

Evaluation of a Rear Entry System for an Advanced Spacesuit

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ABSTRACT

The success of astronauts in performing Extra-Vehicular Activity (EVA) is highly dependent on the performance of the spacesuit they are wearing. The Space Shuttle Extravehicular Mobility Unit (EMU) is a waist entry suit consisting of a hard upper torso (HUT) and soft fabric mobility joints. The EMU was designed specifically for zero gravity operations. With a new emphasis on planetary exploration, a new EVA spacesuit design is required.

One of the key features of any space suit is the entry method. Historical examples of different entry types include waist entry, rear entry, bi-planar entry, and soft zipper type entry. Suit entry type plays a critical role in defining the overall suit architecture. Some of the critical suit features affected by entry type are suit don/doff capability, suit sizing, suit mass, suit volume, and suit comfort. In general, rear entry designs provide better don/doff capabilities. However, mass and limitations to vertical torso length may be disadvantages of the rear entry design. Entry type is also affected by the vehicle and habitat interfaces such as air locks, hatches, and manned rovers. One concept for planetary exploration is to have an unpressurized vestibule attached to the habitat and have the spacesuit attached to the habitat wall acting as an air lock. This scenario is best supported by a rear entry design minimizing the amount of dust and dirt entering the habitat.

ILC has designed a rear entry prototype upper torso for the I-Suit advanced spacesuit. The design facilitates don/doff while minimizing mass and the negative effects on vertical sizing. This paper discusses research performed at ILC Dover to develop the rear entry design and initial evaluations of the prototype.

INTRODUCTION

Performance during EVA is dependent upon the space suit worn by the astronaut. The ability to don the spacesuit quickly and safely is critical to maximizing overall productive EVA time. Self-donning capability is essential. Mobility of the space suit defines the work space envelope. Adequate mobility is also necessary to maximize productive EVA time. Comfort and fit affect

maximum EVA duration. The overall mass of the space suit affects comfort and crewmember fatigue. These suit design characteristics are affected by entry type. Space suit operations such as maintenance, and on-site reconfiguration are also affected by entry type.

Mission requirements affect spacesuit design and entry type. The EMU is designed for zero gravity operations. The requirements for mass, sizing, don/doff method, and mobility will be different for a planetary suit than for the EMU. Spacesuit entry must be optimized for planetary EVA performance and spacesuit operations.

The ILC I-Suit advanced spacesuit has been designed with a rear entry upper torso. Donning capability and mobility of the rear entry suit were evaluated. The rear entry design improved don/doff capabilities with minimal negative effect on mass and vertical sizing. The rear entry I-Suit prototype will be used for future research and optimization of the upper torso for an advanced exploration suit. Figure 1 shows the rear entry I-Suit.



Figure 1. Rear Entry I-Suit

ENTRY TYPES

Various entry types have been designed and tested. Entry types used in previous spacesuits include waist entry, rear entry, tilted rear entry, bi-planar, and soft zipper opening. Other entry type possibilities include a tilted waist entry and neck entry. Entry types are described below.

WAIST ENTRY

Waist entry examples include the early NASA Ames Research Center AX series of spacesuits, the Air Research AES suit, the Shuttle EMU, and the ILC Dover I-Suit. The Shuttle EMU and waist entry I-Suit are similar in that waist entry is through a Body Seal Closure (BSC). The passive side of the BSC is part of the upper torso and the mating side is at the top of the waist mobility joint.

The enhanced Shuttle EMU planar HUT is a fiberglass shell with fixed scye plane openings. A 16-inch BSC is used on all three sizes of planar HUTs. The 16-inch BSC is roughly elliptical in shape with a 16-inch major diameter and a 12-inch minor diameter. The closure is a cam operated spring-loaded pin mechanism controlled by a locking handle.

The waist entry I-Suit has a fabric soft upper torso (SUT). A composite wedge element separates the SUT from the helmet and provides for backpack attachment and pass through of air, water, and electric lines. Three sizes of SUTs have been fabricated, all with a 16-inch BSC. The closure mechanism is a snap ring controlled by a locking handle. Figure 2 shows donning of the waist entry I-Suit.



