft upper torso (SUT). When joined with the lower torso assembly (LTA) of the waist entry I-Suit this rear entry SUT becomes the Rear Entry I-Suit (REI). Design goals of the REI suit were as follows: to provide the lightest possible rear entry system, to improve donning and doffing of the suit compared to the waist entry I-suit, provide excellent range of motion and mobility, and be comfortable over a number of consecutive pressurized suit runs. The waist entry I-Suit and NASA JSC rear entry Mark III, both designed by ILC Dover have been the primary suits used by NASA in all previous Desert RATS testing. ILC Dover has gained valuable information from past Desert RATS advanced spacesuit evaluations and built on these experiences by manufacturing an all-soft rear entry advanced spacesuit.

The waist entry I-Suit is primarily a soft suit, yet incorporates a limited number of bearings at the wrist, shoulder, upper arm, upper hip, and upper leg joints. It represents a compromise between a hard upper torso waist entry suit and an all soft suit, such as the Apollo A7LB suit. ILC Dover first delivered the waist entry I-Suit to NASA in 1998. Since then ILC Dover built another waist entry I-Suit with improvements to the helmet, boots, and waist and brief softgoods. To don the waist entry I-Suit a suit subject dons the LTA and secures the waist belt, which is integrated into the LTA. The waist belt aids in donning the SUT and helps relieve and distribute the weight once the suit is pressurized. A shoulder harness system is integrated into the SUT so once a subject dons the SUT the weight is supported and distributed. The same waist belt and shoulder harness are used in the REI suit to help support the weight once pressurized.

The Hybrid Suit (H-Suit) began as what is known as the Mark III. The Mark III, delivered to NASA by ILC Dover in 1988, is a rear entry hard upper torso (HUT) suit designed to operate at 8.3 psi. The Mark III was part of the NASA Zero Pre-breathe Suit (ZPS) program. At the time it was believed that 1000 to 2000 man-hours per year of EVA would be required for Space Station assembly. The pre-breathe protocol was seen as an over-head issue that needed to be eliminate in order to fully utilize EVA as a viable capability. Since 1988 the Mark III has been retrofitted to include a composite HUT, composite brief, composite hip/thigh, and new boots replacing the EMU hard sole style boots. These changes along with adding a waist bearing and ankle bearings create what is now known as the H-Suit. The H-Suit like the REI suit has a waist belt and shoulder harness system to support the weight of the suit once pressurized.

The 2005 Desert RATS testing utilized the H-Suit and the REI suit. Leading up to the remote field testing in September the Desert RATS team meet at JSC for one week each month from June to August. These weeks were used to prepare the team for what to expect in the desert. Pressurized suit evaluations were made to familiarize the team with the various tests to be done and to verify that all the equipment was in proper working order before taking it out to the desert.

REI SUIT DONNING AND DOFFING

A major goal of any spacesuit system is the ability to easily don and doff the suit. One does not want to struggle getting into a suit much less out of a suit after performing a labor intensive EVA. In addition to ease of donning and doffing, it is important that the suit system be capable of self-donning and self-doffing. Although the current spacesuits used on the space station are not as easy to don and doff, they are self-donning and self-doffing due to safety requirements.

The ease of donning a rear entry suit is primarily related to the size of the opening and the resistance from the LTA. The Russian Orlan DMA is a rear entry suit system used on the International Space Station. This rear entry design has a long narrow opening that requires a crewmember to twist at the hips and shoulders in order to don and doff. The resistance in the LTA is partially addressed in the Orlan DMA by utilizing a liner in the suit, made of a slick layer of fabric between the crewmember and the suit bladder. The H-Suit has a shorter and wider opening that allows a crewmember to more easily don with only minimal bending of the waist. From the initial design to the current Desert RATS testing, the opening for the H-Suit has proven to be nearly optimal. ILC Dover used the opening dimensions of the H-Suit to derive the opening for the REI suit.

The Desert RATS testing verified that the REI suit can be easily donned and doffed. In order to aid in don and doff ILC Dover added a Teflon lining to the hip section of the liquid cooling garment (LCG). The lining covers exposed tubing on the LCG that could potentially snag on the suit while donning and doffing. During the trial runs at JSC, the Advanced EVA team saw the benefits of such an easy modification and incorporated this same enhancement to the LCG worn in the H-Suit.

