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Development and Testing of a Space Suit Analogue for Neutral Buoyancy EVA Research

Jeffrey R. Braden and David L. Akin
Space Systems, Laboratory University of Maryland

ABSTRACT

With NASA's resources dedicated to the six-fold increase in extravehicular operations required for the construction of International Space Station, there are few or no opportunities to conduct neutral buoyancy research which requires the use of pressure suits. For this reason, the University of Maryland Space Systems Laboratory has developed a system which replicates some limited aspects of pressure suits to facilitate neutral buoyancy research into EVA bioinstrumentation and EVA/robotic interactions. The MX-2 suit analogue is built around a hard upper torso with integrated hemispherical helmet and rear-entry hatch. Three-layer soft goods (pressure bladder, restraint layer, and thermal/micrometeoroid garment with integral ballast system) are used for the arms and lower torso. Designed for human use at 2 psid, the MX-2 provides (in a coarse sense) the outer envelope and joint restrictions of operational pressure suits, while providing realistic visual and audio environments and a "dry" interior for bioinstrumentation. This paper details the design, development and testing of the MX-2, and provides an overview of plans for Space Systems Laboratory research using the MX-2 in the University of Maryland Neutral Buoyancy Research Facility. Initial applications include correlation of MX-2 performance in EVA tasks from both neutral buoyancy and space flight, adaptation and integration of the SSL Joint Angle and Muscle Signature system to measure body joint motions and muscular fatigue, test of various approaches to EVA/robotic cooperation, and development of a virtual reality visual environment integrated into neutral buoyancy simulations.

INTRODUCTION

NASA and other space agencies around the world have recognized the benefit of EVA simulation in a neutral buoyancy environment for training astronauts to successfully complete EVA mission objectives. For these simulations, astronauts wear slightly modified, flight rated space suits, such as the Shuttle extravehicular mobility unit (EMU). The combination of the neutrally buoyant environment and the use of suits practically identical to their flight suits provides astronauts with the most accurate replication of their capabilities in orbit. The benefit of such high fidelity simulations is that it helps ensure a safe and successful mission.

Unfortunately, the benefits of high fidelity training rarely trickle down farther than flight training. Limited access to EMUs and the prohibitively high cost of such high fidelity simulation restrict the capabilities of researchers and designers to experience the flight conditions they are supporting. Many design features and human factor considerations are artifacts of working in a pressure suit, and engineers would greatly benefit from experiencing the capabilities and limitations of working in a suit.

It is important to note that obtaining this experience does not require the complexities of a flight rated EMU. Many aspects of a flight rated suit that make testing prohibitively expensive (on the order of $5000/hour) and impractical do not contribute to test fidelity. The use of space-rated designs or materials, and requiring the testing and documentation associated with flight-level safety requirements are extraneous cost and procedural constraints. While astronauts in training require the highest degree of fidelity throughout their flight specific simulations, engineers and researchers do not require all the complexities of a true space suit. A majority of the design and human factors considerations imposed by operating in a pressure suit can be recreated using a lower fidelity analogue to the flight-rated suit. The Maryland Advanced Research and Simulation (MARS) Suit is a space suit analogue to be just that – a lower fidelity test bed for neutral buoyancy EVA research.

Figure 1. The MX-2 standing in its donning station on the deck of the University of Maryland Neutral Buoyancy Research Facility.

The MX-series of space suit analogues have been designed and fabricated with the intent of being a low cost simulator of the general characteristics of a modern day pressure suit. At the same time, since the role of the MX-series is to support EVA simulation at the research and development level, the space suit analogues are designed to serve as testbeds for a variety of different modifications and experiments.

This paper covers the full spectrum of the MX suit project from its conception to future applications, with special emphasis on the current version of the suit, the MX-2. After a brief history of EVA simulations, the design of Maryland's first space suit analogue, the MX-1, is described. A description of the upgrades implemented to upgrade the prototype MX-1 to the operational MX-2 is followed by selected test results for the suit components. This paper concludes with an outline of future testing, planned upgrades, and future applications for the series of Maryland Advanced Research and Simulation suits.

