CREW AND THERMAL SYSTEMS DIVISION

NASA • LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS

ESPO System, CEV Hatch, Suit Don/Doff and LIDS Tunnel C-9 Evaluation Test Report

EVA Systems Project Office

TEST REPORT

DOC. NO.: JSC-65656 DATE: September 2007

NO. OF PAGES: 87

REVISIONS

DATE	AUTHOR	APPROVALS				REV. LTR
		SECTION	BRANCH	DIVISION		

Prepared by

9/17/2007
ESPO Test and Facility Manager – Jeff Patrick

9/14/07
ESPO Test and Facility Test Lead – Jessica Vos

9/11/07
ESCG Test Engineer – Drew Manning

Concurrence

9-17-07
ESPO System Engineering and Integration Manager – Jeff Davis

ESPO Suit Element Manager – Scott Cupples

9/17/2007
ESPO Vehicle Interface Element Manager – Beth Moses

9/18/07
ESPO Crew Office Stakeholder – Mike Gernhardt

9-17-07
ESPO Chief Engineer – Mike Lawson

Approved by

ESPO Program Manager – Glenn Lutz/Lara Kearney

Summary

This report serves to document the test and conclusions reached by the Constellation Program's EVA Systems Project Office (ESPO), for the test conducted on May 8-11, 2007. A Quicklook Report for this test activity was released on May 16, 2007 and is included as Appendix A of this document

The primary purpose of this test was to determine the compliance between the ESPO space suit system architecture and current implementation strategy of that architecture, and the current Constellation Program's Crew Exploration Vehicle Project (CEV) side-hatch dimensions. Additional test objectives were added to make efficient use of the test team and associated resources garnered for the primary objective (i.e., all the various suits and the C-9 facility outfitted to support pressurized suited operations). Those additional test objectives were associated with evaluation of the pressure garment mobility and vehicle needs in order to perform the necessary operations associated with the CEV and the Low Impact docking System (LIDS) tunnel design, and to assess the current EVA System architecture implications associated with in-space suit donning in a volume representative of the CEV without specific donning restraints.,. This test was evaluated in a reduced gravity environment during a series of flights aboard the C-9 Reduced Gravity Aircraft.

This was the first official Constellation Program integrated test between the ESPO and CEV/Orion Projects. The ESPO provided the EVA system hardware, primary test conduct and planning, and C-9 facility costs, and the CEV Project provided CEV mockup hardware. Both projects provided technical expertise throughout the planning in a cooperative and mutually beneficial manner.

From this test, the ESPO has concluded that all CEV hatch opening sizes tested (baseline, wide, and wide/short) appear to be compliant with the current ESPO suit architecture for

in-space EVA ingress and egress operations. There are a number of caveats which, if unfounded, may alter this conclusion. Note that this conclusion is only applicable to the in-space EVA operations, and a further test planned for the Fall 2007 will help determine the compliance between the ESPO suit architecture and the CEV hatch size for the launch pad (1-g) operation phases. The full conclusions and caveats are documented in section 5.1.

Table of Contents

List of Figures

1. Introduction

In Feburary, 2007, ESPO Systems Engineering and Integration (SE&I) identified a need for additional data regarding suited subjects translation through the proposed side hatch for the CEV, based on concerns of crewmembers being able to perform the suited operations through proposed hatch size reductions in the CEV design. This data would be used to confirm the compatibility of the planned CEV hatch with the anticipated ESPO suit system architecture reference configurations as well as provide information regarding the possible impact of future hatch size changes. It was decided that the evaluation would need to include both waist-entry and rear-entry style pressure garments in order to fully emulate the existing ESPO architecture implementation strategy consisting of a two-configuration pressure garment reconfigurable system (referred to EVA System Reference 1 (ESR 1)). Two phases of testing were identified for this evaluation: a 0-g portion using the Reduced Gravity Office (RGO) C-9 test facility to simulate on-orbit ingress/egress and a 1-g portion to be conducted later using the CEV cockpit mockup in the Space Vehicle Mockup Facility (SVMF). The 0-g part of the evaluation was conducted on May 8 and 9, 2007 and is the primary subject of this report.

This test event was supplemented with two additional objectives that had been identified in earlier discussions within the ESPO: 0-g suit donning/doffing in a simulated CEV volume and translation of a suited subject through the CEV/LIDS tunnel including reach and access to actuate hatch mechanisms by a suited subject. Both of these objectives were conducted using waist-entry and rear-entry configuration suits. Suit donning/doffing was evaluated on May 10, 2007 and LIDS tunnel operations were evaluated on May 11, 2007.

Additionally, an alternative concept for an EVA tool harness was worn by the suited subjects during parts the CEV hatch and LIDS translation objectives to evaluate its impact to suited subject mobility. A separate evaluation of the tool operations with the tool harness was added to the May 11th flight day to evaluate this concept and, thus, to ascertain that inclusion of this tool harness in the CEV hatch portion of the test was a valid volumetric and operationally viable approach.

This investigation was coordinated, conducted, and supported by the Engineering and Science Contract Group (ESCG) EVA Development and Verification Testing (EDVT) Team. This group, also known as the "EVA Test Team," supports the EVA Tools and Equipment Branch and the Spacesuit Systems Branch of the Crew and Thermal Systems Division (CTSD) at JSC. This test was sponsored and provided overarching direction by the ESPO Test and Facilities group in response to the ESPO SE&I data request. The two existing technical element of ESPO at the time (Suit Element and Vehicle Interface Element), provided the ESPO technical expertise, emulation hardware, and execution personnel. The CEV (Orion) Project Office, through the Mechanical Design and Analysis Branch (ES5) of the Engineering Directorate and Lockheed Martin Mission Services (LMMS), provided test participation through representative hatch and CEV exterior mockups, and technical expertise in the test planning for the CEV hatch ingress/egress and LIDS translation portions of the test.. The C-9 facility was provided by the Flight Crew Operations Directorate (FCOD) Reduced Gravity Office (RGO).