To doff a rear entry spacesuit a subject must first doff their arms from the suit and then use an overhead bar to pull out of the suit (Figure 1). To aid in doffing, a small step helps the subjects use not only their arms but also their legs to doff the suit.

One challenge for a rear entry suit is being able to self-don and self-doff. The REI suit was designed to allow a suit subject to don the suit and close the rear entry door. Then after a run the subject can open the rear entry door. A difficulty for the suit subject is securing a waist belt and shoulder harness system to carry and relieve the weight of the suit and liquid air backpack. For all the pressurized suit runs at Desert RATS each suit had a support team which aided in donning and doffing along with securing the weight relief devices. Because a fully charged liquid air backpack weighs approximately 80 lbs. and the REI suit weighs 84 lbs. having a way to relieve and distribute the weight is very important. In addition to weight relief, the shoulder harness keeps the shoulder centered in the scye bearing. Being centered in the scye bearing allows the suit subject to have maximum mobility. Currently the REI suit is not fully self-don and self-doff capable. The challenge to self-don and self-doff is not insignificant but at this point in the development process it is not the highest priority.

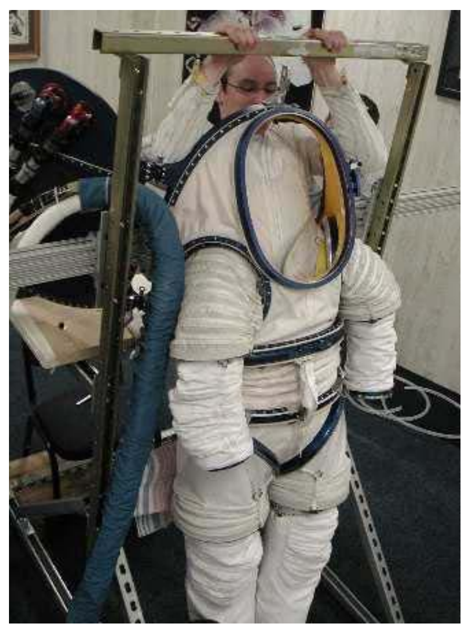

Figure 1 – Don/Doff

The 2005 Desert RATS team evaluated a number of projects over two weeks. The first week of testing evaluated science procedures, HMD capabilities, voice activated commands, and Global Positioning Systems. Half of the suit runs utilized the Mark III and the REI suit working together to accomplish the tasks while the other half were single suit runs. The second week of testing primarily focused on supporting the Science Crew Operations Utility Testbed (SCOUT), a prototype rover.

HEADS-UP DISPLAY

Throughout the two weeks every suit run involved performing a vast array of science experiments. The steps to perform each science experiment were displayed through an HMD (Figure 2). The HMD in the REI suit has an adjustable arm to allow the display to be positioned to the suit subject's preference. The HMD must be positioned so that the eye can easily acquire the image, but this can be difficult to accomplish without restricting normal visibility or head movement in the helmet. The HMD was used to display not only science steps, but also maps. These maps displayed topographical and satellite images of the surrounding area and showed the position of the suit subjects. Before each suit run the maps were updated to mark areas of interest which the Desert RATS team wanted the suit subjects to find. Once the areas were found the subjects performed the science experiments. In order to get a clear image on the HMD it was necessary to have the sun visor down. Without the visor the sunlight washed out the image making the HMD very difficult to view. Overall the HMD performed well during the two weeks of testing. The HMD is capable for field-testing, but many improvements will be required in order for this technology to be flight certified.