Figure 2. Waist Entry I-Suit

REAR ENTRY

Rear entry is generally achieved through a hinged door at the backpack/upper torso interface. Rear entry examples include the Ames AX-5, the Russian Orlan suit, the NASA JSC H-suit, and the ILC Dover rear entry I-Suit. The rear entry suits vary greatly in the geometry of the rear opening.

The Orlan-DMA HUT is aluminum with an integral backpack and helmet. There is one size HUT. The opening is 15.5 inches wide by 31.0 inches tall. The closure is a sliding pin mechanism with six attachments. A draw cable allows the crewmember to pull the door shut and a control handle engages the latch.

The ILC Mark III HUT was an aluminum shell with a hinged door. The door is on an angle of 9 degrees with the vertical plane. The opening was approximately 20.5 inches at the widest point and 24 inches tall. The closure was a cam operated spring-loaded pin mechanism controlled by a locking handle, similar to the Shuttle EMU. NASA JSC has re-fabricated the Mark III HUT with a composite shell; the new version is called the H-Suit. The opening is approximately 19.5 inches wide by 24.8 inches tall and the closure is an interlocking lug mechanism. Figure 3 shows donning of the rear entry H-Suit.



Figure 3. Rear Entry H-Suit

A tilted rear entry has been fabricated for the I-Suit large size SUT. The opening is 20 inches wide by 23 inches tall. The opening is rounded at the corners to allow use of a snap ring closure common with the I-Suit BSC and neck ring. The composite wedge is eliminated. However, a spacer is added to the existing neck ring for attachment of the communication system and head mounted display. The upper portion of the rear closure provides for backpack attachment and pass through of air, water, and electric lines. The lower portion of the rear closure is fabric. Figure 4 shows a comparison of the openings for the Orlan DMA, Mark III, H-Suit, and the ILC Dover rear entry I-Suit.

OTHER ENTRY TYPES

A bi-planar entry was designed and evaluated by Litton during the development of the RX series of spacesuits

and by NASA Ames Research Center in the AX-3. The upper torso has a single closure in both the bottom and rear planes. The bi-planar upper torso can also be hinged at the waist. Soft entry examples include the Gemini and Apollo EVA suits. Donning is through two zippers, one pressure sealing and one outside the pressure boundary in the restraint layer. A tilted waist entry on an angled plane is possible. Entry is through the rear of the waist. The upper torso is donned similar to a waist entry with a larger opening. Finally, a top entry is possible through the neck area.

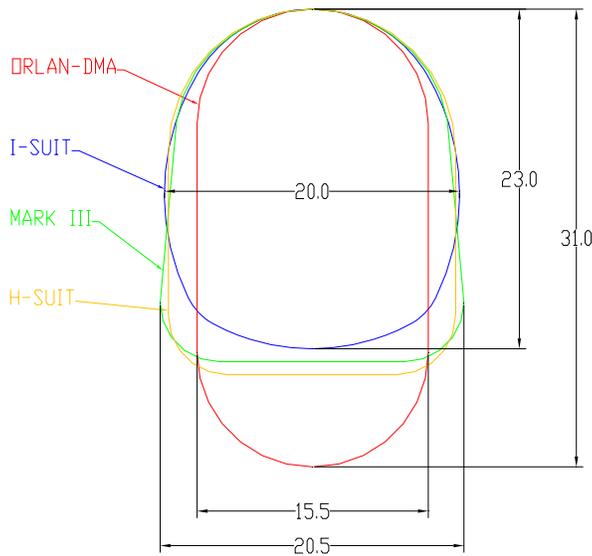


Figure 4. Comparison of Rear Entry Openings

REAR ENTRY DESIGN CONSIDERATIONS

The entry interface has the most direct effect on the upper torso of the spacesuit. In waist entry spacesuits, the inter-scye distance is restricted because the distance must be large enough to allow donning. In rear entry, there is less restriction on inter-scye dimension. However, torso length must be long enough to accommodate the vertical entry. In these designs, there is less length available for the waist component of the lower torso. The rear entry and tilted rear entry designs also have more mass due to the size of the opening and the strength of the closure required to manage the higher pressure loads.