2. Test Objectives

2.1 CEV Side Hatch Ingress/Egress

For this evaluation suited subjects demonstrated egress and ingress through a simulated CEV hatch under 0-g conditions. The purpose of this objective was to gather data for the ESPO SE&I group to allow them to asses the compatibility of the planned CEV side hatch architecture with the current ESPO architecture ESR 1 for the next generation space suit system. This test is a follow up to a 1-g test performed in April 2006.

The mockup for the CEV hatch was designed to simulate the baseline hatch size at the time as well as two other configurations that were provided by the CEV Hatch Subsystem

Manager and the LMMS CEV Hatch Project Manager. This mockup included the current baseline CEV project envelope dimensions of the hatch opening, the hatch itself in a 90 degree open position, a representative outer shell of the CEV in order for the test subjects to complete the translation through the hatch opening and onto the structure, and a complement of handrails and handholds on both the hatch and outer shell mockups. Additionally, provisions were made in this mockup to evaluate alternative hatch opening sizes per request from the CEV Project Office: one hatch opening being wider and shorter than the existing baseline, and one being wider only. There was no provisioning of the CEV interior cabin, as drawing review by the test team determined that the current interior did not appear to pose any significant impacts to the ingress and egress operations for this test. Details of the mockup design and construction are contained in section 4.4.6 of this document.

In order to encompass the full range of ESPO architecture concepts proposed through ESR 1 for use with the Constellation Program, two different suit configurations were used during this evaluation: a rear-entry, “hybrid” Mark III Suit, and a waist-entry, “soft” I-Suit.. Both of these suits had previously been used in 0-g evaluations. Details on both suits can be found in sections 4.4.1 and 4.4.2 respectively. These two particular pressure garments were chosen for the evaluation as they were the best representation, within existing NASA inventory, of the two configurations of pressure garments within the ESR 1 (baseline) implementation concept of the ESPO modular, reconfigurable suit system architecture. To that end, the I-Suit represented the Configuration 1 pressure garment which is planned as the type of suit to be worn in the CEV for Earth launch and entry, and for in-space EVAs based out of the CEV (i.e., a soft, lightweight suit with bearings at specific joints for enhanced pressurized mobility). The Mark-III represented the Configuration 2 pressure garment, which is intended to be optimized for lunar surface EVAs and would normally not be used within the CEV given the current concept of operations. However, it was included in this test as an operational concept currently being considered by the lander project may require that the in-space contingency EVA to return the crew from lander to CEV after lunar ascent may need to be performed by the Configuration 2 suit. Additionally, in order to garner additional data by the ESPO to determine if a single suit concept might be viable for future architecture implementation revisions, it was also useful to test the Mark III. Each pressure garment for this test was pressurized to approximately 4.3 psid.

Two vehicle interface umbilicals were included in this test in order to better emulate the impacts that these umbilcals might have on ingress and egress through the CEV hatch. These two umbilicals were representative of the size umbilicals which might be used to provide the life support consumables from the CEV ECLSS to the crewmember within the pressure garment. The smaller diameter umbilical represented the baseline proposed by the ESPO vehicle interface element, and the second represented a larger diameter based on the possibility of the CEV ECLSS not being able to meet the pressure drop requirements associated with the smaller umbilical. Each suit flown was tested without any umbilical and with each of the design concepts being considered.

The final configuration variable included in the test was the use of an alternative EVA tool carrier. This tool harness was representative of a more conformal method of attaching small tools to pressure garments than is currently used with the existing EMU program. Additional tool development is currently not in the ESPO requirement set, so the purpose of including this hardware in the test was to allow for the provision of tool mounting onto the pressure garment in order to determine the impact of such on hatch ingress and egress operations. The tool harness mockup was used only with the I-Suit for a portion of the translations through the hatch opening and was evaluated both with and without tools attached. Details of the tool harness mockup can be found in section 4.4.9 of this document

2.2 0-G Suit Donning/Doffing

The purpose of this objective was to provide data for input into suit architecture implementation feasibility studies by understanding the ease/difficulty of and techniques for 0-g suit donning and doffing in the anticipated volume available in the CEV. To encompass the full range to possible suit configurations this test included a rear-entry hybrid suit (MK III Suit), two soft waist entry suits (I-Suit and D-Suit) and the current shuttle launch entry suit (ACES). For this evaluation, none of the suits were pressurized. Donning operations were complete once the respective suit seal had been made.

For each of the suits tested several donning/doffing scenarios were evaluated: solo donning/doffing, one-person assisted donning/doffing and two-person assisted donning/doffing. The donning and doffing were conducted in a simulated CEV volume created on the C-9 that represented the open space available in the CEV with the seats folded and stowed to maximize the free volume. It did not simulate the support struts for the seat pallet as these were undefined at the time of the test. Either four or six people were in the simulated CEV volume during the suit operations to mimic possible conditions on-orbit. Suits were evaluated singularly and with two suits being donned/doffed simultaneously.

2.3 LIDS Tunnel Operations

This evaluation was designed to further investigate the capabilities of a suited crewmember to perform a CEV LIDS tunnel translation and mechanism manipulation, including the hatch actuation. It is a follow on to a previous 1-g test that was conducted in April 2006 which produced inconclusive but promising results.

For this evaluation a mockup was fabricated to simulate the CEV and LIDS tunnel dimensions and the suited subjects evaluated reach, access and mobility within the confined space. The majority of this mockup was fabricated by ESPO, but with technical guidance provided by CEV Project (CEV Hatch SSM and LMMS Hatch Project Manager). A representative LIDS hatch with notional control mechanisms was provided by the CEV Project and mounted into the ESPO provided tunnel. Details of the mockup design and construction are contained in section 4.4.7 of this document.