HISTORY

The use of neutral buoyancy research for EVA simulation is as old as human space flight. Astronauts from the Gemini missions trained for EVAs using pressure suits identical to their flight suits and concluded that there was a high probability of success for any EVA task simulated in neutral buoyancy [1]. Since then, neutral buoyancy simulation has played a key role in preparing astronauts for mission success. Facilities like the NASA Marshall Space Flight Center Neutral Buoyancy Simulator and the NASA Johnson Neutral Buoyancy Laboratory (NBL) have been heavily used during preparation for EVA missions, and sometimes shared for research opportunities. Unfortunately, with the closing of the NASA Marshall facility, access to high fidelity flight equipment and tank time is both rare and prohibitively expensive for the research community.

At the University of Maryland's Space Systems Laboratory, the Neutral Buoyancy Research Facility (NBRF) provides a unique alternative to testing at the NASA Johnson NBL. EVA simulation research at the NBRF is currently conducted using teams of scuba divers. A combination of the neutral buoyancy environment, high fidelity hardware mockups, and realistic communication systems can make these simulations very accurate in many respects except for one main area – the replication of the space suit restrictions and limitations.

The inability to dive without the simulation of a pressure suit has been identified as an undesirable condition at the neutral buoyancy facilities worldwide. Perhaps the most significant attempt to fill this void is the European wet suit prototype designed and manufactured to provide a low cost, moderate-fidelity, emulation of the Russian Orlan suit for neutral buoyancy EVA simulation. The Orlan suit replica is water filled, with the test subject wearing a face mask for breathing and vision. While the suit replicates the external envelope of an Orlan suit and mechanical joints provide a rough feel of joint torques, the abandonment of the dry pressurized environment is impractical for bioinstrumentation and support equipment. However, this suit did represent the first and only serious attempt to service the need of researchers to have a low cost, space suit simulator for neutral buoyancy research. The MX-series takes the idea a step farther to not only replicate the most critical pressure suit characteristics, but to provide a suit that also presents a low cost, versatile test bed for neutral buoyancy EVA research [2].

DESIGN AND DEVELOPMENT

GOALS

In 1996, the first Maryland Advanced Research and Simulation Suit project team developed the goals of the project which have endured to this day. They are as follows: [3]

- Provide a livable environment to the wearer when used in both neutral buoyancy and laboratory (1-G) simulations
- Replicate the general exterior envelope of current pressure suits (primarily the EMU) for testing EVA external interfaces

- Provide a similar visual environment for the wearer as that in current pressure suits
- Provide the capability to replicate the joint angle limitations and torque requirements of an actual pressure suit for some selected body joints.
- Maintain thermodynamic equilibrium over a variety of metabolic workloads.
- Provide two-way audio communications
- Provide for biomedical and suit engineering telemetry.
- Provide a testbed for advanced human interface research

MX-1 BASELINE

The MX-1 was the first in the MX-series of space suit analogues. Its design was a feasibility study aimed at meeting the goals established above. The MX-1 configuration has now become the baseline for its operational successor, the MX-2, which is introduced in later sections of this paper. The main design features of the MX-1 are summarized below.

Suit Pressure

As opposed to the water filled suit configuration adopted for the Orlan suit simulator, the MX-1 was designed with a dry interior. This allows a much simpler implementation of bioinstrumentation and general internal upgrades. In order to avoid the increased complexities of a pressurized suit, it was initially decided the suit would operate at, or just above, ambient pressure. This would prevent any high pressure "blow-out" scenarios in case of a tear in the suit, while at the same time provide enough pressure to prevent the suit from flooding following a tear.

Hard Upper Torso (HUT)

The hard upper torso (HUT) of the suit was designed to be the central body of the entire suit just like in the EMU or Orlan space suits. As opposed to the waist-entry configuration of the EMU, a rear entry configuration was adopted from the Orlan suit for several reasons. Studies have shown that "the design of a bottom entry HUT involves a trade between don/doff ease and operational shoulder/arm flexibility and range" [4]. In order to avoid this complexity, a rear entry hatch was implemented along with planar shoulder bearings, allowing both a simple don/doff procedure and maximum control over shoulder/arm flexibility and range. The greater volume required for the rear hatch allows greater access to the backpack components without compromising any performance characteristics of the suit.