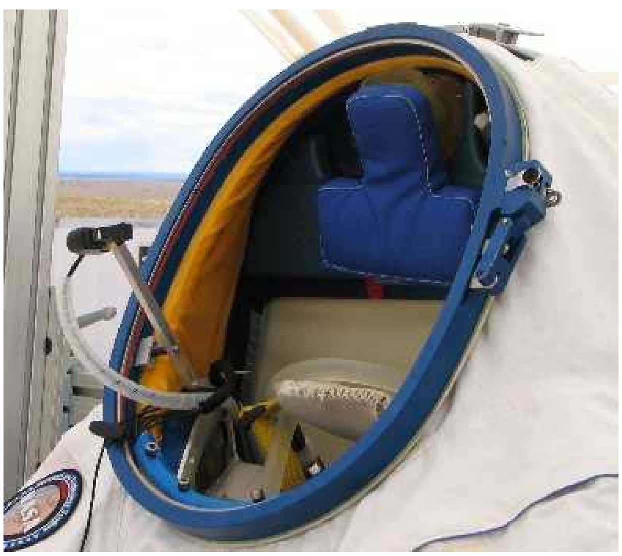

Figure 2 – Helmet Mounted Display

REI SUIT PERFORMING SCIENCE EXPERIMENTS

The science experiments the REI suit performed included the following: core sampling (Figure 3), microbial testing (Figure 4 and 5), soil sampling (Figure 6 and 7), and rock sampling (Figure 8). The science experiments were not meant to challenge the mobility of the suit, but rather to evaluate the tools needed to perform each task. If the science tools functioned properly then the work required of the REI suit would be minimal. In some instances the tasks required the suit to perform at a high level. Figures 5 and 8 show how it was necessary to hold a stable position while bending over to take microbial swabs and hammering on a rock. In each instance the waist mobility joint in the REI suit allowed the subject to hold a stable position and get low enough to perform the tasks.

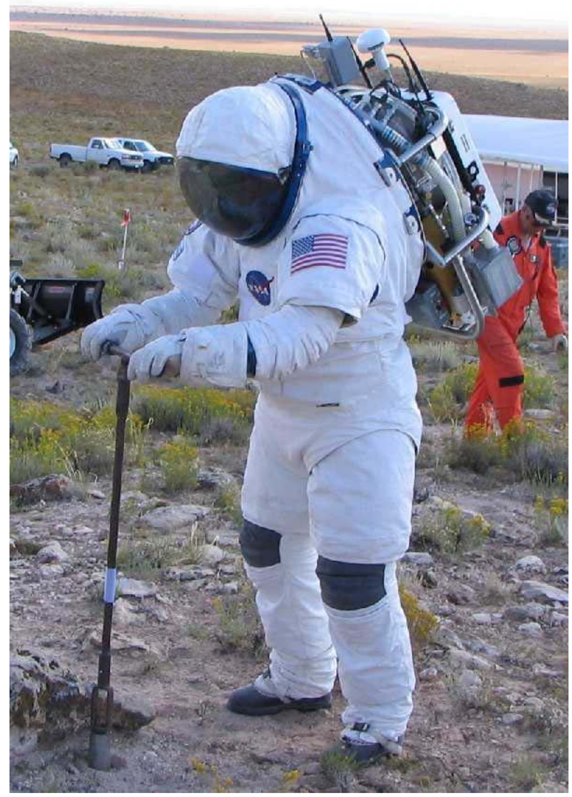

Figure 3 – Core sampling

On the second day of testing in the desert the shoulder harness loosened and the weight of the liquid air backpack shifted to the scye bearings and suit came to rest on the suit subject's shoulders. The run was cut short and a more robust locking mechanism was added to secure the shoulder harness. From that point forward the shoulder harness stayed in place.

The REI suit was involved in a number of tests which evaluated microbial contamination. Transferring microbes from Earth to either the Moon or Mars could threaten the validity of many scientific experiments.

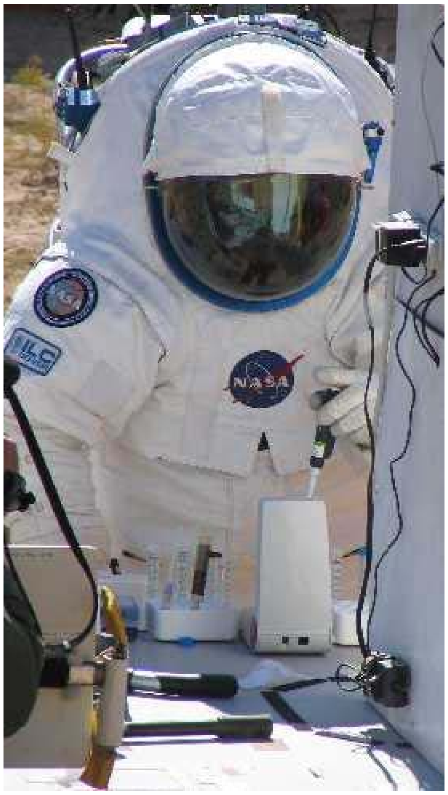

Figure 4 – Testing microbial levels

The REI suit was used to evaluate forward contamination by checking the microbial levels on the suit before, during, and after a pressurized suit run. Even though the instruments used to retrieve and measure microbial levels were not designed to be handled by spacesuit gloves, the Phase VI gloves currently used on the space shuttle and space station had the dexterity to handle the small, delicate tooling (Figure 4). The results from the testing showed that for lunar and planetary exploration improvements would be required for the outer garment. The microbial levels were highest at the wrist bearings.