The subjects performed this evaluation using both rear-entry (Mark III) and waist-entry suits (I-suit and D-Suit). Suits were tested in both the pressurized and un-pressurized conditions. Subjects were requested specifically to assess their ability to access areas identified as possible locations for control mechanisms for the LIDS hatches.

2.4 Tool Harness Evaluation

The assessment of the tool harness concept was conducted as part of the CEV hatch and LIDS tunnel test objectives and as a stand alone evaluation. During the CEV hatch and LIDS tunnel operations with a subject in the I-suit, the tool harnesses effect on reach and mobility of the suited subjects was noted. As a stand alone the subjects evaluated the harnesses configuration and mobility, tool retrieval and stowage, and using the Body Restraint Tether (BRT) attached to the tool harness.

It should be noted that the ESPO has not initiated requirement or design development of any future tools for the Constellation program, primarily due to the philosophy that existing ISS and SSP EVA legacy tools will be “purchased” for the initial capability phase of the Constellation Program. However, for this particular test, a method of securing a small complement of tools onto the pressure suits without incurring the larger volume overhead of those ISS and SSP legacy tool carriers was warranted, in order to ensure that a small tool complement was considered in the hatch size evaluation. Had a legacy tool carrier, such as the existing Modular Mini Work Station, been used for this test, it was felt that this might give an unfair negative assessment of the existing hatch size given that the simplified in-space contingency EVAs forecast at this time for the CxP would not require a highly refined (or as large) a tool carrier system for in-space contingency EVAs. Considering that, for the ISS phases of CEV, the current plan is to use EMUs out of the ISS airlock, and that new tools might be developed for the later uses of CEV (for the lunar mission) to enable a small complement of tools to be carried without the penalties incurred by some of the existing EVA legacy tools, it is believed that an emulation of a future tool carrier for the purposes of this test was useful. Thus, this test should not be viewed as an evaluation of any particular design concept for a future EVA tool carrier, but more as a part of the test support equipment to assist with determining the pressure garment mobility requirements and constraints associated with a more conformal tool carrier concept, and potentially to aid as a springboard for future requirement development of tool carriers at a time when the ESPO determines is appropriate for full implementation of a Tools and Equipment element.

Additionally, in order to validate that the tool carrier (referred to as tool harness) employed for the hatch test was also a viable concept for EVA worksite tasks, a standalone test was also performed with just the tool carrier during this test. This test phase executed the tool harness concept through a small set of typical EVA worksite tasks (such as retrieving tools off the tool carrier concept). Had the stand alone test indicated that this tool harness did not promote EVA worksite tasks, it may have raised doubts about the viability of using it as part of the hatch assessment tests.

3. Test Team

Test Sponsor..Jeff Patrick (NASA/ESPO T&F Manager)
Test Sponsor...Tim Rupp (NASA/CEV Hatch SSM)
Principal Investigator (Suit)............................Jessica Vos (NASA/ESPO T&F Test Lead)
Principal Investigator (Suit).................. Amy Ross (NASA/ESPO Suit Element PG SSM)
Principal Investigator (Suit Backup).......Lindsay Aitchison (NASA/ ESPO Suit Element)
Principal Investigator (Umbilicals)Nicole Jordan (NASA/ ESPO VI Element Deputy Mngr)
Test Engineer (Lead Test Conductor)...................................Drew Manning (ESCG/EC5)
ESCG Hardware Representative... Victor Lawrence (ESCG/EC5)
LMSO Hardware Representative...........Paige Carr (LMMS/CEV Hatch Project Manager)
Advanced Suit Lab Technician Representative .... Kevin Gronemen (ILC/ESPO T&F)
Crew Representative ....Mike Gernhardt (NASA/ESPO Astronaut Stakeholder)
RGO Representative ....Dom Del Rosso (NASA/CC4)
Test Safety Representative...Jessie Zapata (AND/NS226)
Test Safety Representative...Greg Tonnies (ESCG/EC5)

Test Subjects

May 8, 2007 – Mark III Suit .... Mark Dub (NASA/EC5)
May 8, 2007 – I-Suit .... Brian Daniel (NASA/EC3)
May 9, 2007 – Mark III Suit ....Mike Gernhardt (NASA/CB)
May 9, 2007 – I-Suit ....Amy Ross (NASA/EC5)
May 10, 2007 – Mark III Suit .... Piers Sellers (NASA/CB), Richard Watson (NASA/EC5)
May 10, 2007 – I-Suit ....Brian Daniel (NASA/EC3), Lindsay Aitchison (NASA/EC5)
May 10, 2007 – D-Suit.........Brian Daniel (NASA/EC3), Lindsay Aitchison (NASA/EC5)
May 10, 2007 – ACES .... Piers Sellers (NASA/CB), Richard Watson (NASA/EC5)
Brian Daniel (NASA/EC3), Lindsay Aitchison (NASA/EC5)
May 11, 2007 – Mark III Suit ....Dave Wolf (NASA/CB)
May 11, 2007 – I-Suit .... Mark Dub (NASA/EC5)
May 11, 2007 – D-Suit... Brian Daniel (NASA/EC3)

4. Test Description

4.1 Test Specific Procedures

The test series consisted of 4 separate C-9 flights, which consisted of two days of CEV Hatch ingress/egress evaluations, one day of advanced suit don/doff evaluation and one day of LIDS tunnel and tool harness evaluation. All parabolas for each flight were performed at microgravity or simulated 0-g.