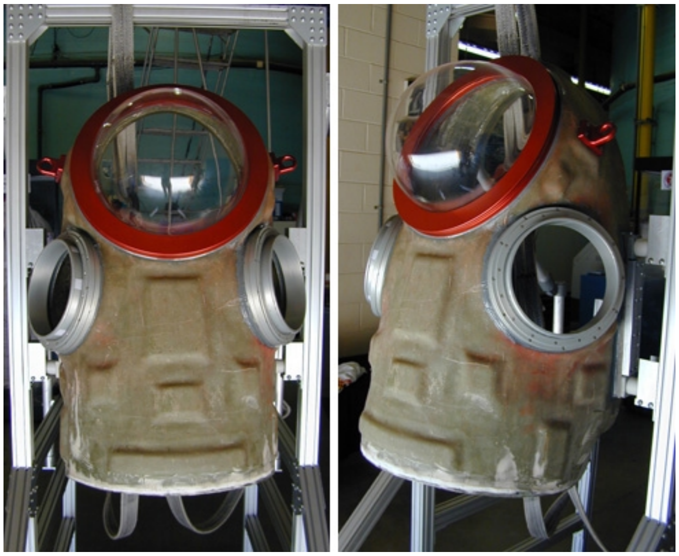


Figure 2. The Hard Upper Torso (HUT). Originally made for the MX-1. Slightly modified for the current MX-2 suit.

The MX-1 HUT, shown in Figure 2, was constructed using an epoxy resin fiberglass composite. The fiberglass and resin were hand molded over a plaster mold of the primary test subject. Aluminum blocks were incorporated between layers to become integral hard points for mounting a variety of attachments to the HUT. Finally, the arm bearings and helmet ring were attached using both high-strength Hysol epoxy and stainless steel fasteners.

Soft Goods

The two arm segments and lower torso assembly (LTA) are collectively known as the soft goods. The MX-1 soft goods were neoprene dry suit parts, custom made to fit the primary test subject and interface with the HUT. Custom fit dry suits are popular in the SCUBA market which makes these neoprene parts readily available at a low cost. Patch kits also make repairing these pieces easy and inexpensive. In order to replicate the joint torques of an EMU, strips of additional neoprene could be added to selected joints to add bending resistance. This concept is very similar to that used on the European emulation of the Orlan suit, except the elasticity of the neoprene is used to replace the rotational springs in their wet suit [2].

To avoid the complexities of an additional interface to the soft goods, the arm segments and LTA were ordered with integrated neoprene gloves and standard, rubber-soled neoprene boots. Although rather crude as an analogue to the EMU gloves and boots, the dry suit technology offered a low cost, readily available solution. In a coarse sense, the gloves also provided a simple replication of decreased dexterity and tactile feedback common in all EVA gloves [5].

Liquid Cooling Garment

To prevent the test subject from overheating during a simulation, a liquid cooling garment (LCG) was developed. Much like the same garments found in NASA's EMU and the Russian Orlan suit, the MX-1 LCG is a tight fitting garment laced with tubing. The garment itself is made from an inexpensive lycra dive skin with 1/8th" tubing spaced 1" apart. Chilled water is pumped through from the surface and then released through a tap in the backpack to the ambient water. This tap can alternatively be fitted with a hose for use out of the tank in a laboratory environment.

Backpack

The MX-1 backpack was designed to have the same external envelope as the Shuttle EMU. This was done for two reasons. First, it helps satisfy one primary goal of replicating the external envelope of a real EMU. Second, by sizing the backpack to the Shuttle EMU and matching key backpack interfaces, it was hoped that the MX-1 would be able to interface with many common donning stations and suit room interfaces at other facilities.

A pressurized aluminum box that contains all air system, cooling water, and audio communication components constitutes the bulk of the backpack volume. Spare room was also allocated for future electronics associated with bio-instrumentation or human factors experiments. Dual redundant air supplies sit above this pressurized box and fill out the rest of the backpack volume.