The REI suit was not completely tested for cross contamination, but knowing that the bearings are the primary area for leakage made it clear that a design improvement will be required. Improvements will have to be made to the thermal micrometeroid garment (TMG) or by adding a protective layer to contain microbes.

One unforeseen challenge for the suit subjects during one suit run was with the on-back recharge. During the first week of testing after performing approximately forty-five minutes of testing the first on-back recharge was attempted. The dewars for the recharge were connected to the liquid air backpacks and for approximately 15 minutes each suit subject had to stand still while the recharge took place. Suit runs usually require both subjects to be actively working together to perform a task (Figure 7). During the recharge both subjects were unsure how much range of motion was allowable. By not being able move around freely the weight of the liquid air pack and suit were more concentrated causing the discomforts of the suit to be multiplied. Having something externally aid in supporting the suit would have been very beneficial.

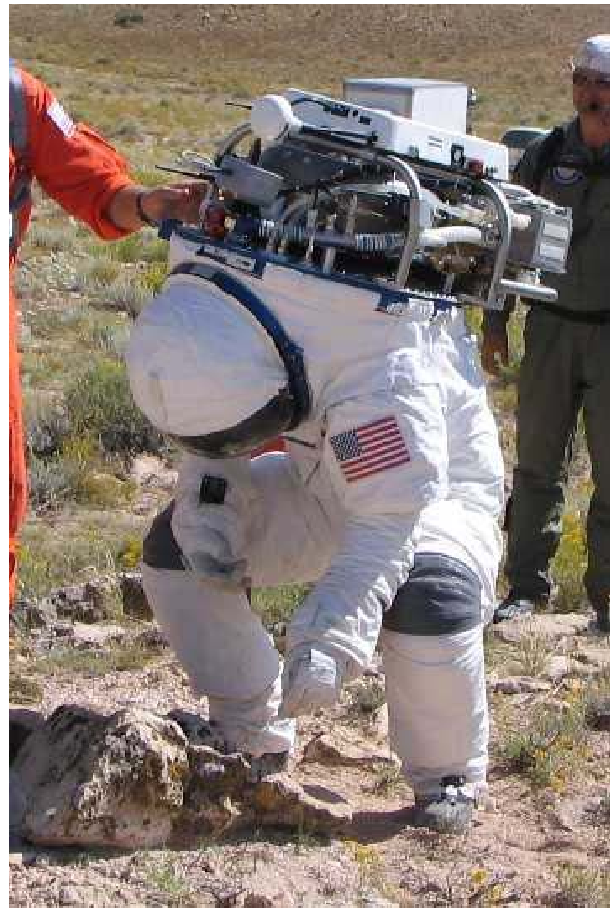

Figure 5 – Taking a swab sample

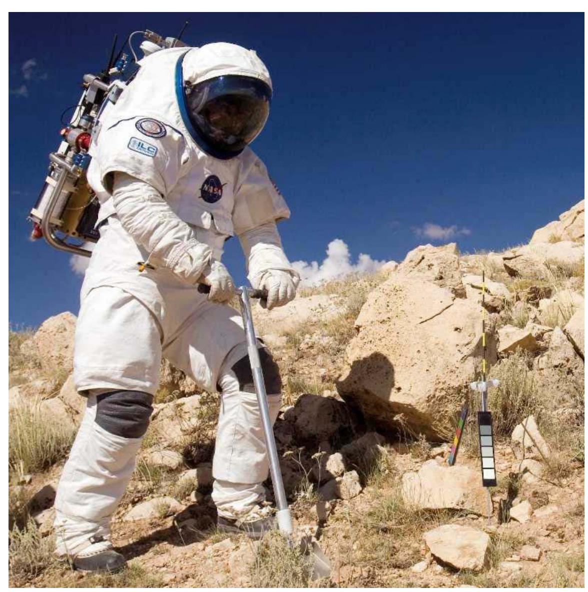

Figure 6 – Collecting a soil sample

During each science experiment the two suit subjects were in constant communication with each other, the test conductors, and a voice activated system. For both the REI suit and the H-suit an array of microphones are positioned on the neck ring in front of the helmet and two speakers are mounted to the rear door. In some instances the voice-activated systems would pickup cross talk and perform tasks which were not desired. To eliminate this problem ear buds were integrated into the suits to replace the speakers. The voice-activated system allowed the suit subject to control what was displayed on the HMD. The system showed promise for being a very beneficial aid to the suit subject. The ability to toggle between various computer programs and science procedures will help make the task run more efficiently.