CLOSURE DESIGN

The door on the I-Suit is the passive half of the rear closure and is attached with two hinges. The upper portion of the door has pass-thrus for air, water, communications, and head mounted display. The lower portion of the door is a fabric structure to reduce mass. The active half of the closure on the SUT is a snap ring mechanism with locking handle similar to the helmet and BSC closures. However, a custom seal in the SUT-side closure replaces the O-ring seal used in the other

locations in order to reduce the force needed to close the mating halves. Figure 5 shows the rear closure.



Figure 5. Rear Closure

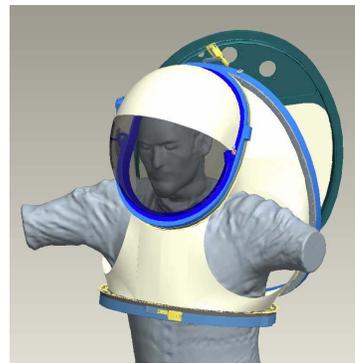
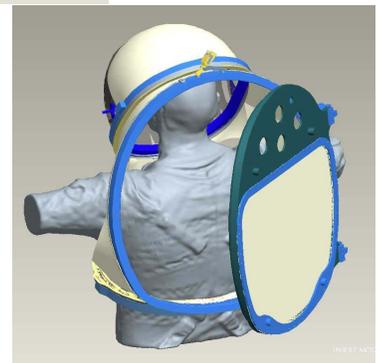
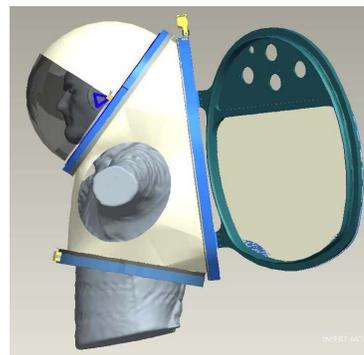


Figure 6. Rear Entry I-Suit SUT Model

UPPER TORSO

The upper torso on the rear entry I-Suit is a fabric structure like the waist entry I-Suit. The upper torso design is created through a model that can be revised and quickly fabricated to allow evaluations of change in size, scye bearing plane, etc. Figure 6 shows the rear entry suit model on the scanned surface of a suit subject.

Through iteration, a SUT model has been developed with a hinged rear door and no wedge element. The BSC ring, scye bearings, helmet and neck ring are interchangeable between the rear and waist entry I-Suits. Figure 7 shows a comparison of the waist entry and rear entry SUTs. The angle of the neck ring is unchanged. The inter-scye distance is sized for a large subject and is similar to the large EMU HUT. The vertical and horizontal angles of the scye bearings are based on the Mark III design. However, taking advantage of the flexibility of a fabric structure in donning, the angles are optimized with a smaller diameter scye bearing than the Mark III.

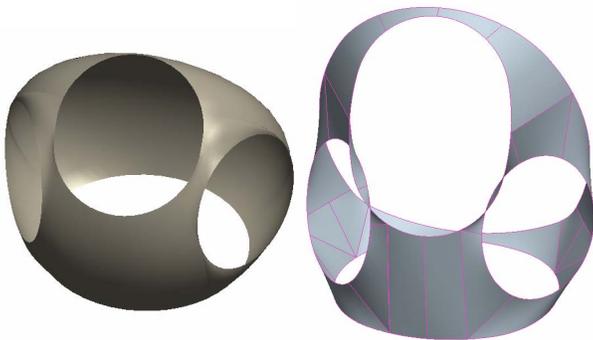


Figure 7. Comparison of Waist Entry and Rear Entry SUTs

SOFT UPPER TORSO VERSUS HARD

The primary advantage of a soft upper torso is the ability to quickly and easily redesign and fabricate new sizes and new configurations of scye, neck, and rear openings. Other advantages include reduced weight and the potential for active repositioning of neck and scye openings to improve mobility as discussed below. For these reasons, the soft upper torso is pursued for the I-Suit. Soft and hard upper torso designs must be studied to determine the best trade-off of features for a particular mission. Features include: mass, volume, structural issues such as impact resistance and ability to interface with light weight bearings and closures, shelf life and useful life, maintenance issues such as non-destructive inspection and reparability, cost, radiation and dust protection, etc. Advances in materials and technologies such as self-healing bladders that can mitigate risk of puncture and tear make a soft upper torso a promising design.