4.2 Data Collection

The video, audio and still photographs recorded during the evaluations serves as the primary data deliverable for this test. No loads or joint-specific biomechanical data was taken during the test. Comments from the suited subjects and observers were noted for inclusion in the post-test analysis. The video/audio recordings were distributed to primary test personnel and are available through the EDVT, CTSD Space Suit Systems Branch (EC5), or through JSC TV Operations (located in Building 8). The still photographs taken during the test are available on the internet through the JSC Reduced Gravity Program Photographs webpage (http://zerog.jsc.nasa.gov/).

4.3 Aircraft Layout

The plane layout for flight days 1 and 2 is shown in Figure 4-1. Figure 4-2 shows a view of the plane from the aft portion looking forward. The photo is taken from the seating area. Details on the construction of the CEV hatch mockup are included below.

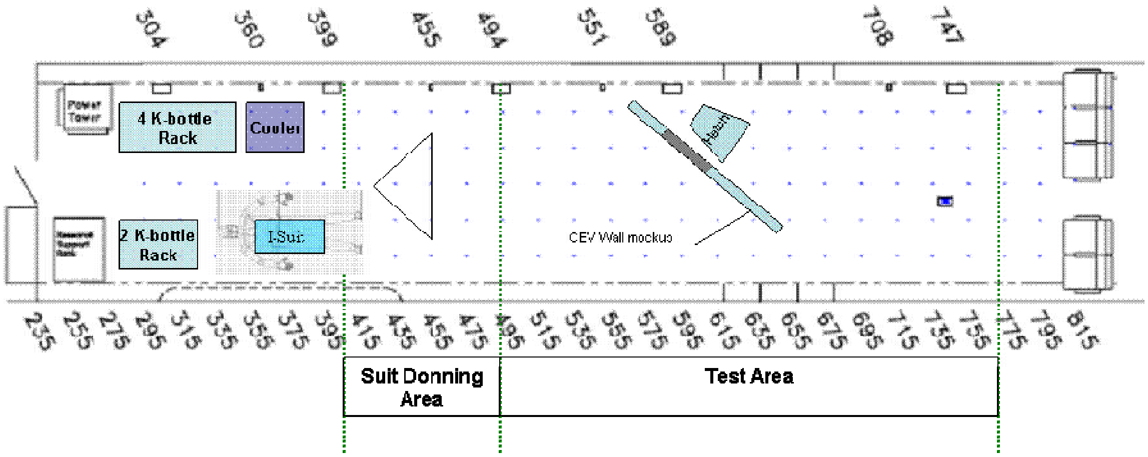


Figure 4-1 Plane layout for Flight Days 1 and 2

Figure 4-2 Plane Layout Flight Days 1 and 2, aft looking forward

The plane layout for Flight Day 3 is shown in Figure 4-3. The arc representing the inner wall of the CEV was delineated on the floor of the C-9 using duct tape. Four sections of orange plastic safety fencing were suspended from aluminum poles to provide extra visual clues to help constrain the subjects to the test area during the donning/doffing operations. Two of these sections can be seen in the background of Figure 4-4.

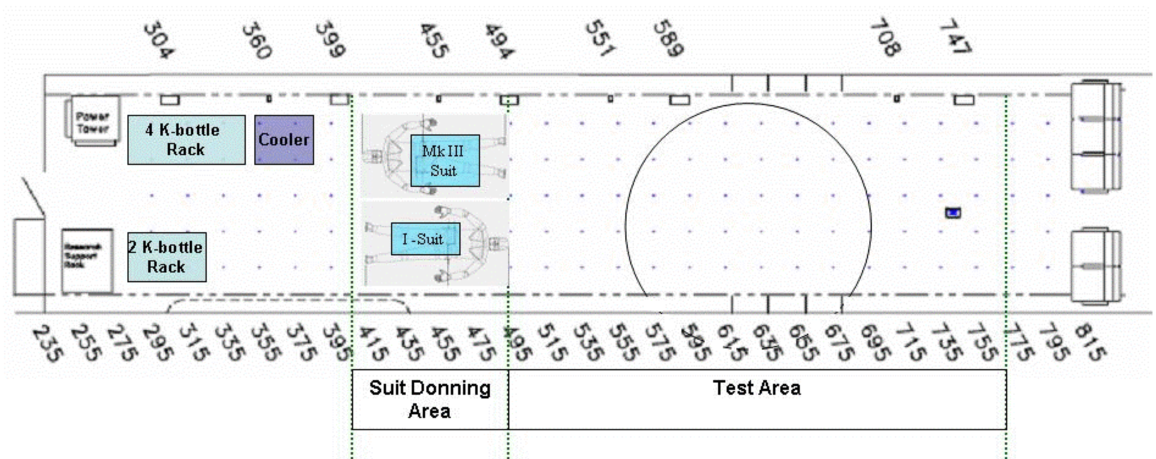


Figure 4-3 Plane Layout for Flight Day 3

Figure 4-4 Plane layout on Flight Day 3

The plane layout for flight day 4 for the LIDS tunnel and tool harness evaluation objectives is shown in Figure 4-5.

