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Modified Advanced Crew Escape Suit Intravehicular Activity Suit for Extravehicular Activity Mobility Evaluations

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The use of an intravehicular activity (IVA) suit for a spacewalk or extravehicular activity (EVA) was evaluated for mobility and usability in the Neutral Buoyancy Laboratory (NBL) environment at the Sonny Carter Training Facility near NASA Johnson Space Center in Houston, Texas. The Space Shuttle Advanced Crew Escape Suit was modified to integrate with the Orion spacecraft. The first several missions of the Orion Multi-Purpose Crew Vehicle will not have mass available to carry an EVA-specific suit; therefore, any EVA required will have to be performed by the Modified Advanced Crew Escape Suit (MACES). Since the MACES was not designed with EVA in mind, it was unknown what mobility the suit would be able to provide for an EVA or whether a person could perform useful tasks for an extended time inside the pressurized suit. The suit was evaluated in multiple NBL runs by a variety of subjects, including crewmembers with significant EVA experience. Various functional mobility tasks performed included: translation, body positioning, tool carrying, body stabilization, equipment handling, and tool usage. Hardware configurations included with and without Thermal Micrometeoroid Garment, suit with IVA gloves and suit with EVA gloves. Most tasks were completed on International Space Station mock-ups with existing EVA tools. Some limited tasks were completed with prototype tools on a simulated rocky surface. Major findings include: demonstrating the ability to weigh-out the suit, understanding the need to have subjects perform multiple runs prior to getting feedback, determining critical sizing factors, and need for adjusting suit work envelope. Early testing demonstrated the feasibility of EVA's limited duration and limited scope. Further testing is required with more flight-like tasking and constraints to validate these early results. If the suit is used for EVA, it will require mission-specific modifications for umbilical management or Primary Life Support System integration, safety tether attachment, and tool interfaces. These evaluations are continuing through calendar year 2014.

Nomenclature

ACES	=	Advanced Crew Escape Suit
ARGOS	=	Active Response Gravity Offload System
cu in.	=	cubic inch
DCCI	=	David Clark Company Inc.
EMU	=	Extravehicular Mobility Unit
EOS	=	Emergency Oxygen System
EVA	=	extravehicular activity
ISS	=	International Space Station
IVA	=	intravehicular activity
LCG	=	Liquid Cooling Garment
LPU	=	life preserver unit
MACES	=	Modified Advanced Crew Escape Suit
NBL	=	Neutral Buoyancy Laboratory
NUI	=	Neutral Buoyancy Laboratory umbilical interface
psi	=	pounds per square inch

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psia	=	pounds per square inch absolute
psid	=	pounds per square inch differential
TCU	=	thermal control underwear
TMG	=	Thermal Micrometeoroid Garment

I. Introduction

The Modified Advanced Crew Escape Suit (MACES) is the baseline launch, entry, and abort suit for the Orion Multi-Purpose Crew Vehicle spacecraft. The primary jobs of the suit are to allow normal crewmember functions while protecting the crew during the dynamic phases of flight and to provide a backup to the primary vehicle life support systems. During the prelaunch phase, the suit protects in case of a pad abort in which the crew must flee a compromised vehicle and may be exposed to fire, smoke, or various toxic chemicals. During launch and landing phases, the suit protects the crew in the cabin environment and provides a redundant pressurizable atmosphere in case of an issue with the primary vehicle systems. Most space programs have found extravehicular activity (EVA) to be a useful way of accomplishing tasks outside the vehicle. This has been especially true in recovering from issues encountered during flight, such as the solar array deployment failure experienced during Skylab. If EVA operations are required by mission plan (as in the case of an asteroid retrieval mission) or to recover from a vehicle failure, that operation will have to be completed by the MACES. This is a departure from the original design intention of the suit; each of the elements of the EVA need to be assessed before EVA requirements are levied on the suit.

II. Modified Advanced Crew Escape Suit Description

The MACES is the baseline suit for the Multi-Purpose Crew Vehicle (Fig. 2). It is a derivative of the Space Shuttle Advanced Crew Escape Suit (ACES) (Fig. 1). The ACES is manufactured solely for NASA by David Clark Company Inc. (DCCI), located in Worcester, MA. The ACES is also categorically defined as the DCCI Model S1035 (Barry) . The ACES heritage is derived from the original launch/entry suit (DCCI Model S1032), which NASA incorporated into the Shuttle Transportation System as part of the Crew Escape System that was developed after the Space Shuttle Challenger accident (1986). The ACES is a full-pressure suit with a nominal contingency operating pressure of 3.46 psia. Oxygen was delivered to ACES from the Orbiter at 100 psi and regulated by the suit to atmospheric pressure (or up to 3.46 psia in a cabin depress contingency). The ACES featured an "open-loop" demand air system, meaning that expired air is vented out of the suit and into the cabin atmosphere at ambient pressure (Fig. 3).

