

Suitport Feasibility - Development and Test of a Suitport and Space Suit for Human Pressurized Space Suit Donning Tests

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The suitport concept has been recently implemented as part of the small pressurized lunar rover (Currently the Space Exploration vehicle, or SEV) and the Multi-Mission Space Exploration Vehicle (MMSEV) concept demonstrator vehicle. Suitport replaces or augments the traditional airlock function of a spacecraft by providing a bulkhead opening, capture mechanism, and sealing system to allow ingress and egress of a space suit while the space suit remains outside of the pressurized volume of the spacecraft. This presents significant new opportunities to EVA exploration in both microgravity and surface environments. The suitport concept will enable three main improvements in EVA by providing reductions in: pre-EVA time from hours to less than thirty minutes; airlock consumables; contamination returned to the cabin with the EVA crewmember. To date, the first generation suitport has been tested with mockup suits on the rover cabins and pressurized on a bench top engineering unit. The work on the rover cabin has helped define the operational concepts and timelines, and has demonstrated the potential of suitport to save significant amounts of crew time before and after EVAs. The work with the engineering unit has successfully demonstrated the pressurizable seal concept including the ability to seal after the introduction and removal of contamination to the sealing surfaces. Using this experience, a second generation suitport was designed. This second generation suitport has been tested with a space suit prototype on the second generation MMSEV cabin, and testing is planned using the pressure differentials of the spacecraft. Pressurized testing will be performed using the JSC B32 Chamber B, a human rated vacuum chamber. This test will include human rated suitports, a suitport compatible prototype suit, and chamber modifications. This test will bring these three elements together in the first ever pressurized donning of a rear entry suit through a suitport. This paper presents the design of a human rated second generation suitport, the design of a suit capable of supporting pressurized human donning through a suitport, ambient pressure testing of the suit with the suitport, and modifications to the JSC human rated chamber B to accept a suitport. Design challenges and solutions, as well as compromises required to develop the system, are presented. Initial human testing results are presented.

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I. Introduction

Suitport replaces or augments the traditional airlock function of a spacecraft by providing a bulkhead opening, capture mechanism, and sealing system to allow ingress and egress of a spacesuit while the spacesuit remains outside of the pressurized volume of the spacecraft. This presents significant new opportunities to EVA exploration in both microgravity and surface environments.

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Suitport capitalizes on the atmospheres working group recommendation of an 8 psi and 32% cabin environment for exploration spacecraft. The reduced cabin pressure allows the suitport and the suit to be exposed to full cabin pressure while maintaining a lightweight, EVA friendly design. Suitport was originally patented in 1989 by M. Cohen. Subsequent development focused on a vehicle and suits designed for hazardous materials work.

The suitport has recently been tested on three variants of the lunar rover and microgravity exploration concept demonstration vehicles at JSC and as part of Desert RATS⁵. This testing has shown true potential to change the way NASA as an agency utilizes Extra-Vehicular Activity (EVA). A suitport bench top demonstrator built at Ames Research Center has also demonstrated the functionality of the suitport pressurizable seal⁶. The next step is a true human in the loop feasibility test.

To enable a human in the loop feasibility test, the suitport design was updated based on lessons from the first generation suitports, and the goals of the second generation Space Exploration Vehicle (SEV). The intent was to design an integrated vehicle and suitport that would be pressurizable. Both the aft bulkhead of the Multi-Mission Space Exploration Vehicle, MMSEV, and the suitport were designed to accommodate a pressurized vehicle. For cost savings, the bulkhead was not manufactured as a pressure vessel, but the suitports were. Three outer suitport frames and two inner suitport frames were then manufactured with two planned to outfit the MMSEV second generation cabin, referenced as cabin 2A, and one outer frame dedicated to chamber testing.

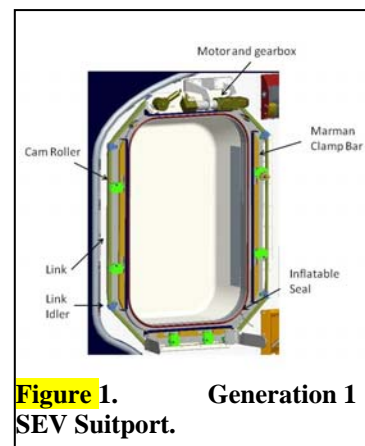
II.