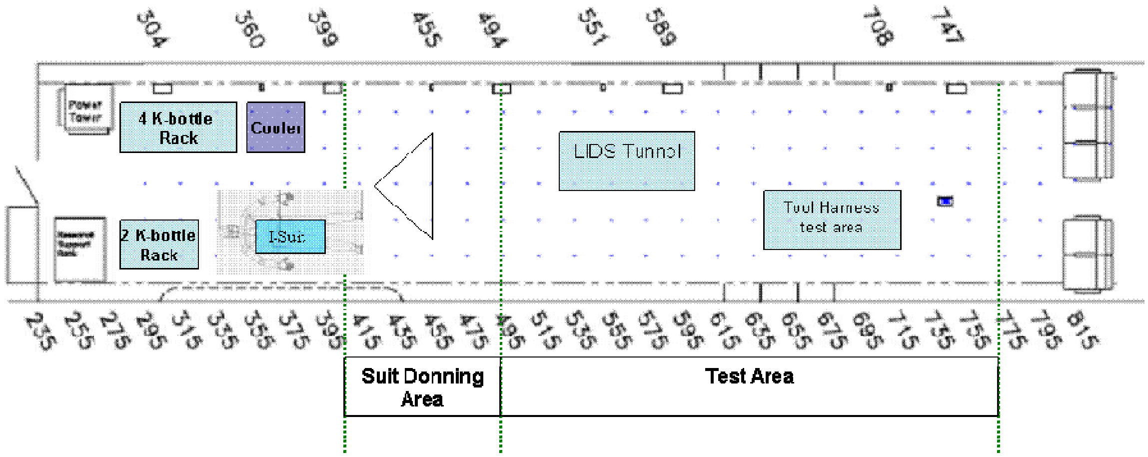


Figure 4-5 Plane Layout for Flight Day 4

4.4 Hardware Description

4.4.1 Mark III Advanced Space Suit Technology Demonstrator

The Mark III Suit (Figure 4-6) represents a rear-entry hybrid space suit configuration in that it is composed of hard elements (upper and lower torso sections) and soft elements (elbows and knees). The Mark III also has bearings located at several joints for enhanced mobility, including the shoulder, upper arm, wrist, waist, upper hip, mid-hip, upper leg, and ankle joints. The lower torso design also allows for abduction and adduction of the legs to a small degree. The suit is entered through a hatch on the backside of the hard upper torso. Suit subjects wore a Liquid Cooling Garment (LCG) for cooling during suited operations. Subjects are integrated into the suit by a waist belt weight relief system and shoulder straps. The MK III suit weighs approximately 120 pounds.

.

At the time of the test, the Mark III was the closest resemblance within NASA inventory in suit style to that of the ESPO ESR 1 configuration 2 style suit. This suit is primarily built for partial-gravity (i.e., lunar) type ambulation and tasks. The amount of hardware inventory available for this suit limits the anthrompometric range possible for testing purposes. Thus, the test subjects included in this test only represent a narrow spectrum of the current anthropometric range of crewmembers required by the Constellation Program.

Following the performance of this test, an additional suit has been procured by NASA which can offer an alternative configuration 2 style suit for inclusion into future testing (Rear-Entry I-Suit), however this additional suit will not significantly expand the anthropometric test subject range.

4.4.2 I-Suit

The I-Suit is a waist-entry soft suit and represents a compromise between a hard/hybrid suit and an all-soft suit (like the Apollo A7LB) in that it has bearings located at the shoulder, upper arm, wrist, upper hip, lower hip, and ankle for enhanced mobility while pressurized. The I-suit also has a body seal closure (BSC) and a rigid frame for backpack integration. The I-Suit weighs 64 pounds. At the time of the test, the I-Suit was the closest resemblance within NASA inventory in suit style to that of the ESPO ESR 1 configuration 1 style suit. The amount of hardware inventory available for this suit limits the anthrompometric range possible for testing purposes. Thus, the test subjects included in this test only represent a narrow spectrum of the current anthropometric range of crewmembers required by the Constellation Program.

Figure 4-6 Mark III suit

4.4.3 D-Suit

The D-Suit (Figure 4-8) represents another soft suit configuration. The D-Suit incorporates a body seal closure ring and upper arm bearings, but all other components and mobility joints are fabricated of soft goods. Pulley/cable and sliding cables systems are used at the shoulder and waist/hip joints to supplement the mobility of patterned soft goods at these locations while pressurized. The D-Suit weighs 26 pounds. At the time of this test, the D-Suit did not represent a configuration of ESR 1, however, it was included in the testing as an alternative to collect data in anticipation of future ESR revisions.

Figure 4-7 I-suit with tool harness installed

Figure 4-8 D-Suit

4.4.4 Advanced Crew Escape Suit (ACES)

The Shuttle ACES is manufactured by the David Clark Company. It's is a full-pressure suit assembly that consists of a coverall assembly, gloves, helmet, communications carrier, thermal underwear, liquid cooling garment (LCG), bubble helmet, an anti-gravity suit, and boots. The outer layer of the suit is flame retardant Nomex and the inner bladder is constructed from one layer of Gortex. The gloves must be connected to the suit in order to provide the pressurization (3.5 psid). The ACES improves upon the mobility of the Launch/entry Suit (LES) originally used by the Shuttle program and provides vent flow to the torso, hands, and thighs, which was not available in the LES. The total ACES suit weight with all crew escape equipment is 91.0 lbs. At the time of this test, the ACES did not represent a configuration of ESR 1, however, it was included in the testing as an alternative to collect data in anticipation of future ESR revisions.