Air System

The MX-series air system is an open-loop system which nominally feeds supply air to the suit from the surface, and eventually returns exhaust back to the surface, thus eliminating any bubbles during operation. Surface air is supplied from a human-rated air compressor and filtration system. After passing through a sensor suite on the surface, the air passes through an umbilical and into the monitoring system in the backpack. From here the air is forced to circulate around the interior of the suit via air channels before being returned to the surface for venting.

Dual redundant air supplies are also designed into the air system in case of a surface air failure. The first redundant air supply is controlled by a demand regulator set to supply air should the supply pressure drop below a set value. The second redundant supply is attached to a scuba regulator located within the helmet. In the unlikely event of a failure in all three suit supplies, the helmet ring can be removed by a safety diver who can then provide air for an emergency ascent.

MX-2 UPGRADE

The MX-1 design never made it into the operational phase, but was a feasibility study meant to lay out a baseline for future suits in the MX-series. MX-2 is the first suit being made for testing and operation. In preparation for these events, two main changes from the baseline MX-1 design have been made.

The fundamental driver for the MX-2 upgrade was suit pressure. The baseline configuration of MX-1 called for an approximately 0.5 psi differential between suit pressure and ambient. As described above, this positive pressure prevents flooding and prevents a high pressure blow out of the suit. Theoretically this works. In practice however, this is a rather unstable configuration. The pressure gradient in water is roughly 0.5 psi/ft. The resulting 1.5 psid gradient from the waist (reference pressure location) to the upper and lower-most extremities makes maintaining a positive pressure over the entire suit at a nominal 0.5 psid impossible for neutral buoyancy operations. This leads to suit volume changes, a problem identified in the scuba-diving community as dry suit inversion. While scuba divers are trained to deal with such a problem, this change in volume – and thus, buoyancy – is unacceptable for the suit simulation application. Fortunately, with an increase in suit pressure to 2 psid, the suit pressure can be monitored from the waist and neither the uppermost suit extremity nor the deepest will ever see a negative pressure difference. In order to adopt this stable configuration, the MX-2 was upgraded to an operating suit-ambient pressure differential of 2 psid. This change to the MX-1 baseline propagated into two main subsystems.

MX-2 Air System

The first and most obvious subsystem affected is the air system. The main technical challenge of developing the air system is designing a backpressure regulator sensitive enough to constantly regulate the suit pressure during rapid ascents and descents in the neutral buoyancy tank. Fortunately, increasing the operating pressure of the suit makes this challenge slightly easier, and thus makes the MX-2 air system a much more robust system than that on the MX-1.

MX-2 Soft Goods

Neoprene dry suits are typically made to be ambient pressure suits. As such, they are not meant to hold significant internal pressures without ballooning. With the increased operational pressure of the MX-2, the neoprene soft goods were replaced with a layout much like the Orlan and Shuttle EMU suit, comprised of a pressure bladder and a separate restraint layer. Flat pattern mobility joints are designed into the fabric of both the restraint layer and the pressure bladder to facilitate range of motion requirements. Rather than adding and removing strips of neoprene to simulate joint torques, joint torques are now replicated by in-house tailoring of joint sizes and layouts. The added benefit of this approach is that the fabric induced joint torques should better replicate the hysteresis curves observed in EMU joint torque profiles [6].

An additional layer was also added to the soft goods for the MX-2 design. This outer layer is similar to the thermal/micrometeoroid garment on the Shuttle EMU in that it provides an outer covering to protect the inner layers. This layer also acts as an integral ballast system. An array of weight pockets facilitate quick and efficient suit balancing for proper neutral buoyancy testing.

Figure 3. The 3 layers that make up the new soft goods used on the MX-2.

Since the soft goods are now made in-house, the design of the arms and lower torso assembly can be readily upgraded to include added features. The first changes involve upgrade modifications to the boots and gloves. The design of EVA gloves is perhaps the most intensive and most important aspect of EVA performance. However, redesigning the glove is beyond the scope of the MX-series at this point. Therefore, the MX-2 has simply replaced the neoprene gloves of the MX-1 with higher fidelity equipment. The MX-2 arm assemblies now end with a quick disconnect which mates with the standard Shuttle EMU wrist ring disconnect. Adapters to this interface will allow a variety of other gloves to be tested on the MX-2. Although these gloves (designed to operate at 4.3 psid) will be operated at 2 psid on the MX-2, studies have shown that these pressures will still significantly reduce hand task performance [5]. The boots have also been modified to replace the dry suit boots on the MX-1.