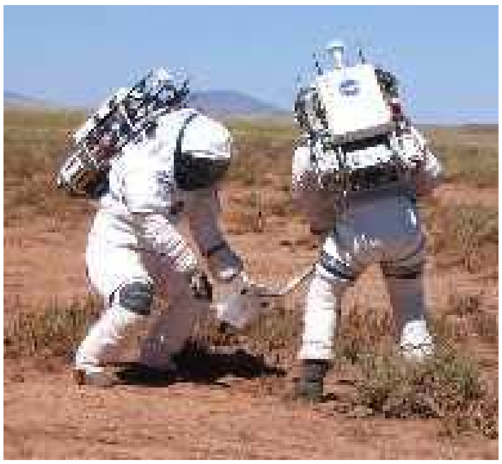

Figure 7 – Collecting a soil sample

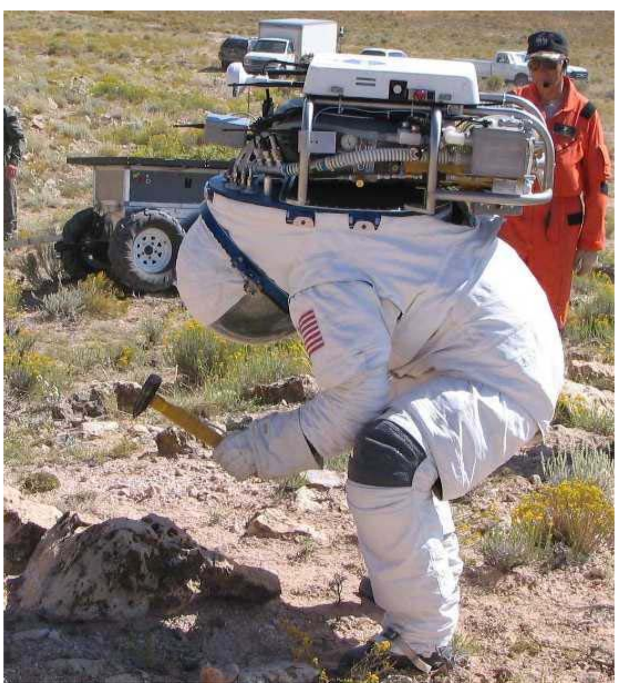

Figure 8 – Collecting rock sample

REI SUIT WORKING WITH SCOUT

The SCOUT vehicle was designed as a mobile testbed for advance rover technologies. Some of the advanced technologies included: space suit following (Figure 12), voice-activated controls, and autonomous driving. The REI suit and SCOUT worked very well together. Ingress and egress evaluations verified that the step into SCOUT was easily achieved (Figure 9). After stepping up onto SCOUT the REI suit subject used markers to verify alignment with the seat. Holding onto a strap (Figure 10) the subject was able to sit down and begin leaning back toward the back support. Without being able to see behind it was difficult to know how far to lean back. Once fully seated, being able to secure the seat belt was also difficult due to the location of the seat belt.