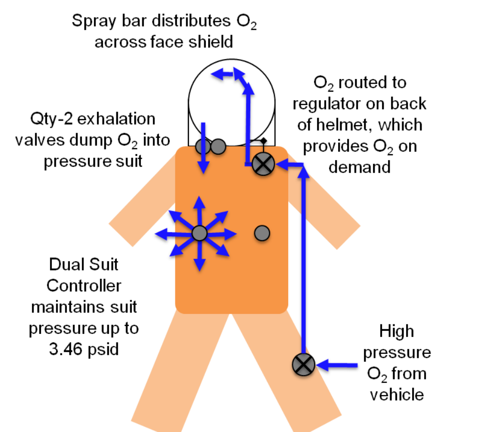

Figure 1. Shuttle ACES operational schematic.

In case of an in-flight emergency, the ACES function was to protect the crew from cabin depress, and to allow for high altitude (<35,000 ft) bailout. The ACES contained supplementary oxygen in the form of twin 60 cu in. bottles, which stored the gas at 3000 psi. This provided the crew with approximately 10 minutes of oxygen at sea level and increases at higher altitudes. The crewmember's body temperature is regulated within the ACES by a liquid cooling garment that provides cool water flown though tubes that envelope the entire body. The ACES is comprised of three layers of fabric. The innermost layer, or bladder layer, is the actual pressure vessel. It is comprised of seam sealed Gore-Tex fabric. The second layer of ACES, the restraint layer, is a net-type material, dubbed "Linknet" by DCCI. Linknet provides shape to the bladder layer in the torso and arm regions while allowing for moderate mobility at full pressure. The outmost layer, or cover layer, is made of high-visibility

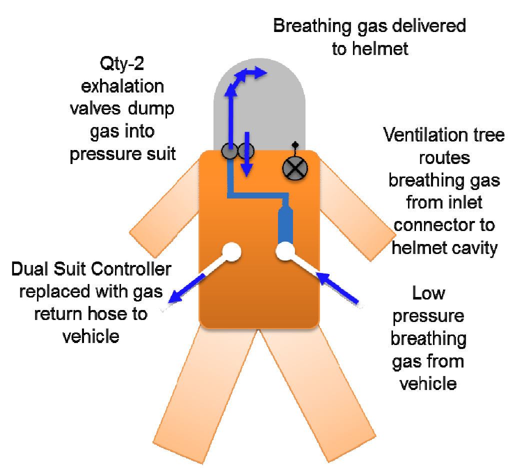

Figure 2. MACES operational schematic.

orange Nomex. The cover layer serves the purposes of abrasion protection, momentary fire protection, and high visibility for rescue scenarios in the event of an orbiter bailout. The cover layer also serves as the restraint for the legs.

A. General Modified Advanced Crew Escape Suit Characteristics

General physical characteristics of the standard ACES are largely unchanged for the MACES. Pressure garment composition, helmet, gloves, boots, cooling, communications assemblies, and undergarments are nearly identical. Modifications to the ACES are divided into three categories:

1. Closed-Loop Breathing System (primary)
2. Open-Loop Breathing System (secondary)
3. Functional Modifications

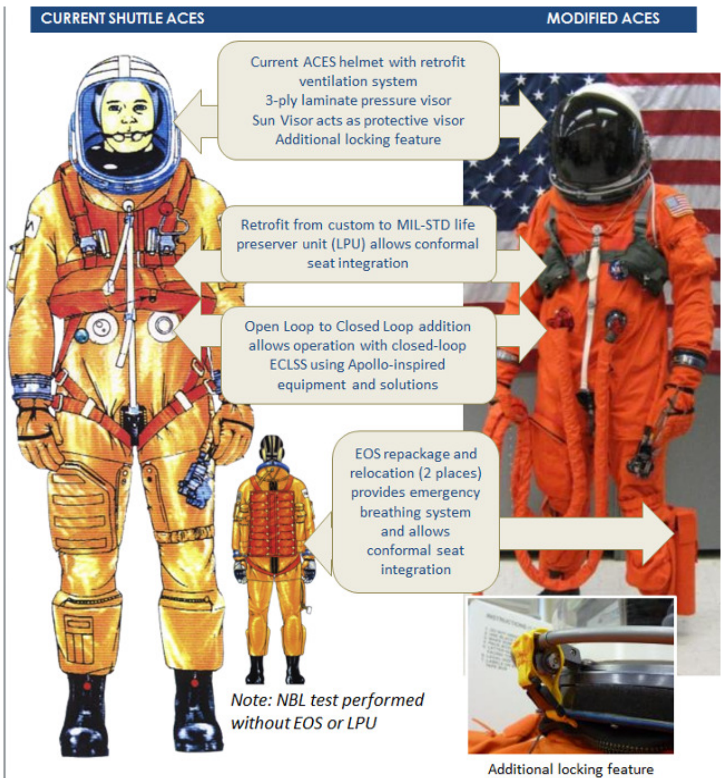

Figure 3. ACES to MACES changes.

1. Primary Breathing System

The primary breathing system in the MACES is a closed-loop system. The breathing loop air inlet is mated through Apollo-era fittings, manufactured by Air-lock, Inc. (Milford, CT), and which are located on the lower-left abdomen. Air is routed through an internal ventilation tree through the neck dam, and into the helmet breathing cavity. Expired breathing gas is vented through the neck dam exhalation valves, and into the suit body. Gas is exhausted from the suit through an Apollo-era connector on the lower-right abdomen.

2. Secondary Breathing System

The secondary breathing system used in the MACES is an open-loop system identical to that of the standard ACES. High-pressure (50-120 psia) gas is fed through a high-pressure hose to the suit breathing regulator located immediately below the neck ring on the anterior side. Gas is delivered based on breathing demand though the helmet spray bar. Expired breathing gas is vented through the neck dam exhalation valves into the suit body. Gas is exhausted from the suit through a backpressure regulator that is opened for open-loop operations. Air for the secondary system is delivered from either facility-provided air or through leg-mounted emergency oxygen bottles as worn in the current ACES ensemble for shuttle operations. High-pressure hoses for the modified ACES are integrated into the cover layer of the suit and plumbed in series to the legacy EOS bottles. These are worn in custom pouches on the outer flanks of the lower legs.

3. Auxiliary Modifications

The ACES life preserver unit (LPU) and Emergency Oxygen System (EOS) are incorporated in the parachute pack assembly harness. Since the Orion capsule does not support bailout, a parachute pack assembly is not needed in the MACES. As such, the harness has been simplified and components have been relocated to better integrate to the conformal fit seats employed by the Orion capsule.

The MACES have been outfitted with a modified mil-spec LPU-10. The LPU-10 was re-sewn to incorporate international orange Nomex and webbing for higher visibility. Additionally, the harness was modified to incorporate lift capabilities for crew rescue operations. This harness may be used for MACES testing for seat fit and mobility evaluations. The EOS bottles were relocated to the outer flanks of the legs of the wearer via removable Nomex fabric pouches. The EOS bottle pressure regulators are identical to those used in ACES; however, the actuation mechanism was modified to optimize the regulators for leg-worn use. The EOS bottles will be attached to the suit-mounted high-pressure lines via quick disconnect at the regulator.

B. Common Suit Hardware

The helmet remains unchanged from that used in the standard ACES configuration and may be used interchangeably between all suits and suit sizes. Recommendations from the Columbia investigation have been incorporated into the overall suit/seat integration including restraint of the helmet to prevent basal skull facture. Gloves are also unchanged and may be used interchangeably between suits, provided the gloves are sized appropriately to the wearer as per standard ACES. Liquid cooling garments (LCGs) and thermal control underwear (TCU) are under evaluations for redesign to reduce pressure drop. Normal ACES LCGs/TCUs are anticipated to be used in the interim, though any LCG/TCU may be used so long as it can be interfaced through the Biomedical Interface Pass. The Communications Carrier Assembly was unmodified and is interchangeable according to wearer size. Padding is being added to the assembly to provide head protection. Boots and boot styles are interchangeable. TCUs are interchangeable for style and size between suits.