III. Second Generation Suitport Design

The first generation suitport utilized 4 v-guide clamp bars in a rectangular layout to clamp a Suitport Interface Plate, SIP to a flange on the aft bulkhead of the vehicle. This was meant to emulate the Marman clamps used on circular interfaces, and is thus called a Marman clamp suitport. See figure 1.

The second generation suitport endeavored to reduce the complexity of the suitport mechanism and mechanical overrides. This was done by using two angled Marmon clamp bars instead of the four used on the first generation. A Portable Life Support System and SIP shape were negotiated with the NASA PLSS and suit teams that would allow the Marman clamp to wrap around the now angled corners of the SIP. It was known at the outset that this would leave a short top section and a longer bottom section of the SIP unsupported, but was desirable since it reduced part count significantly.

Prior to detailed design of the suitport, alignment of the suited crewmember to the suitport was investigated. This allowed replacement of the existing alignment guides with a combination of a tapered PLSS, a small nose alignment

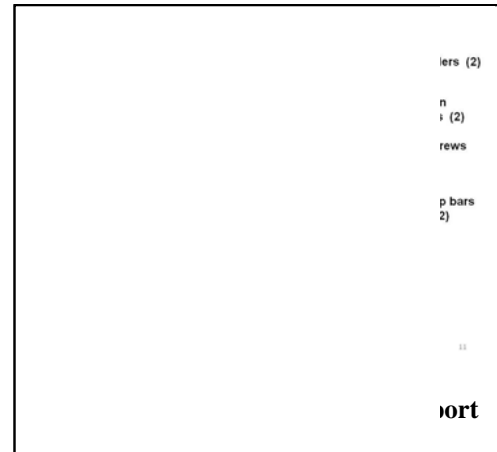


⁵ Romig, B., Kosmo, J., Gernhardt, M., and Abercromby, A., "Desert Research and Technology Studies 2008 Report," SAE Technical Paper 2009-01-2563, 2009, doi:10.4271/2009-01-2563.

⁶ Chartres, J., Koss, B., Brivkalns, C., Webbon, B. et al., "Preliminary Development of a Suit Port for Planetary Surface EVA — Design Studies," SAE Technical Paper 2009-01-2586, 2009, doi:10.4271/2009-01-2586

guide on the suitport, and a saddle on the SIP. These features were deemed less obtrusive than the original alignment guides, although they require a little more training of the crewmember for proper use.

To further simplify the suitport design, the linkages and cam rollers from the first generation design were replaced with lead screws and bevel gears. This design change allowed us to maintain tight coupling of the two marman clamps with fewer parts and less adjustment than the linkages and cam rollers. The motor and gear drive were replaced with a custom motor using the design of the JSC Robonaut actuator, similar in size to an elbow. The stator, rotor, bearings, and a harmonic drive were purchased, with the remaining parts custom machined. This allowed deletion of the pip pin decoupler for the manual override, as the Robonaut actuator can be back driven.



IV. Suit Compatibility with Suitport

The use of suitports creates several unique challenges for space suit design. Those design challenges, along with work that has been completed to address them, are discussed in the following paragraphs.

Z-1 Suit Overview

The Z-1 prototype space suit assembly (SSA) was developed as part of an effort to begin tackling suitport related design challenges and to demonstrate suitport feasibility during the manned delta pressure suitport test. A description of the Z-1 SSA is provided below. Features of the suit that are unique to suitport operations are described in the following sections.

The Z-1 suit (Figure X) is commonly described as a “soft” rear-entry planetary exploration suit. The ‘soft’ is a bit of a misnomer because the suit actually contains several hard mobility elements; the term ‘soft’ is intended to convey the idea that the primary structures of the suit are pliable fabrics when unpressurized. The Z-1 suit has bearings in the following locations: 3-bearing shoulder (scye, mid-shoulder, upper arm), wrist, waist, hip, thigh, and ankle, and also employs several soft mobility elements to allow for pressurized mobility.



ice suit

Suit Port Interface Plate

Perhaps the most obvious impact to the space suit assembly for suitport compatibility is the addition of a suitport interface plate (SIP), shown in Figure X. The SIP acts as the mating and sealing surface between the suit and the suitport. While the SIP concept has been demonstrated in the past on mock-up space suits, the Z-1 suit development was the first attempt at a SIP capable of handling the pressure loads experienced during suitport operations. The final Z-1 SIP is a 0.75 in thick aluminum plate with a 1 in thick stainless steel stiffener across the top and a stainless steel saddle, which is used for alignment but doubles as a stiffener, across the bottom. The stiffeners are required to keep the deflection of the SIP within an acceptable range to ensure proper SIP-to-suitport sealing. The Z-1 SIP assembly weighs 28 lbs, which is a significant mass increase above the suit’s 126 lb base weight. Future work is targeted at SIP mass reduction.