Figure 4. The new boots for the MX-2 are fitted with the same heel used on the Shuttle EMU to lock into standard EVA foot restraints.

The MX-2 boots, shown in Figure 4, are industrial boots that have been integrated into the restraint layer. The soles of these boots have been fitted with the standard aluminum heel connector used on EMU boots to interface with the standard NASA foot restraints used on orbit. This new boot improves the feel of the suit as well as makes it a useful tool for simulating complete EVA operations.

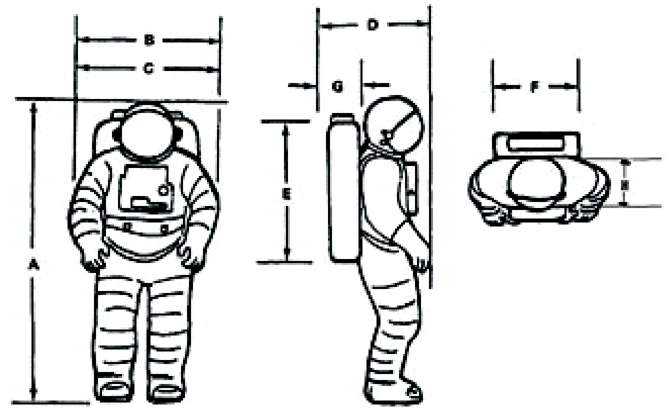
TESTING

The primary objective of the MX-2 is to begin testing and operation of the first Maryland Advanced Research and Simulation Suit. As modifications to the MX-1 baseline are completed, the suit's components are tested and then integrated for full suit tests. At the time of publishing this article, several components have been tested, while others are still in the process of being upgraded. The following two sections summarize the testing and suit evaluation performed to date, and the testing planned for the immediate future.

SUIT CHARACTERIZATION AND COMPONENT TESTING

Suit Envelope & Range of Motion

One of the primary goals of the MX-series is to provide the general exterior envelope of current pressure suits. To verify a general match to the exterior envelope of NASA's EMU, several suit measurements were made in conjunction with those used in NASA Standard 3000 [7]. The following diagram and tables summarize the measurements taken and compare the maximum dimensions for both the Shuttle EMU and the MX-2.



Size Range (Shuttle EMU)		
	95th Percentile Male	MARS Suit MX-2
A - Height	75.5 in	74.5 in
B- Maximum breadth at elbows (arms relaxed)	33.4 in	34.0 in
C - Maximum breadth at elbows (arms at side)	26.0 in	34.0 in
D - Maximum depth with PLSS/SOP	27.0 in	26.3 in
E - PLSS height	32.0 in	32.0 in
F - PLSS breadth	23.0 in	23.5 in
G - PLSS depth	7.0 in	7.5 in
H - PLSS to DCM distance (maximum)	20.77 in	19.5 in

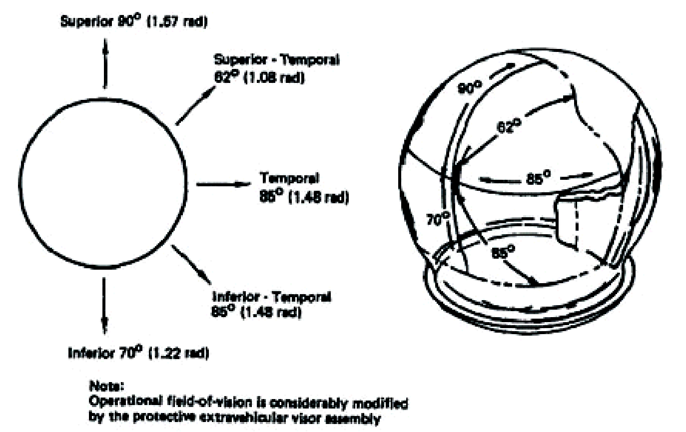
Figure 5. External Envelope Comparison Between the Shuttle EMU and MX-2 [7].