III. Early Modified Advanced Crew Escape Suit Pressurized Mobility Evaluations

In 2010, when the MACES was beginning to be evaluated as the launch, entry, and abort suit for Orion, testing began to assess the suit's ability to complete pressurized tasks that would be required if the Orion capsule became depressurized. These tasks focused on operations where the suit was restrained in the seat, and grew in 2011-2012 to include the ability to ingress the seat and to translate in microgravity in the unpressurized Orion cabin. Also of interest was the ability of the MACES to be comfortable during extended periods of pressurization. After these evaluations, higher-fidelity tests were completed on the Active Response Gravity Offload System (ARGOS) and in the zero-gravity (Zero-G) aircraft. Feedback from these tests was positive, but the feedback strongly pointed to the need for a longer-duration, multi-axis simulation accomplished in the NBL. For all of these evaluations the suit was pressurized to 4.0 psid. The final operating pressure requirements for Orion are still being developed.

A. Lab Environment Testing

The first pressurized evaluations in this series were completed in the lab environment with the subject in standing or seated postures (upright and recumbent). It was quickly determined that the sizing procedure used during the Space Shuttle Program put the subject into suits that were too large for good pressurized mobility. The shuttle ACES configuration required a parachute harness that is not included in the Orion version. To perform its function correctly, a parachute harness must be fit tightly to the crewmembers body. In an attempt to make the suit/harness combo more comfortable, many crewmembers would upsize their suit to allow for more movement unpressurized. This also meant that the suit expanded a great deal when pressurized leading to poorly pressurized mobility. Elimination of the harness increased the comfort of the subject and allowed for downsizing of the suit to create a closer pressurized fit that provided more mobility. Evaluations indicated the need for testing that more closely resembled the conditions on orbit.

B. Active Response Gravity Offload System Testing

The NASA Johnson Space Center Engineering Robotics division constructed a weight-relief system capable of simulating a very low-friction environment. This ARGOS system received approval in 2012 for manned testing, and work began to integrate MACES with this system. The suit is attached to the ARGOS via a hang gliding harness that was modified to interface with the suit. Testing with the ARGOS demonstrated the feasibility of translation/body stabilization/tool manipulation (Fig. 4). Operations were conducted with male and female crewmembers. Based on the results of this testing, recommendations were made for higher-fidelity testing on the Zero-G aircraft and in the NBL. Due to a failure of the ARGOS in 2013, this ground simulation is not currently available for manned testing.

Figure 4. MACES translating on ARGOS.

C. Zero-Gravity Testing

Due to the limitations of the ARGOS to support full 6-degree-of-freedom motion, microgravity testing on a Zero-G flight was completed in August 2012 (Fig. 5). This test was to determine whether the ARGOS results would match the results of higher-fidelity tests. Two days of Zero-G testing were completed with four subjects attempting to ingress the Orion seat in the pressurized suit, and attempting to perform translation and body stabilization. The subjects were all able to ingress the seat and demonstrate the requested translation and body stabilization exercises. The subjects reported that they were less stable in Zero-G than on the ARGOS, but they also reported that their experience in ARGOS gave them a good idea of how the suit would perform in Zero-G. The main drawback of the Zero-G test is the short duration of microgravity. Each parabola is approximately 20 seconds. This amount of time does not allow full simulation of complex tasks such as attaching seat belts once inside the seat.

Figure 5. MACES on Zero-G aircraft.

IV. Modified Advanced Crew Escape Suit /Neutral Buoyancy Laboratory Integration

Neutral buoyancy has been the preferred method of evaluating microgravity EVA tasks since its development in the 1960s for the Gemini program. It consists of balancing the mass/volume of the spacesuit so that the mass of the suit matches the mass of the water it displaces. The suit is neutral; not floating or sinking, in the water column. This allows the subjects to evaluate tasks while they float in simulated microgravity. Some of the major benefits of neutral buoyancy are the ability to closely match microgravity conditions, the ability to conduct continuous operations for extended periods of time (6 hours +), and 6-degrees-of-freedom of motion (three translation axes and three rotation axes). In addition to being balanced to be neutrally buoyant, the suit must also be weighed out to eliminate righting moments. Righting moments occur when a section of the suit displaces less water than its mass and sinks, while another area of the suit displaces more water than its mass and floats. This causes a fishing bobber effect in which one part of the suit tries to rotate toward the pool surface. It is corrected by shifting weight from one section of the suit to another section.

