DRESSED FOR SUCCESS: EVA SYSTEM COMPETANCY AND CONTAINMENT FOR SCIENCE CAPABILITIES AND CONTAMINATION CONTROL. Dean. B. Eppler, SAIC/Constellation Advanced Projects Office, Mail Code ZX, NASA-JSC, 2101 NASA Parkway, Houston, TX 77058; dean.b.eppler@nasa.gov.

Introduction: The key to significant lunar science and exploration return lies in supplying the crews on the surface with a robust EVA capability. This capability should include high mobility pressure garments; tactile, dexterous gloves; reduced overhead in preparing for and recovering from EVAs; management of regolith contamination; and control of suit leakage to prevent planetary contamination. Building on the legacy from Apollo, Shuttle and ISS, the present complement of prototype surface suits have made good progress toward achieving these goals for the future lunar surface suit system. The next step is to translate the lessons learned from these systems into requirements for the next generation surface EVA system.

Apollo Legacy: The Apollo space suit was a departure from the previous tradition of providing astronauts with pressure garments that were to be used in emergency cabin depressurization. Emergency suits should be reasonably comfortable when unpressurized, and provide a safe environment for the (assumed) limited period of time when they were needed during an in-flight emergency. In contrast, the Apollo space suit provided the crew with reasonable comfort and mobility, including pressurized operations for up to 8 hours at a time on the lunar surface. In addition, the pressure garment needed to provide a host of other nominal and emergency capabilities, including performing as a comfortable prebreathe "container" for pre-launch pure O_2 prebreathe; protect the crew during the launch to orbit acceleration of up to 4.5 g; act as a survival suit in case of launch abort into the Atlantic Ocean; provide contingency spacewalking capability to transfer the crew from the Lunar Module (LM) to the Command Module (CM) in lunar orbit in the event of an internal hatch failure; and provide up to 104 hours of unpressurized survival in the event both the LM and the CM could not be repressurized after the lunar surface mission. The two Apollo suit models, the A7L and the A7LB, fulfilled each of these tasks admirably – 12 lunar surface crews completed over 160 man-hours of lunar surface EVA between 1969 and 1972. However, the A7L series had some deficiencies in mobility that taxed each of the crews that wore them. The most significant of these deficiencies was glove mobility – the gloves proved to be very stiff, with limited tactility and dexterity, and resulted in substantial forearm and hand fatigue and finger damage. The pressure garment, as well, had deficiencies in mobility that were overcome by a combination of ingenuity, surface tools, and the lesser demands 1/6 g environment put on crew mobility. Chief among these were the stiffness of the torso, which precluded the ability to walk normally and bend over for extended periods of time. To accommodate limited bending, the suits were provided with straps that allowed the crew to hold the suit in a particular position without extended muscular effort. Dropped tools proved, on some occasions, to be impossible to pick up without a grabber tool that could be employed in a standing position. In the case of walking, the low lunar gravity allowed relatively easy mobility with a variety of gaits, although walking uphill was difficult. Lastly, the lack of a rotational joint at the shoulder made motions like hammering difficult, particularly in terms of putting power into a hammering swing.

Managing regolith contamination was difficult with the suit design which, in some cases, collected regolith rather than shed it. Later missions provided crews with brushes to remove a certain amount of regolith before entering the LM, but the fatigued state of the crewmembers hands at the end of an EVA limited the effectiveness of these approaches. However, the limited duration of the lunar landing program and reduced development budgets did not allow suit system designers any real opportunity to address regolith concerns before the end of the last Apollo landing.

Prototype Suit Development Progress: Since the mid-1990s, NASA has been testing a variety of new spacesuit designs in the laboratory and in the field, laying the foundation for the development of a new planetary surface suit system that builds on the legacy of Apollo. These suits have been tested using on a variety of exploration tasks, including geologic fieldwork, outpost infrastructure deployment, rover operations, human and robotic rover interaction, and information systems for EVA crewmembers. In addition, these tests have been conducted using geologists and engineers as the suit subjects, ensuring that the people directly engaged in the testing know the professional requirements to be imposed on EVA surface operations, and are able to apply the experience of testing to improving existing systems and developing new systems.