Self Adjustable Gloves and Boots

Another suit impact brought on by suitport operations is the ability of



Suit

crewmembers to perform nominal suit adjustments, such as tightening their glove palm bar and boot instep. In an airlock, these operations would nominally be performed prior to suit pressurization; however, during suitport operations, the suit will be pressurized during donning, and crewmembers will be required to perform any necessary adjustments at pressure. Without the ability to effectively tighten the palm bar on the gloves, mobility and glove fit during the EVA may be negatively impacted, and hand fatigue may increase. Similarly with the boots, lack of proper instep sizing may cause difficulty when walking in a gravity environment.

In order to address these potential issues, ILC Dover developed the Self Adjustable Phase VI gloves and Self Adjustable Rear Entry I-Suit (REI) boots. The gloves and boots are modified pairs of Phase VI gloves and REI suit boots, which allow the crewmember to make glove and boot adjustments at pressure.

The Self Adjustable REI boot has a Boa™ device mounted its tongue (Figure X), which provides instep sizing. The Boa™ Device consists of a commercial-off-the-shelf (COTS) dial-based closure system, which is a ratcheting mechanism with a 3 to 1 gear advantage. It provides continuous adjustments in one direction and can be released by pulling the knob to the out position. Four different adjustment mechanisms were developed and delivered with the Self Adjustable Phase VI Gloves: a COTS Boa™ device similar to the one on the boots, two custom ratcheting devices, and a spring device. All four mechanisms are self adjustable by the crewmember at pressure and are meant to provide the same indexing as the existing Phase VI glove palm bar strap. The custom t-handle adjustment device is pictured in Figure X. Preliminary evaluations with the self adjustable gloves and boots have shown promising results, and the adjustment mechanisms will be further tested during the manned delta pressure suitport test.



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Self Donning and Doffing

A third impact of the suitport concept on suit design is the requirement for a crewmember to be able to self don and doff his or her suit. Traditionally, EVA crewmembers have assistance from intravehicular activity (IVA) crewmembers while donning and doffing their space suit; however, that assistance would not be available when using the suitport paradigm.

Crewmembers would need to be able to perform all suit donning and doffing activities without assistance. Challenges associated with self don and doff of a suit include opening and closing the suit hatch, latching and locking the suit hatch while pressurized to 8.3 psid., and donning and doffing a shoulder and/or waist belt harness.

The development of the Z-1 suit began to look at addressing these items, particularly the ability to latch and lock the suit hatch while at 8.3 psid. The Z-1 suit lock/latch mechanism is located along the hatch ring with its pivot point 30 degrees off of vertical (Figure X). Preliminary testing in the Z-1 suit has shown that the latch/lock mechanism is accessible by the test subject while the suit is pressurized to 8.3 psid. The manned delta pressure suitport test will further evaluate subject's ability to reach and operate the latch/lock mechanism in its current location. Results of the testing will help to drive the latch/lock mechanism design for the next Z-suit iteration, the Z-2 suit.

Some effort was also spent during the development of the Z-1 suit to address opening and closing the suit hatch. The hatch closing capability was demonstrated during initial Z-1 testing through the use of a Teflon coated cable closure system; however, durability of the closure cable coating proved to be an issue, and the cable was removed from the suit.

An additional challenge comes into play with the hatch open/close mechanism because the thickness of the suitport frame and vehicle aft bulkhead, combined with the potential for suitport vestibule interference create the need for a non-traditional suit hatch hinge mechanism. This mechanism must allow the suit hatch to translate backwards by four inches prior to pivoting open. Some preliminary prototypes have been developed with this type of hinge, and forward work is planned to develop additional concepts for opening and closing the suit hatch, including concepts which use the suitport vestibule door to assist with these operations.

Further work is also required to incorporate a self donnable shoulder/waist belt harness.