Figure 4-9 ACES suit

4.4.5 Mark III Donning Stand

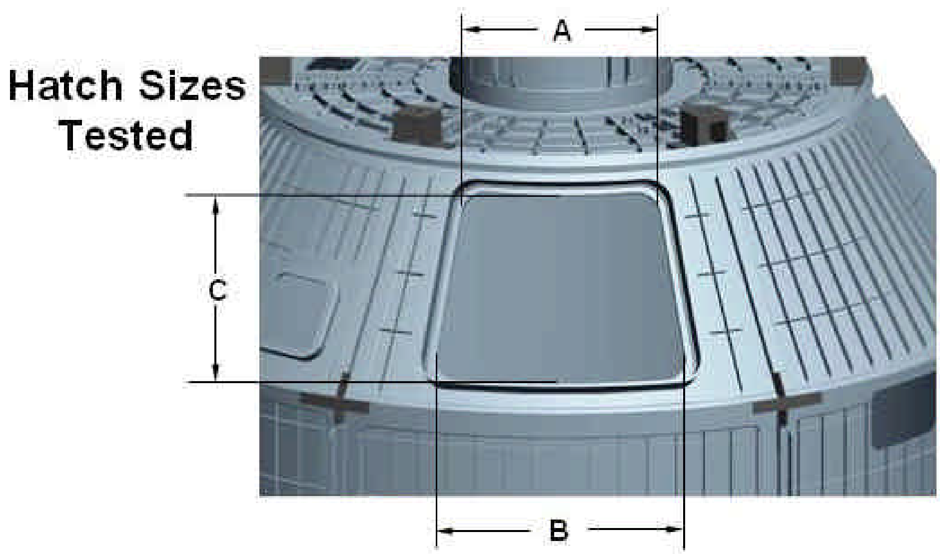
The Mark III donning stand supports and secures the Mark III suit in an upright attitude during suit don and doff. The subject may also rest in the stand during nominal aircraft flight periods. The stand is a tube structure and is bolted to the floor of the plane.

4.4.6 CEV Hatch Mockup

For the CEV hatch ingress/egress test objective, a simulated wall with hatch opening was created that could be securely mounted in the C-9 and configured to represent three different hatch sizes. The base structure for the CEV wall was fabricated from two layers of 3-inch thick polystyrene foam with ¼-in. hardboard on the faces. The mockup was made in three sections, two end pieces that were mounted to the floor of the C-9 and a middle "hatch opening" section that was held in place with pins and could be re-configured with one of two sections with different sized opening in them. The overall dimensions of the assembled wall mockup were approximately 8 feet in length and 4 feet in width. The mockup was attached to the floor of the C-9 via the seat track hardware provided by the RGO and was further stabilized during test operations by four ratchet straps ran from the mockup to interfaces mounted in the ceiling of the C-9. Figure 4-10 shows the mockup in the baseline hatch configuration ready for use.

The hatch opening could be set into three configurations: the current hatch baseline size, a wide hatch configuration that represents the widest possible opening identified at the time of the testing with the baseline hatch height and a wide/short configuration that used the "wide hatch" width measurement and a height dimension shorter than the baseline configuration. Figure 4-11 shows the hatch dimensions tested.

Figure 4-10 CEV wall mockup



	A	B	C
Baseline	30.9	38.3	32.1
Wide Hatch	32.5	40.5	32.1
Wide/Short	32.5	40.5	31.1

Figure 4-11 CEV hatch dimensions

The test configuration also included a mockup of the CEV hatch hard-mounted to the floor of the plane in the open configuration (Figure 4-12). The hatch was at a fixed 90° angle relative to the hatch opening and could be configured to match either hatch width dimension. This mockup included volumetric obstructions representative of the hatch hinges and handhold on the inner surface of the hatch. The hinge volumes were based on the most current information available from the CEV design team at the time of the test and denote the gross dimensions of the mechanisms. The presence and location of the handhold on the hatch is test specific and is based on concepts under consideration by the vehicle development group.

Figure 4-12 CEV hatch mockup

Additional handrails were installed on the exterior surface of the CEV wall mockup. The location of these handrails was based on the latest design concepts available.

4.4.7 LIDS Tunnel and Hatch Mockup

The concept for the C-9 LIDS tunnel mockup was derived from the mockup used for the 1-g testing conducted previously under the auspices of the Advanced Project Office, EVA Pre-Project, in April 2006 The tunnel was fabricated in two sections, one representing the CEV portion and the other for the Lunar Lander Surface Access Module (LSAM) portion. The diameter of each section of the tunnel represented the clear volume available for translation and did not hardware that may be present in the tunnel but outside the clear translation volume. Each section of the tunnel was 30 inches long. The CEV portion of the tunnel had an inner diameter of 36 inches while the inner diameter of the LSAM portion was 32 inches (Figure 4-13).