The present suits that are being tested are the Mark III hybrid suit, consisting of a hard upper torso and briefs with soft goods for the arms and legs, and several variants of the ILC-Dover I-suit, an all-soft-goods suit with a rear entry variant. Both of these suits incorporate rotational and flexural bearings to improve suit mobility at critical joints (shoulders, wrists, waist, hips and ankles). In addition, improved flat-patterning techniques for soft goods have improved the flexural mobility of the knees and elbows. Lastly, these tests have made use of improved gloves from the Space Shuttle/ISS Programs which increase hand dexterity and mobility while significantly reducing hand fatigue.

A decade of testing in these suits has resulted in a number of results. First, suit mobility and glove dexterity have made tremendous advances since Apollo, and can support the exploration goal of frequent, routine EVAs without damaging crewmembers in the process. In some cases, testing of geologic field activities with both shirtsleeve and suited test subjects has shown that suit mobility is comparable to shirtsleeve mobility, even when carrying a 90+kg suit in 1g.

Second, in-suit recharge of the portable life support system (PLSS) is a relatively easy activity, provided the appropriate valve interlocks are built to prevent malfunctions. This can increase safety by making any rover a consumables depot, as well as offload suit system on-the-back weight by reducing the standard consumables load.

Third, electronic information systems are clearly the area of highest potential to change suit systems and improve EVA efficiency. However, the rush to "computerize" space suits should be tempered by the requirement to make electronic systems transparent to crew operations, not an added burden and time sink. Electronic-based information delivery systems, particularly helmet-mounted displays, are superior to hard copies. However, the manner in which data is manipulated will be critical. Voice commanding is still problematic, unreliable, and competes with the standard voice communications for priority. Display controls should be on suit sleeves; the front of the suit is less favorable due to visibility and arm compression concerns.

Fourth, robotic, manned and hybrid rovers are great devices. Manned rovers greatly reduce crew fatigue and consumable usage and extend EVA time and, as indicated above, can increase safety through the use of on-board consumables. Unmanned rovers are essential tools for a variety of operational duties, such as scientific and operational reconnaissance, equipment transport and instrument deployment, and should be included in all manned exploration activities as a critical "crewmember". There are a wide variety of approaches for rover autonomy and control during EVA, but no obvious best approach has emerged from testing so far.

Planetary Protection Issues in Suit Design: The human in the suit represents a significant source of biological contamination. Although a "leak-proof" suit would be desirable, all pressure garments, of necessity, leak through joints, glove, and helmet connections. The particular issue for suit design is limiting the leak rate to an acceptable level. Leak rates from the Shuttle/ISS EMU are ≈40 SCCM, which includes oxygen from the PLSS, any exhaled respiration gases, any solid particulates and off-gassing products shed from the suit materials, and biological particulates shed from the crewmember. Leak rates from the Mark III are considerably higher, on the order of 1500-2000 SCCM. However, this higher number is, in a sense, not comparable to flight-qualified pressure garments, which have more stringent standards for leak rates and higher design tolerance for parts that may contribute to leakage. In addition, the Mark III has a pressurization history >1000 hours over almost 20 years, which is far longer than flight qualified pressure garments are subjected to. The biological load from the I-suit after a number of EVAs has been characterized in the field [1]. Although more rigorous tests need to be completed, preliminary results suggest that the external surfaces of the gloves will carry a significant biological load associated with donning unless these surfaces are cleaned after suit donning and prior to exit from the airlock [1]. One of the critical tests of the future pressure garment will be a biological challenge, wherein the actual biological output of the pressure garment into vacuum will be characterized. With respect to operational concepts to limit biological contamination on Mars, preliminary discussions between the space suit system and science communities has centered around investigating any potential site of extent Martian life with robotic devices first, to be followed up with humans in EVA suits. The logic in this approach is based on the notion that a mechanical device can be sterilized more easily than a human in a suit, so the first line of investigation will be with the sterilized implement.

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[1] Maule, J. et. al., (2006) Int. Conf. Env. Sys. Pap. 06ICES-185.