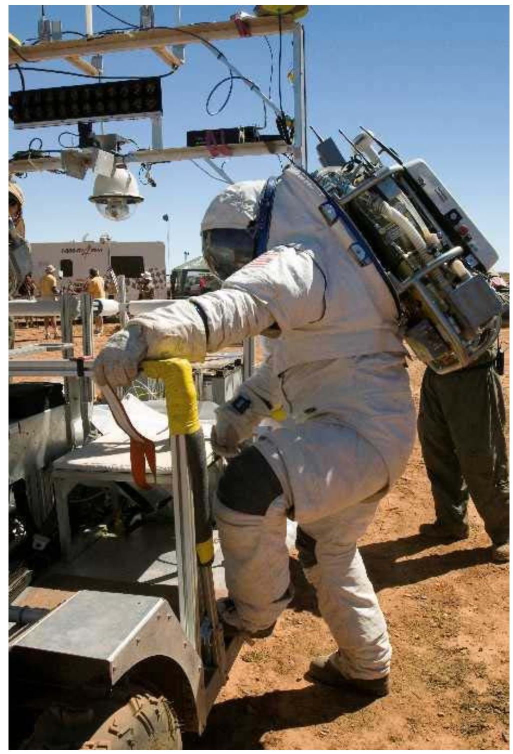

Figure 9 – Don/Doff of SCOUT

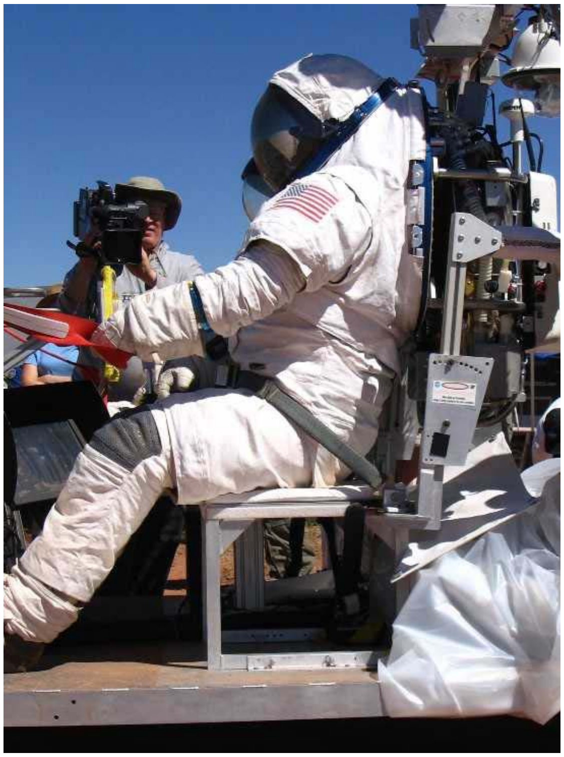

Figure 10 – REI suit seated posture

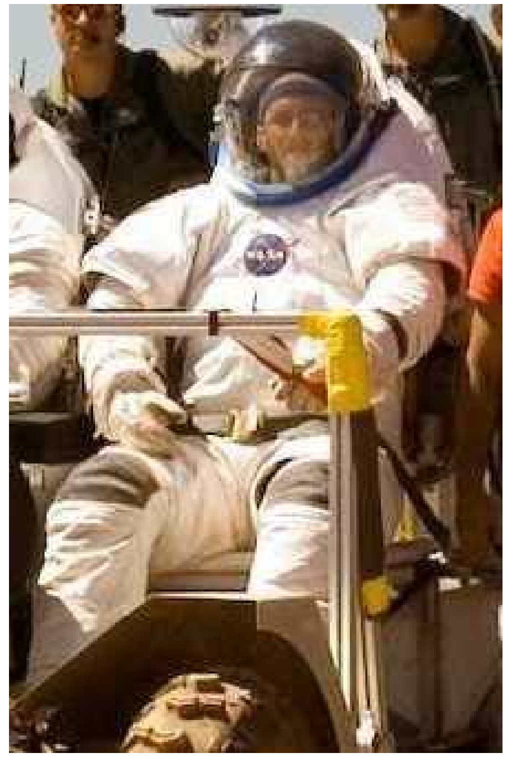

FIGURE 11 – REI suit seated visibility

The location of the belt was just in sight, looking through the REI suit helmet bubble, but was just out of reach. The seatbelt had to be handed to the subject in order to be secured. Once secured by the seatbelt the suit subject never felt unstable, even while taking tight turns over rough terrain. The seated posture on the SCOUT in the REI suit was similar to sitting in a chair without a spacesuit (Figure 10). Visibility while seated on the SCOUT was unconstrained because the suit subject did not sink down into the suit. It was anticipated that the hip and leg bearings, on the REI suit, may become pressure point while seated, but a full week of riding and driving the SCOUT resulted in no discomfort to the suit subject. One area for improvement to the SCOUT would be increasing the distance between the seats. Most of the SCOUT testing used both the H-Suit and REI suit together. With two pressurized suits seated next to each other there was constant bumping of elbows and the passenger had to make sure to give the driver adequate room to control the rover.