Human Factors Considerations



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In addition to suit hardware considerations, there are also several human factors considerations which must be taken into account in developing a suitport compatible suit. One of the major considerations is that of suitport alignment. Multiple tests have been performed over the past four years to evaluate suitport alignment in a 1-g environment. The most recent test series, carried out in 2010, led to the selection of a slightly tapered PLSS, as well as the current nose alignment guide (Figure X), to aid in suitport alignment. This alignment system will be tested for the first time in 1-g with a pressurized suit during the manned delta suitport test. Additional testing is planned in the summer of 2012 to evaluate suitport alignment in reduced gravity environments.

A second human factors consideration has to do with the placement of suit don/doff aids within the vehicle. The current don/doff aids available to the crewmember in the Generation 2A suitport design include an overhead pull-up bar and a dip bar. Testing was performed in 2010 to determine an acceptable location for the pull-up and dip bars. Data from this testing was based off of donning and doffing an unpressurized suit. The location and functionality of these don/doff aids will be further evaluated with the suit at an 8.3 psid delta pressure during the manned delta pressure suitport test.

A third consideration dealing with human factors is the donning angle of the suit. The Generation 1 suitports put the suits at a 0 degree (vertical) donning angle. Experience with these suitports at Desert Research and Technology Studies (RATS), as well as with existing rear-entry space suit prototypes indicated that this positioning could be improved by increasing the donning angle. Testing performed in 2010 concluded that from a human factors perspective, the optimal donning angle is approximately 18 degrees? (canted forward from the vertical position). While optimal for suit donning, an 18 degree aft bulkhead angle was not optimal for vehicle designs. A compromise was made between the suitport and MMSEV projects, and the Generation 2A suitports are canted 10 degrees? forward.

ADD PHOTO OF NAG AND SADDLE

Figure X. Nose alignment guide (NAG) and saddle used for suitport alignment.

Additional Considerations

While the paragraphs above have discussed several of the suit challenges associated with the implementation of suitports, it has mainly focused on areas where work has been or is currently being carried out, and is by no means all-encompassing. Several other suitport related design challenges which were not discussed include the implementation of thermal protection on the SIP, routing of necessary PLSS pass-thrus (i.e. vacuum vent lines) through the SIP, the design and operation of the suitport manual override, and the implementation of the infrastructure for buddy rescue scenarios on suitport.

V. Testing of the Generation 2A Suitport

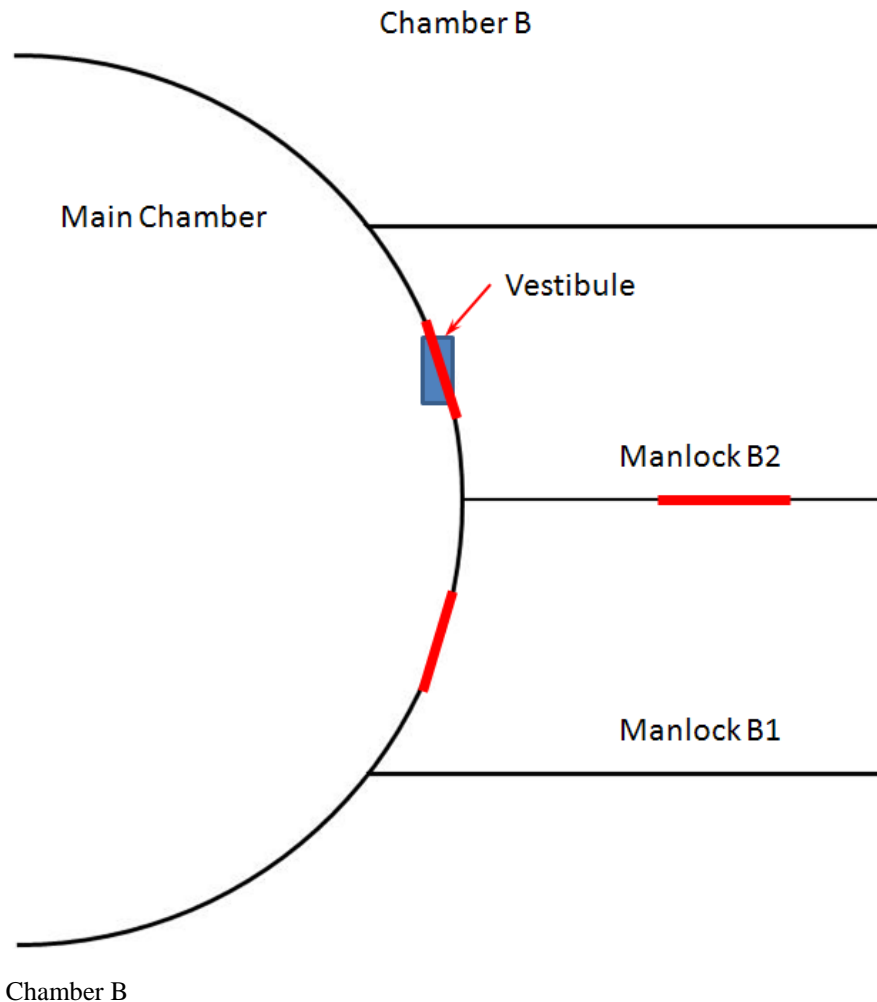
In order to test pressurized suit donning through a suitport, a vehicle or facility is required. It was determined the best facility to allow thorough testing of the suitport would be to add modifications to the JSC B32 Chamber B. This chamber was selected as the suitport could be installed into an adapter in one manlock door, and people or rescue technicians could still access the inside of the chamber through a second manlock. The test protocol will start simple, with a simple delta pressure test. The chamber will be evacuated to 6.4 psia, with the manlock at ambient, so that a delta of ~ 8.3 will exist for suit donning and suitport operations.