Although the elbows do not pinch in as much as the EMU suit (Figure 5, “C”), the more critical constraint (Figure 5, “B”) is right on. Figure 5 therefore illustrates that the MX-2 accurately replicates the same general external envelope as the Shuttle EMU.

The next step in this category of suit characterization will be range of motion studies. MX-2 mobility capability will be compared to the EMU descriptions available in NASA-STD-3000 [7]. These tests will be run upon completion of the MX-2 soft goods and air system upgrades.

Field of View

Another primary goal of the MX-series is to provide a similar visual environment for the wearer as that in current pressure suits. To verify this goal was being achieved, field of view measurements were taken from the MX-2 and compared to the requirements listed in NASA Standard 3000 for the Shuttle EMU [7]. The results of this characterization are summarized below in Figures 6 and 7.



Note:
Operational field-of-vision is considerably modified by the protective extravehicular visor assembly

Figure 6. Field of View Measurements for the Shuttle EMU Helmet [7].

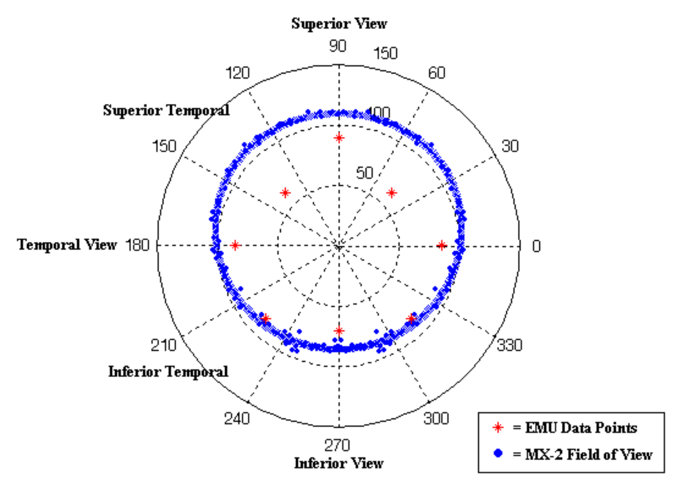


Figure 7. Field of View Measurements for the MX-2.

As the charts show, the hemispherical helmet provides a greater field of view than the EMU helmet. This feature allows the MX-2 to test advanced suit design concepts that require a larger field of view (e.g., heads up displays), while a simple visor assembly can be added to shrink the field of view if necessary for EMU simulations.

Joint Torques

The goal of providing the capability to replicate the joint angle limitations and torque requirements of an actual pressure suit for some selected body joints is perhaps the most difficult goal to accomplish for this project. The design and fabrication of fabric mobility joints has been the focus of much research in industries and space agencies around the world. It is not the goal of this project to invest the time and money into this research, but rather to provide a reasonable approximation to the limitations and abilities of actual pressure suit joints. To do this, an apparatus has been developed to help characterize joint torque behavior. Joint segments (primarily elbow joints) are built and pressurized to 2 psid in a glove box. A mechanical arm is then inserted into the arm segment and mounted to the glove box. From this mechanical arm, measurements can be made to produce plots following joint angle versus torque. These hysteresis curves can then be compared to those of a typical Shuttle EMU elbow joint [6].

At this time, the second generation of this mechanical arm is still in production. However, qualitative comparisons of the MX-2 elbow design and the EMU elbow joint have indicated the MX-2 elbow provides a reasonable approximation to EMU joint torques. Quantitative analysis and subsequent elbow modification will be available upon completion of the mechanical arm.

Burst and Leak Testing

The strength of the suit is of critical importance to operator safety and long-term operation of the MX-2. In order to ensure the integrity of the suit, each segment of the suit is tested individually and then again as a fully integrated system. While tests to investigate the strength of the suit against user-induced loads are still being developed, testing the strength of the suit components under environmental pressure loads is currently underway. The first components to be tested are the arms. Three identical arms have been built for the MX-2. The first was subjected to a burst-strength test where the arm was pressurized while pressure and air flow rate measurements were recorded electronically. For safety reasons, it was required that the arms be able to hold at least three times nominal operating pressure without catastrophic failure. Three times nominal operating pressure, or 6 psid, was reached without any problems. Pressurization continued to three times the nominal operating pressure of the Shuttle EMU, or 12.9 psid, also without any problems. The test was ended at 13.2 psid when an axial restraint line failed. This test was an incredible success, considering the arm withstood more than three times the operating pressure of the Shuttle EMU and more than six times the operating pressure of the MX-2 without any catastrophic failures.