The drawback of this simulation is that it requires the subject to be underwater. This limits observer access and increases safety risk to the subject. Water also creates frictional resistance that is not present in a space vacuum. Prototype suits are not typically evaluated underwater because of the safety and logistical difficulties associated with operating in that environment. The last time that new NASA EVA suits conducted underwater evaluations was in the late 1980s with the MKIII and AX5 suits as a part of the development of the International Space Station (ISS).

A. Safety Considerations

The NBL represents a higher level of risk than lab testing or the Zero-G aircraft since the issues with suited testing are combined with the hazards of scuba diving. Over the past 30 years, the Extravehicular Mobility Unit (EMU) has compiled an impressive safety record; the NBL underwater operations are used as a model on how to safely complete hazardous tests. Because of this, the community was more comfortable trying to match the process of the EMU rather than starting from scratch. This approach starts with interface control requirements between the suit and facility, uses joint signatures on the associated hazard analysis, and performs rigorous tests of nominal and off-nominal situations. The NBL has a number of support systems: safety divers, Breathing Gas Systems, cranes, medical staff on site, and hyperbaric and hypobaric chambers. All of these systems were kept in place with the same personnel and procedures to ensure all MACES tests were conducted safely. The suit and test operations were screened by a requirements review as well as incremental safety reviews for each step of the development.

B. Integration to Existing Neutral Buoyancy Laboratory Systems

Given the developmental nature of the project, the attempt was made to leverage as many of the existing NBL suit support systems as possible, and to stay within the experience gained with the EMU. Since the major interface requirements of the MACES matched those of the EMU, the NBL facility systems were not modified. This allowed for the use of existing NBL drawings, hazard analysis, and operating procedures for divers, gas/water supply systems, crane operations, and medical support. The suit pressure used for the NBL is 4.0 +/- 0.5psid which matches the pressure used for EMU in the NBL. The NBL umbilical interface connector was left unchanged for MACES operations, thus allowing the facility to switch umbilicals between EMU and MACES depending on the suit being supported that day. An incremental approach was taken to integrate the suit that began with using the suit unmanned on the pool deck, performing dry runs of the procedures manned, and testing the suit in the water unmanned prior to the first manned in-the-water use of the MACES.

C. Suit Modifications for Neutral Buoyancy Laboratory Use

To integrate the MACES with NBL, the suit required some changes from the intended flight configuration. The ACES parachute harness was added back to the suit to provide a lifting interface from the pool deck to the water. This also provided an interface point for the NBL umbilical interface (NUI); i.e., the silver box that can be seen on the back of the suit. The NUI performs the same functions as the EMU NBL Primary Life Support System, integrating the suit to the facility end of the umbilical and providing gas/water/communications to the suit. To simplify integration with the NBL communications system the EMU comm cap is worn inside the MACES. The NUI contains the relief valve for the system, so the MACES internal relief valve was plugged. Weights or foam must be added to different areas of the suit to make the suit neutrally buoyant. To allow weight/foam to be placed on various parts of the suit, packs with small pouches were added to different areas of the suit to allow for placement of the weight/foam. For the initial testing, weight pouches were placed on the lower leg, the upper leg, the front of the lower torso, the front of the upper torso, the neck, and the upper arm (Fig. 6). Areas for improvement were identified and incorporated as the suit was tested. These changes are discussed below.

Figure 6. MACES in NBL with weight packs.

D. Unmanned Evaluation

Two sets of unmanned evaluations were completed with the MACES/NBL integrated test setup prior to manned use. The first was completed on the pool deck and served to dry run test procedures, verify nominal operation of the system, and test off-nominal flow conditions. The second test – called a cornman test – simulated the mass of a human with sealed bags of dried corn. This allowed a full demonstration of test procedures. Weighing out the suit was completed with the cornman. This demonstrated that the various weight pouches added to the suit were sufficient to balance the suit in the water column. The suit was taken up and down the water column at typical ascent/descent rates to confirm the Environmental Control System response to the new suit. All Environmental Control System parameters were nominal, and the team proceeded to manned testing.