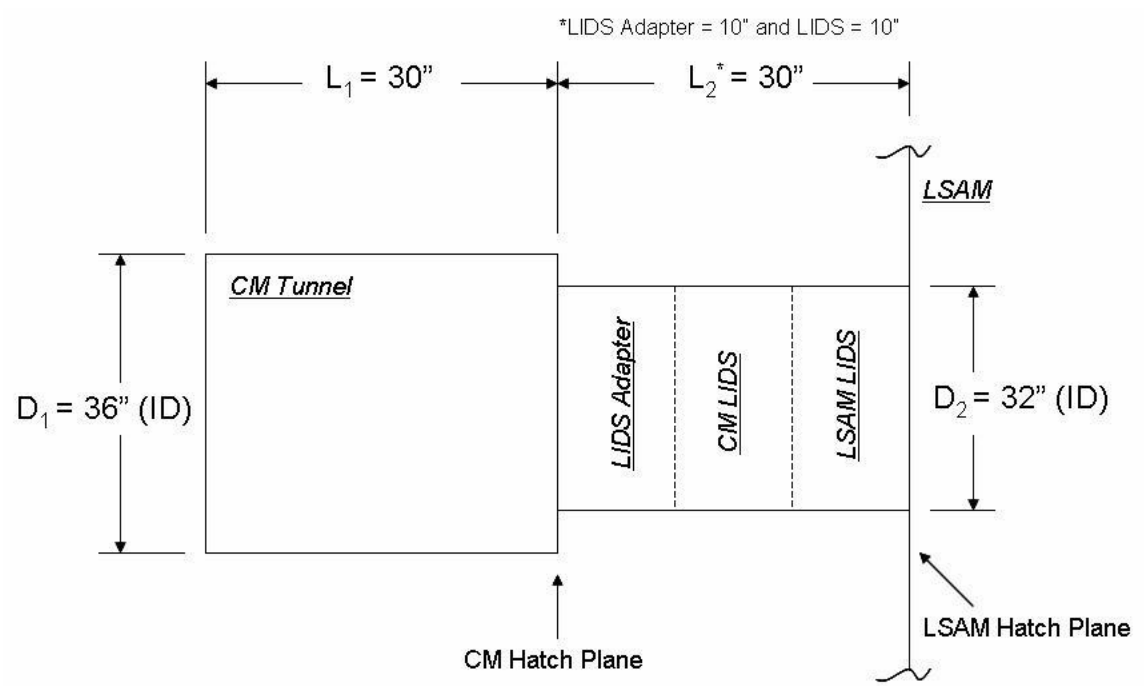


Figure 4-13 CEV docking tunnel to LSAM translation path dimensions

The LIDS tunnel was constructed out of clear polycarbonate sheets with plywood ribs to provide structural support and means for attachment. The LSAM portion of the tunnel had several cutouts to be used as translation aids. These mimicked the potential hardware in the LSAM LIDS tunnel that could be of use for translation. The CEV LIDS tunnel did not have any translation cutouts and at the time of this test it was anticipated that the tunnel walls would be smooth in the CEV. The tunnel sections were constructed in two pieces that were held together with pins and could be separated easily in the event of an emergency with the suited subject. The entire tunnel was supported on eight polystyrene foam bases and attached to the floor of the C-9 by ratchet straps (Figure 4-14). A low fidelity hatch mockup was provided by the LMSO LIDS group and was used at the transition interface between the CEV and LSAM tunnels to give the test subjects a general idea of interface locations and operations as well as allowing for the testing of the planned hatch removal scenario (Figure 4-15). The far end of the LSAM tunnel was blocked to give the subjects a clear indication of the translation distance and a location for simulating hatch operations at the LSAM.

Note that since the performance of this test, the Constellation Program has stood up the Lunar Lander Project, but the term LSAM has been retained for purposes of this report only.

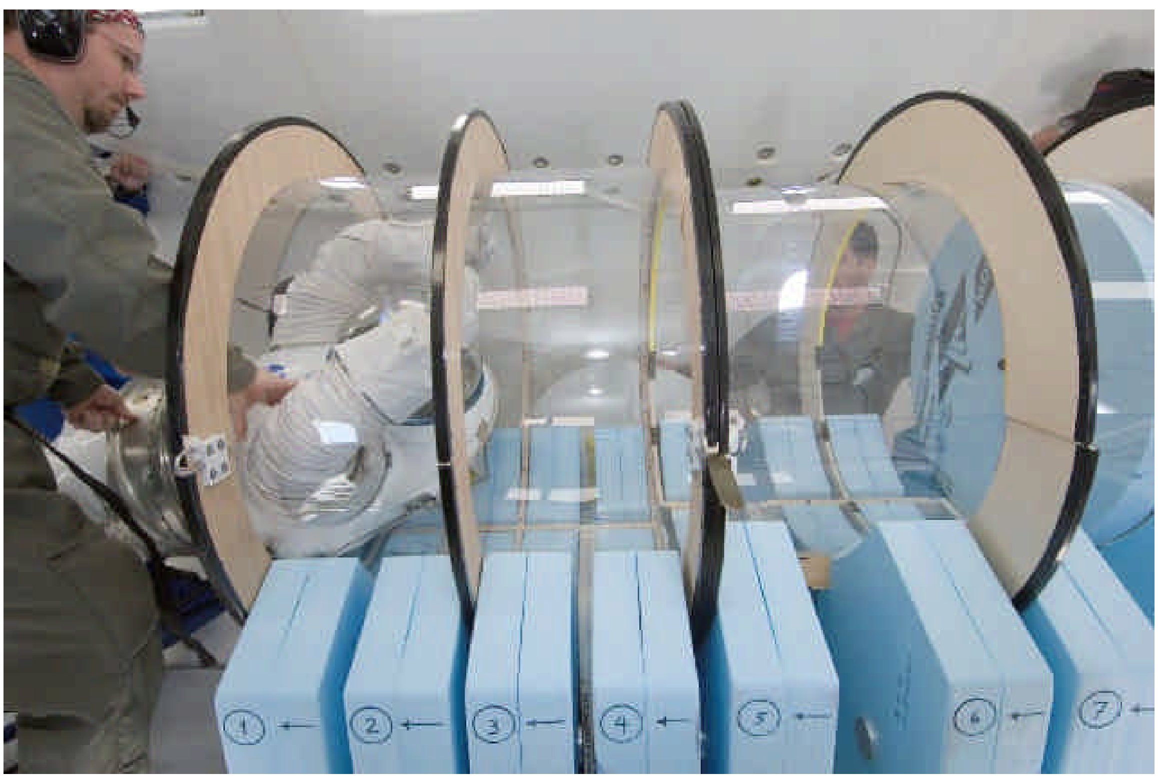


Figure 4-14 LIDS tunnel mockup

4.4.8 Umbilicals Mockup

Two volumetric mockups of the ESPO Vehicle Interface Element (VIE) umbilical design concepts were used to increase the fidelity of the egress and ingress operations performed by the suited crewmembers. The mockups incorporated simulations of the hoses for oxygen and water as well as electrical

Figure 4-15 Close-up of LIDS tunnel with low fidelity hatch in place.

conductors for power, data and comm. The water and oxygen hoses were Teflon with Kynar braid and the power, data and comm cables were bundles of 6, 12 and 14 conductors with Teflon braid covering. The connectors were fabricated from SLA resin, aluminum or stainless steel and represented the two design concepts that are currently being considered (Figure 4-16). The umbilical mockups were 12 feet long to allow for evaluation of their impacts to ingress and egress. These mockups were non-functional and did not replace the suit support umbilical.. The size and configuration of the umbilical mockups is shown in figure 4-17. Note that the mockups were not representative of a pressurized umbilical.