The other two arms have been made for eventual operation but are required to pass through pressure testing for quality assurance purposes. They, and any other arms to be used in operation, are required to be identical to the burst tested arm and must be tested to 1.66 - 2.0 times operational pressure to ensure they are structurally sound for use. The second two arms for this test were indeed identical in construction to the burst-tested arm. They were brought up to 3.7 psid and 4.0 psid respectively without any problems.

The quality assurance tests also allow the arms to be examined for leak rates. A leakage rate is recorded for each arm and stored in a database. Once the other suit components (HUT, LTA, backpack) have been similarly tested, the overall MX-2 leakage rate will be compared to the overall suit flow rate. While NASA's requirements for EMU leakage rates are overly stringent for our purposes, one future role of the MX-2 is to be used in a metabolic workload test that requires the measurement of oxygen consumption. In order to sustain accurate readings, it is the goal of this project to minimize suit leakage. The preliminary leakage requirement for the arms has been set to no more than 1% of total suit flow. This amounts to approximately 0.06 SCFM, or1,700 SCCM. Leakage on the current arm segments averages 495 SCCM per arm or 990 SCCM for the pair of MX-2 arms, which is well below the current arm requirement.

FUTURE TESTING

The air system is perhaps the most critical component to test thoroughly to ensure operational safety. The first tests with this subsystem will be unmanned and designed to verify that the regulation system is maintaining suit pressure at various depths, and that pressure differential is accurately maintained at all potential ascent/descent rates.

Following the complete check out of the air system, the suit will enter a period of operational tests that will check out all subsystems. Paramount throughout this phase is crew safety. Before any test subjects are introduced into the water, contingency plans and emergency procedures will be performed on the deck. For the first water tests, the suit will be tethered to the bottom of the tank to prevent an uncontrolled ascent. The test subject will then go through a buoyancy checkout in which they will verify there is no tendency to change buoyancy at different depths or in different poses or orientations. This test will also serve as a checkout for communications and telemetry feeds.

Upon successful completion of the operational test dives, the MX-2 will enter a period of performance evaluation. The suit will be used in simulations of tasks with known performance metrics in both neutral buoyancy and space flight. The Experimental Assembly of Structures in EVA (EASE) was a Shuttle experiment developed and flown by the Space Systems Laboratory in 1985. The extensive database on assembly performance from this mission includes data on neutral buoyancy performance in both Apollo A7L-B and Shuttle EMU suits as well as flight data in the EMU.[8] This data will be used in comparison of the performance of the MX-2 in the same assembly task. This task, as well as others, will be repeated to obtain a performance evaluation of the MX-2 space suit analogue.

FUTURE APPLICATIONS AND UPGRADES

APPLICATIONS

The MX-2 is designed to be a general-purpose testbed for advanced EVA research. To that end, it will be used in a number of ongoing and planned future research areas.

The Space Systems Laboratory has developed an advanced EVA biomedical instrument which monitors body motions, and measures the rate of muscular fatigue onset. The Joint Angle and Muscle Signature (JAMS) system was tested in EMUs at the NASA Marshall Neutral Buoyancy Simulator, but had to be self-contained, which limited the data collection capacity.[9] JAMS will be fully integrated into the MX-2, and available for quantitative neuromuscular evaluation of experimental tasks.

The Space Systems Laboratory (then at MIT) conducted the Experimental Assembly of Structures in EVA (EASE) experiment on shuttle flight STS 61-B in 1985. This flight data yielded valuable quantitative correlation of an extensive neutral buoyancy database in EVA operations. However, one of the most interesting correlations could not be performed, as there has never been metabolic workload instrumentation available on neutral buoyancy suits. The surface-supplied life support system for MX-2 will be instrumented with O2 and CO2 partial pressure sensors in the air return line, as well as flow meters and inlet/outlet temperature sensors in the water-cooling lines. This will allow continual real-time measurement of metabolic workload, which will provide quantitative metrics on comparative approaches to issues such as suit design details.