E. Manned Evaluations

1. Manned Neutral Buoyancy Laboratory testing – first runs

A total of eight manned MACES events were completed in the NBL during fiscal year 2013 (Fig. 7). The first runs demonstrated the ability to interface with the NBL systems and weigh-out the suit, and to determine the subject's ability to use the suit underwater. Because of the development nature of the suit, operational time underwater was limited to 2 hours until cycle testing was completed and a drink bag was incorporated into the suit. Task were limited to tasks that are accomplished regularly in the EMU. For the first runs, only one suit was constructed for use in the pool. This allowed the team to build confidence in the suit prior to longer test events with more complex objectives. The NBL divers were able to weigh the suit out with the available weight pouches. A new chest weight was added to the suit in the second run that improved downward visibility. During one weigh-out, the crewmember noted that he could change his position inside the suit and modify the weigh-out balance of the suit such that he could rotate the entire suit without touching any structure. The subjects practiced translation and body positioning. They successfully completed translation and body control exercises and provided feedback that padding could help reduce shifting in the suit. The weight packs on the arms were noted as causing some resistance to arm motion. During subsequent tests, the arm weight packs were removed allowing better arm mobility. It was noted that the MACES has a different work envelope than the EMU, and that time in the suit would be required to learn how to work in the suit comparable to how crewmembers learn to work the EMU. Tether points were made available to the subjects attached to the harness, and they were able to see the tether points and reach them with the gloved hand. It was noted that having a floating tether point introduces more effort than a solid tether point such as the EMU mini-workstation. The crew simulated placing feet in a foot restraint, and felt that using an EMU-style foot restraint would not be an issue in this suit. The suit experienced some expansion from the beginning of the run. The crew felt that there was more room overall in the suit than at the beginning of the run. This was experienced previously in EMU as the soft goods shift; however, the effect seemed to be a bit more than is typical with EMU.

Figure 7. MACES translating in NBL.

2. *Manned Neutral Buoyancy Laboratory – later development in 2013*

Improvements were made to the suit in the following runs. The Crew Survival team constructed a second size suit to expand the subject pool, added padding to the suit to increase comfort and usability, increased the cooling capability, and incorporated a drink bag. The overall test time was increased to 4 hours; this was based on the incorporation of the drink bag and the completion of cycle testing to prove out the durability of the suit. The ACES IVA gloves were replaced with EMU gloves, which were designed for greater loads and harsh thermal environments.

The subjects in these tests all had significant EMU experience and gave positive feedback on getting to use the EMU gloves. Since these gloves are already approved for EVA use with a significant number of available sizes and known flight requirements, it is safe to adopt the use of these gloves for a capsule-based EVA mission. It also significantly decreases cost and schedule risk since every modern EVA glove design/certification effort has required 2+ years of development and greater than a million dollars in cost.

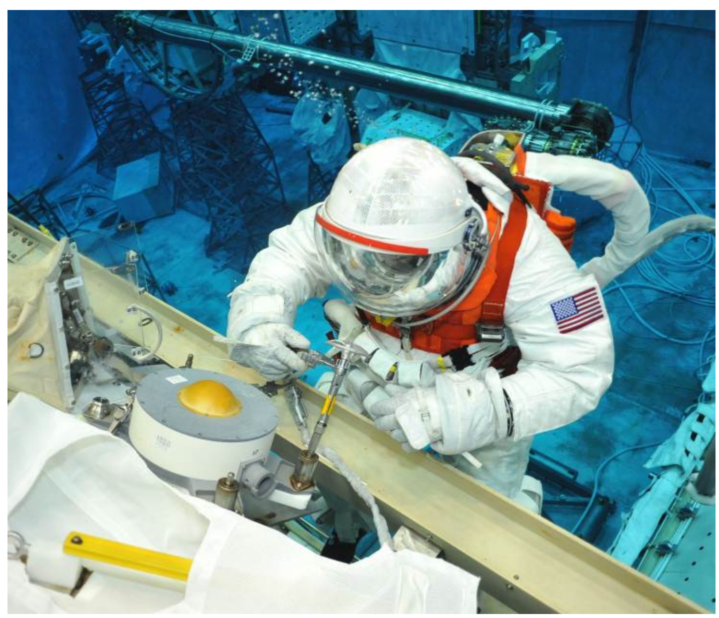

Figure 8. MACES performing tool operations with TMG.

During these runs, the test subjects began attempting more complex tasks. Tasks that were successfully completed included: ingress/egress of the ISS airlock hatch, translating with a tool bag, translating across complex geometries including a boom, manipulating medium-sized tools/mock-ups (articulating portable foot restraint, global positioning satellite antenna), performing two-handed tool operations, and early simulation of possible asteroid EVA tasks. Crewmembers successfully completed these tasks; however, the crew did note a number of areas where the suit should be improved. The most significant of these comments related to the area of the work envelope and the need for better arm mobility.