The second point for selecting chamber B, is that it is extensible to subsequent vacuum testing, and then later human thermal vacuum testing with a suitport.

The test objective of the Gen 2A unmanned test is to verify that the Gen 2A suitport would operate at a delta pressure of 8.3 psid.

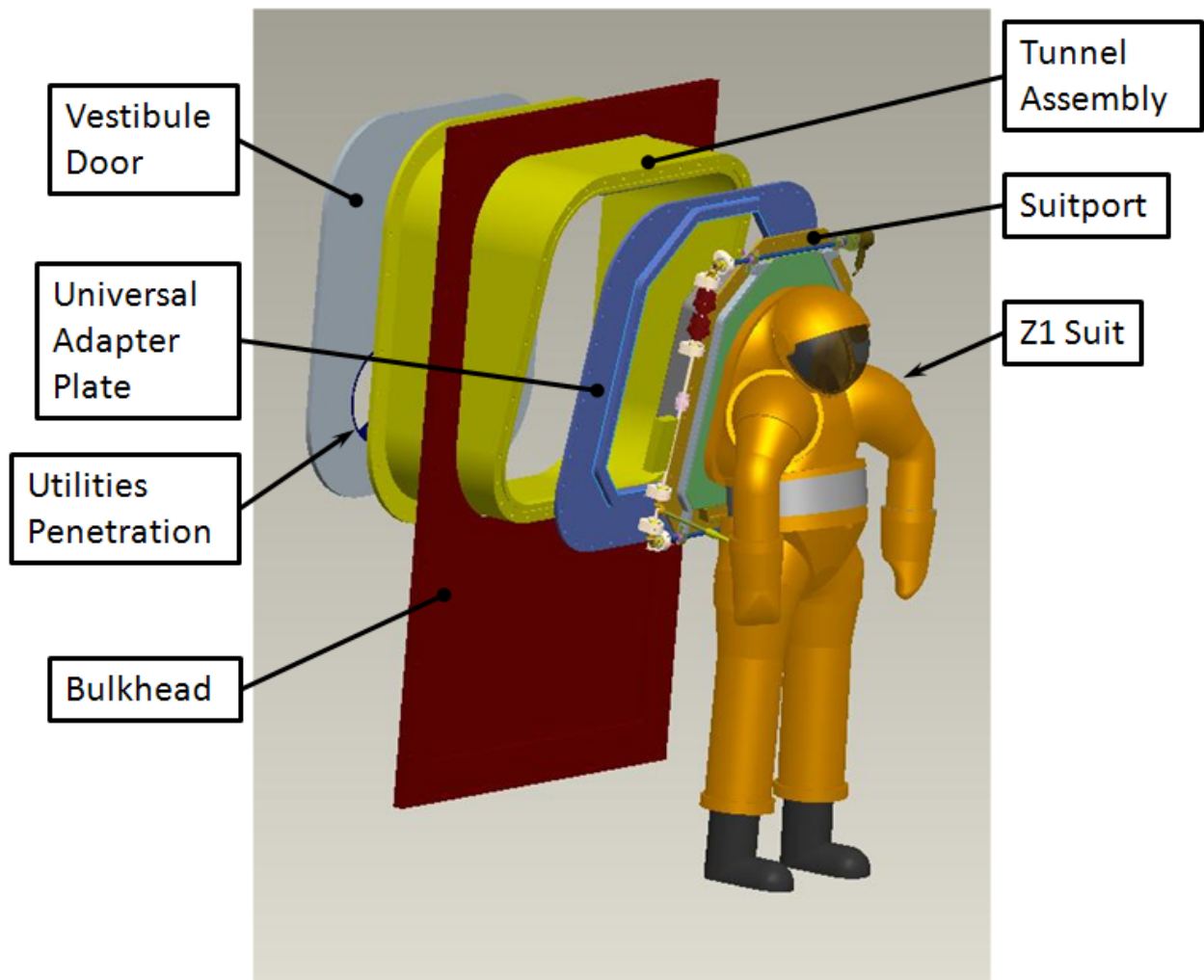
The test objective of the Gen 2A manned is to demonstrate suitport docking and undock from a Gen 2A suitport and donning and doffing from the space suit.