The MX-2 helmet was specifically designed to accommodate head-mounted display units internally. One of the planned research applications of the MX-2 is to investigate advanced EVA controls and displays. Computer graphics and high-resolution video will be provided to the wearer, and assessed for impact on EVA operations. One of the longer-range goals is to develop fully immersive virtual environments with realistic dynamics. Unlike the current use of VR for crew training, in which the subject is standing in a laboratory with full earth-gravity preload on the postural muscles, in this concept a test subject in simulated microgravity will be provided with a computer-generated visual field. In a visionary scenario, one might imagine realistically simulating an ISS EVA in neutral buoyancy, where the only physical hardware that is used are the crew handholds and interfaces. All other “mockups” are limited to computer animations, along with a much more realistic visual image than the walls of the neutral buoyancy tank would provide.

The Space Systems Laboratory has a long and extensive experience in advanced EVA glove design. This has included glove simulations, a robotically-augmented EMU glove, and various forms of mechanical counterpressure glove technologies. While many early evaluations of advanced gloves can be performed in a glove box in the SSL, the important next step is to perform realistic end-to-end simulations to assess wearability, resistance to tearing and abrasion, and effect of the technology on task performance. The MX-2 is well suited to this, especially with the use of the JAMS system to obtain quantitative data on the rate of fatigue onset with competing gloves on identical tasks.

UPGRADES

The modular nature of the MX-2 is designed to accommodate easy and regular upgrades, in order to test advanced EVA technologies in a realistic simulation environment. Early efforts will focus on advanced space suit design technologies, including alternative soft good designs in the arms, and assessment against “hard suit” rotary joints in the shoulders and elbows. Alternatively, mechanical counterpressure approaches will be tried, ranging from simple replacement gloves to fully integrated hand/arm gloves integrated to the suit at a higher level of the arm. Similarly, the lower torso assembly may be augmented or replaced by multi-roll hip and/or knee joints. The modular nature of the MX-2 will also accommodate advanced robotic components, such as might be used for direct force augmentation or reduction of wearer work loads for actuating major suit joints.

MARS suit development is planned far beyond the MX-2. The Space Systems Laboratory is already researching alternative fabrication technologies which will allow the creation of future suit components (particularly the hard upper torso, backpack, and hatch assembly) with much less investment of time and labor than the hand laid-up system used in the MX-1 and MX-2. Lightweight suit simulations will be useful for research into planetary surface operations, particularly the SSL core research into EVA/robotic interactions. Advanced suit concepts, such as the Command/Control Pressure Suit [10], can be prototyped and evaluated much more conveniently than for a flight-rateable unit.

CONCLUSION

The Maryland Advanced Research and Simulation Suit program, while not producing flight-rated pressure suits, has the potential to dramatically increase the possibilities for performing advanced research and technology development for EVA. Through the use of the MX-2, the SSL plans to continue and dramatically expand its signature research into human/robotic cooperation, obtain biomedical data never before available from neutral buoyancy simulations, assess advanced pressure suit technologies in a quantitatively rigorous manner, and advance the state-of-the-art in space simulation through the adaptation of virtual reality techniques to the underwater environment. By separating the EVA research activities from the prohibitive constraints imposed by flight-type suits, the MX-2 and successive units in the MARS Suit line may provide the initial proof-of-concept results that will spur badly-needed federal investment in advanced EVA technologies.

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CONTACT

For more information on the MX-2, please contact Jeff Braden (jeffbraden@ssl.umd.edu) or Dr. David Akin (dakin@ssl.umd.edu) at the Space Systems Laboratory, Bldg. 382, University of Maryland, College Park, 20742.

The URL for the Space Systems Lab is: http://www.ssl.umd.edu.

The MX-2 project page can be found at http://www.ssl.umd.edu/homepage/projects/Projects.html.

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