WEIGHT

The weights of the rear entry and waist entry I-Suit SUTs are compared in Table 1. The rear closure is approximately 9 pounds heavier than the BSC closure. The fabric structure weight is similar between the two SUTs. The scye bearings, and internal systems such as water lines, vent system, and harnesses are also considered to be the same for both SUTs. The composite wedge used on the waist entry is shown separately as is the neck ring spacer used on the rear entry I-Suit. While, the current rear entry I-Suit makes use of the existing BSC, the closure is not required and would be replaced with a fabric attachment ring. The estimated weight of this SUT attachment ring is shown. In total, the rear entry I-Suit is 7.6 pounds more than the waist entry I-Suit.

Table 1. Rear Entry and Waist Entry I-Suit SUT Weights

	Rear Entry I-Suit (lbs.)	Waist Entry I-Suit (lbs.)
Closure (Rear vs. BSC)	13.7	5.0
Composite Wedge	—	4.4
Neck Ring Spacer	0.8	—
SUT Attachment Ring (estimated)	2.5	—
Total	17.0	9.4

PERFORMANCE

The predominant effect of entry type is don/doff capability. Donning/doffing of a rear entry spacesuit is easier than a waist entry suit. The aspects of mobility that are affected by entry type and upper torso design include shoulder mobility and waist mobility. Proper fit and comfort are possibly the most important factor in good suit performance, particularly for an exploration spacesuit. Sizing, proper indexing, and mass are crucial to obtaining proper fit and comfort.

DON/DOFF

Don/Dooff capabilities include the ability to self-don, the ease of donning/doffing, the ease of alignment in sealing the closure, and emergency extrication capability. In general, don/doff capabilities of all rear entry suits with a hinged door are similar. Assumptions can be made regarding the I-Suit based on the experience of H-Suit and Orlan DMA. Self-donning has been demonstrated on-orbit in the Orlan-DMA. However, as shown in Figure 4, the size of rear openings has varied. A longer opening

requires more twisting of the hips while a shorter opening require more bending over.

The ease of donning is primarily related to the size of the opening. The ease of doffing is related to the size of the opening and to the resistance of the space suit lower torso. Donning and doffing are also affected by the donning stand and any donning aids. A donning stand was designed and fabricated for donning evaluations of the rear entry I-Suit. The donning stand allows the suit subject to sit on a bench at the level of the rear opening and to pull up on a bar above the rear opening.

Preliminary manned evaluation showed little to no difficulty in donning the rear entry I-Suit using the donning stand. Harnesses and water lines are routed to fasten in the rear and were secured by a technician after the subject had donned the suit. The subject is able to latch the rear door unaided. Likewise, when doffing, the subject is able to unlatch and “crack” open the rear door unaided. Doffing was more difficult than donning due to the lack of resistance in the lower torso, the fabric tended to be carried up with the subject. Refinement of the donning stand to stabilize the waist ring could help alleviate this tendency.

MOBILITY

For an exploration spacesuit, it may be desired to provide better downward reach and mobility. Waist flexion will be critical in an exploration spacesuit for kneeling and examination of ground features. In general, a rear entry design allows optimization of scye angle and inter-scye distance and therefore may afford better reach and shoulder mobility. However, a rear entry design may be more restrictive in range of waist flexion than the waist entry design.

A preliminary manned evaluation was conducted with a subject experienced in the waist entry I-Suit. Subjectively, the subject reported little to no difference between the mobility of the rear entry and waist entry I-Suits. The subject was able to reach overhead, in front, out to the side and behind with no difficulty. The subject noticed no difference in the range of shoulder motion except that he could not fully abduct his shoulders with his arms out horizontally, which is more difficult for him in the waist entry suit. The subject noticed no difference in waist mobility and was able to sit and rise from a sitting position. Figure 8 shows the subject in the rear entry I-Suit.

A NASA funded study is being conducted to identify potential actuators and methods for force multiplication to position and reposition the SUT scye angles after donning. One example of actuator technology, a “fluidic muscle”, is a pneumatic tube that contracts in length with increasing internal pressure. Figure 9 shows “fluidic muscles” installed on a pressurized extra-large waist SUT. Figure 10 shows scans of the SUT with the

scye planes located at three different breadth positions. This technology is compatible with the rear entry I-Suit as well, and could increase mobility for specific tasks such as hammering on the ground versus overhead work.