The test is planned for Chamber B located at Lyndon B Johnson Space Center, Houston Texas. Chamber B is a circular chamber 25 feet in diameter and 26 ft in height used for manned space suit testing. There are two manlocks connected to the main chamber. Manlock B1 has a weight relief system for traditional space suit testing. Manlock B2 allows nominal access and acts as a staging area for emergency technician. Multiple doors can be opened and closed to seal each section of Chamber B from each other. The main chamber and the two manlocks can deliver pressures of 1×10^{-4} Torr to 14.7 psia. The main chamber can deliver temperatures of -300 to 250+ degrees Fahrenheit.



For the Gen 2A suitport test, the test facility is fabricating a bulkhead that bolts to the doorway between the main chamber and manlock B2. For manned testing, the emergency rescue technicians are located in manlock B1. The bulkhead consists of four major subassemblies the bulkhead, the vestibule door, the tunnel assembly, and the universal adapter plate. The bulkhead not only bolts to the doorway between the main chamber and manlock B2 but also acts as a seal between the two volumes. The vestibule door seals the tunnel assembly from the manlock B2 to allow pressure equalization between the main chamber and the tunnel assembly. The pressure between the tunnel assembly and the main chamber needs to be the same to allow the space suit to undock. In addition, the vestibule door provides a penetration for the utilities that are needed for manned testing. The tunnel assembly extends the

entry and exit area for the suitport due to the cylindrical shape of the test facility. To facilitate testing of future concepts of suitport, a universal adapter plate bolts to the tunnel. The suitport mates to the universal adapter plate and is the only piece of test hardware that needs to be rebuilt to accommodate changes in suitport shape or design.



For the unmanned test, the Gen 2A suitport is bolted to the universal plate. The hole, used for entering and exiting the space suit, in the middle of the suitport is sealed with a blanking plate. The clamps on the suitport that normally secure the suitport interface plate secure the blanking plate for testing. As part of the unmanned test, the clamps will be cycled to verify the mechanisms for the suitport. A brace developed by the test facility supports the blanking plate to prevent the plate from falling to the ground when the clamps are in the open position. The vestibule door is sealed and the test facility begins the process of lowering the pressure within the chamber. A series of leak checks are performed on the both the Chamber B hardware and the suitport hardware prior to actual testing. After confirmation that both the Chamber B hardware and the suitport hardware pass leak check, the chamber operators start the pumps that lowers the main chamber pressure from 14.7 psia to 6.3 psia. The 8.3 psid between 14.7 and 6.3 psia provides the pressure that stresses the suitport. The strain gauge records the strain levels at predefined locations on the suitport with the 8.3 psid. The test personnel equalize the pressure between the main chamber and the vestibule after which the suitport clamp mechanism cycles four times for hardware verification.

For the manned test, the Z1 suit is docked to the Gen 2A suitport at ambient atmosphere. The test personnel seals the main chamber and depresses the main chamber down to 6.3 psia. The vestibule remains at 14.7 psia. The suit test subject dons the suit at 8.3 psid. Both the suit and the vestibule are sealed. The test personnel equalize the pressure between the main chamber and the vestibule. The suitport clamps release the space suit and the manned Z1 suit undocks from the suitport and performs a series of mobility tasks. After completion of the mobility tasks, the

Z1 suit docks to the suitport. The vestibule pressure rises to 14.7 psi. The test personnel open the vestibule door. The suit test subject opens the Z1 suit hatch and doffs the suit. The test is repeated four times for both human factors data and hardware verification.