It was noted that the ideal work envelope in the MACES is the lower abdomen region, with the subject's hands approximately shoulder width apart. This is due to the MACES being patterned for an aircraft pilot to have his or her hands on the yoke/stick while in the seated position. During a microgravity EVA, the position of the hands near the level of the face is preferred so that the crew see their hands and protect the helmet from damage. It is also important that the crew be able to bring their hands together to work with tools and tethers. Out of these runs, it was recommended that the suit arms be rebiased to a higher position with the arms more together. It was also recommended that arm bearings be added to the bicep region to improve mobility.

Figure 9. Simulated asteroid sample collection.

A Thermal Micrometeoroid Garment (TMG) was added to the suit to simulate the thermal protection that would be required in a microgravity EVA (Fig. 8). The TMG was constructed from a similar fabric layup to an EMU TMG. The exterior is made from ortho fabric for abrasion protection. The thermal protection is made from multiple layers of aluminized Mylar, and liner layer is made of neoprene-coated nylon. The subject commented that the TMG did not limit his mobility, and he was mostly unaware that it was present.

Simulated asteroid tasks included translating across ropes over boxes filled with rocks, incorporating body stabilization exercises using ropes in tension, and attempting to collect an asteroid sample using an EVA wipe (Fig. 9). The subjects found that they could translate across the ropes freely, but that body stabilization would need to be improved for detailed sample observation and collection (especially if two-handed tasks such as core drilling would be required). It is intended to incorporate EMU boots into the MACES in fiscal year 2014 for use in the NBL to demonstrate the ability to restrain the MACES to allow two-handed tasks.

3. Future Neutral Buoyancy Laboratory work

In 2013, orders were placed for four new suits that had mobility enhancements. Two of these suits will have the shoulder rebiased so the neutral arm position is higher and more toward the center of the chest. The other two suits will have the shoulder rebiased and an arm bearing added along the bicep with higher mobility elbow joint. EMU boots will be added to the suit and analyzed for possible loads. Major objectives for 2014 testing include: evaluating mobility enhancements, attempting to ingress/egress EMU foot restraints, accomplishing two-handed tasks inside of the EMU foot restraint, testing with two crewmembers in the water at one time to evaluate the crew's ability to help one another, and testing on higher-fidelity capsule mock-ups that will more accurately represent an asteroid-type EVA (video).

V. Evaluation Results

Subjects were consistently able to complete the tasks requested of them. A variety of standard tasks were attempted. The suit did allow for consistent translation and body positioning. Gross body motions generally required less effort than fine two-handed tasks. The need for better body stabilization was also highlighted. The suit does require basic changes to optimize performance. Most notably, repositioning the arms higher so that the work envelope is better aligned with crew's field of vision and allows the crew to protect the helmet visor. Increased mobility in the arms is also highly desirable. Often, the completion of a task required different techniques than are used with an EMU. In the case of translation, EMU translation is generally accomplished along the long axis of the body with the hands close together. Conversely, with the MACES translation sideways and hands at shoulder width was more common. Some operations required a significant amount of effort that could not be sustained for multiple hours. Metabolic rates were collected and are being analyzed for predictions of MACES metabolic rates during EVA. Suit fit is of critical importance in an EVA. It was found that a proper pressurized fit is much tighter than a comfortable unpressurized fit. It was also observed that the pressurized fit has a much smaller window of adjustment than the unpressurized fit. Since this suit will be used for multiple phases of flight, the fit will have to be a compromise between the different phases.

VI. Conclusion

This was the first time in more than 20 years a new NASA suit has been evaluated in a neutrally buoyant environment. The development of interface requirements was useful to the MACES team and to other prototype suits that will follow in the coming years. Much work remains to improve the suit and increase the fidelity of the simulation. This work will continue in 2014. Neutral buoyancy is still the best available EVA simulation, and it will continue to play a large role in the evaluation of upgrades to the suit.

Acknowledgements

This work would not have been possible without the dedicated work of the entire Crew Survival Engineering Team, their efforts are the foundation of this project. The author would also like to thank the teams at the NBL and ARGOS for their efforts in integrating the MACES with their systems.

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Videos of proposed asteroid mission: https://www.youtube.com/watch?v=jXvsi7DRyPI
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