Figure 8. Rear Entry I-Suit Subject Evaluation



Figure 9. Fluidic Muscles Installed on X-Large SUT

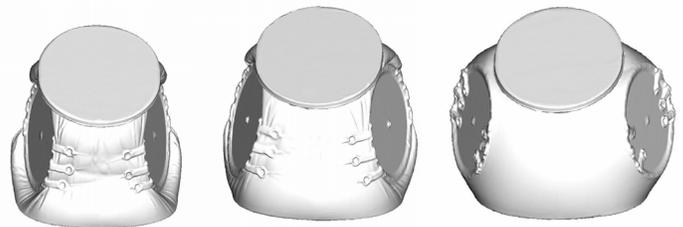


Figure 10. Repositioning Scye Plane

SIZING, COMFORT AND FIT

Rear entry type suits can have limitations on torso sizing and may not accommodate smaller crewmembers. The current rear entry I-Suit is sized to fit large subjects; a size between the current medium and x-large waist entry I-Suit SUTs. The use of a fabric upper torso allows rapid redesign and fabrication of multiple and/or custom sizes. Assuming the use of common neck ring, scye bearings, and rear closure between all I-Suits, it will be possible to reduce the inter-scye distance and breadth of the SUT to fit smaller crewmembers. There will be some limit to minimizing the torso length. A small rear entry SUT is possible.

Reduced mass results in better comfort and reduced crewmember fatigue. As shown in Table 1, the rear entry SUT is 7.6 pounds more than the waist entry SUT. The rear entry I-Suit SUT is expected to contribute less to system mass than a hard upper torso and/or larger rear opening.

SUIT OPERATIONS

New suit operation for planetary exploration will include on-site maintenance and reconfiguration, vehicle and robotic interface, and a new air lock interface. Simplicity, and commonality, will be principal factors. The I-Suit rear closure has been designed with the same mechanism as the helmet disconnect. The simplicity of this snap ring will facilitate on-site maintenance. Stowage capacity for tools and spares will be better for the common snap ring closure. On-site reconfiguration to change-out life support and components between suits will have to be evaluated for rear entry suits. Rear entry assumes that a life support component will be changed-out by removing and replacing the rear door or by access through the inside of the door. Connections will be made across the rear closure. In addition, the technology being advanced for the I-Suit to actively reposition the scye planes could allow resizing of one SUT to fit different crew, thereby reducing the need for upper torso change-out.

Vehicle and robotic interfaces will require that the upper torso be designed to accommodate umbilical attachment, robotic controls, and computer interfaces. Improved visibility and mobility will be required. Figure 11 shows a subject in the waist entry I-Suit able to board and sit on a commercial all-terrain vehicle. Similar capabilities will need to be demonstrated with the rear entry I-Suit. Preliminary evaluations of sitting in the rear entry I-Suit show no interference with the rear closure.

Finally, one concept for planetary exploration is to have the spacesuit attached to the habitat wall, acting as the air lock. A rear entry suit is the best candidate for this concept.



Figure 11. Waist Entry I-Suit on ATV

CONCLUSION

The ILC I-Suit advanced spacesuit has been designed with a rear entry upper torso. The upper torso on the rear entry I-Suit is a fabric structure like the waist entry I-Suit. A SUT model has been developed with a hinged rear door. The active half of the closure is a snap ring mechanism with locking handle similar to the helmet and BSC closures. The BSC ring, scye bearings, and helmet are interchangeable between the rear and waist entry I-Suits. The upper torso design is created through a model that can be revised and quickly fabricated to allow evaluations of change in size, scye bearing plane, etc. This capability is a prime advantage of a soft upper torso. The soft upper torso is pursued for the I-Suit for this reason as well as a potential reduction in weight, the potential for active repositioning of the scye planes, and potential advantages in on-site maintenance and reconfiguration. Evaluations have shown that the rear entry design improves donning capabilities with minimal effect on range of motion. The mass of the rear entry I-Suit compares favorably to the waist entry I-Suit and is greatly reduced from the EMU. Upper torso designs must be studied further to determine the best trade-off of features for a particular mission. Maintenance, vehicle, and air-lock interfaces must be defined and evaluated to optimize the upper torso for an advanced exploration suit. The Rear Entry I-Suit will be used as a test bed for further research and optimization.

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