SCOUT has multiple methods for getting from one location to another. The rover can be driven manually, remotely, or autonomously. When driven manually a T-bar is used for steering and power and an onboard computer allows the suit subject to select the driving mode. SCOUT can be driven in two-wheel steer, four-wheel steer, forward, and reverse. In contrast to the HMD, it was noted that to view the onboard computer clearly the sun visor needed to be up.

During the trial tests at JSC it was noted that the handle used for power and steering control did not provide adequate resistance for the pressurized suit subjects. Without some resistance in the handle it was very difficult for a pressurized suit subject to maneuver the SCOUT with precision. Adjustments were made to provide more positive feedback for the driver and the problem was solved.

The week of SCOUT testing revealed many advantages to using a rover. The testing took the suit subjects further from base camp than any previous Desert RATS testing. In order for this to be accomplished on-back recharges were performed in route. In contrast to the first week, where each suit subject had to stand, sitting on SCOUT made the process painless. Within a short amount of time the suits were recharged and testing continued. With a rover less energy is expended getting to the test site. Being able to drive up to the test site and have the science tools readily available made the process go very smoothly.

CONCLUSION

Overall the REI suit performed very well during the two weeks of Desert RATS testing (Figure 13). Because Desert RATS is a “learning-by-doing” field activity the lessons learned during the 2005 trip will help many people understand just how much will be required to have a successful mission to the Moon and Mars.

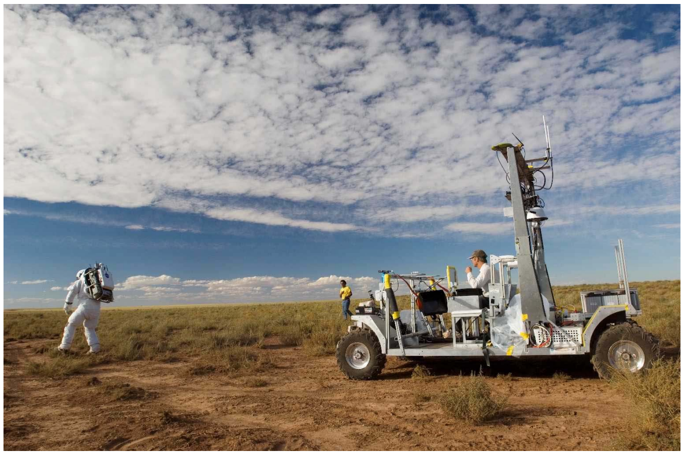

FIGURE 12 – SCOUT performing REI suit following

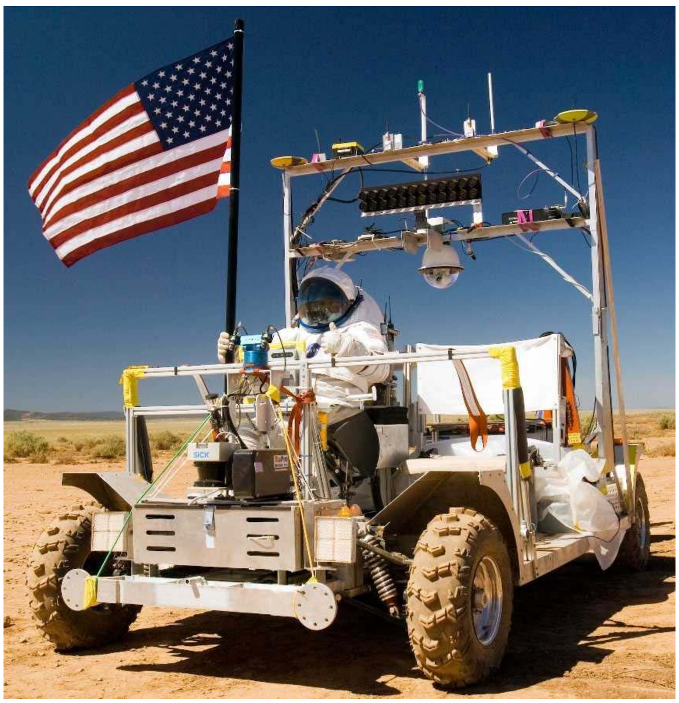

FIGURE 13 – REI on SCOUT mission complete

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