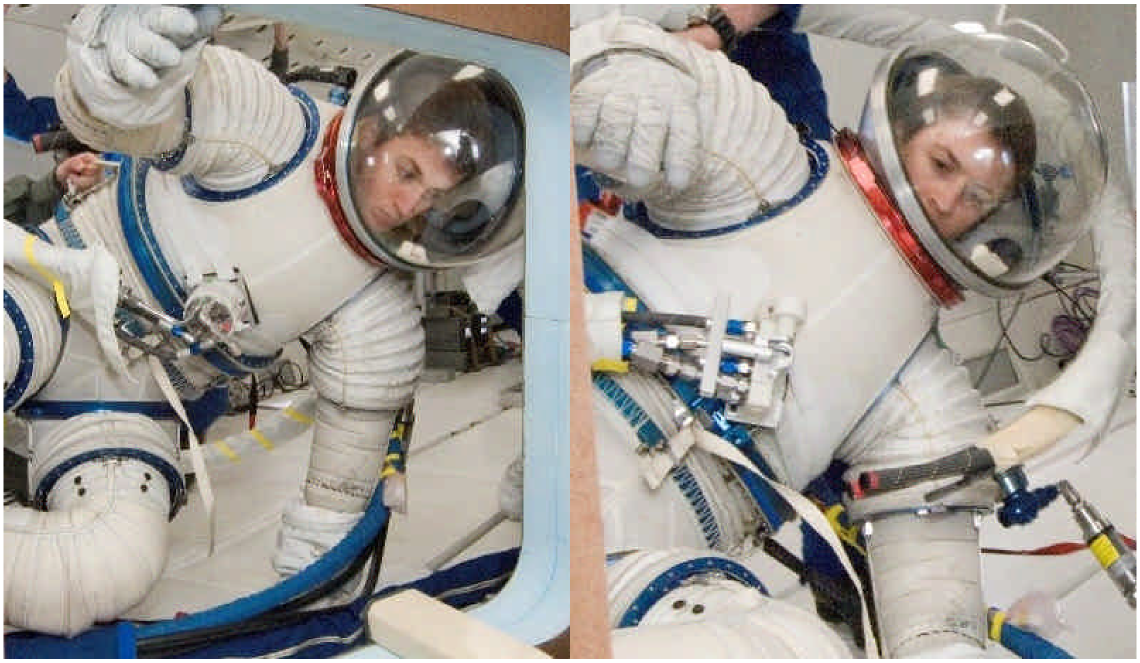
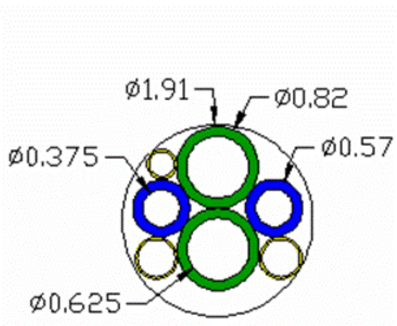


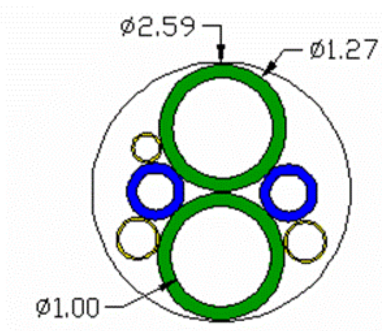
Figure 4-16 The Large and Small umbilical mockups

Umbilical Cross Section and Diameter

- **Umbilical Cross Section – Based on Umbilical Models**



5/8" O2 Umbilical



1" O2 Umbilical

- **Umbilical Major and Minor Diameters – Measurements from umbilical mockups**

	Major Diameter	Minor Diameter
5/8" O_2 Umbilical	1.83"	1.68"
1" O_2 Umbilical	2.65"	2.52"

Figure 4-17 Details of the umbilical mockups

4.4.9 Tool Harness

A mockup of an alternative EVA tool harness concept was used with the I-suit during this evaluation to assess the impact of the tool harness and anticipated tool complement on egress/ingress by suited crewmembers. An assessment of tool usage operations with regard to the tool harness design was also performed. The tool harness was constructed from an off the shelf parachute harness with retractable tethers, bayonet receptacles and O, D and V rings sewn onto it.

The EVA tools flown for use during these evaluations were: small EVA trash bag, EVA pry bar, Essex wrench, one adjustable tether, and two retractable tethers (Figure 4-18). A Body Restraint Tether (BRT) was added during the stand alone tool harness evaluation.

Figure 4-18 I-Suit with tool harness and tool complement

4.4.10 Space Suit Support Hardware

The hardware required to support the suited subject was provided by CTSD and included:

- K-Bottles of breathing air; manifold support for 6 bottles total
- Breathing air pressurization system; provides 6 acfm minimum
- Breathing air and cooling water umbilical
- Liquid Cooling Garment water cooling system
- Communication system (headsets were worn by all test personnel to talk and/or listen to the suited subject as well as the C-9 Aircraft personnel)

4.4.11 EVA Handrails

An EVA task board with two handrails mounted on it was used for the tool harness stand alone evaluation to provide a stable worksite for simulated tool operations. A single 24-in. handrail was added to the floor of the plane on the interior side of the CEV wall mockup to provide suited crewmembers a translation aid for the ingress portion of the CEV hatch evaluation. The placement of this handrail was test specific and did not represent a particular structure in the CEV (Figure 4-19).

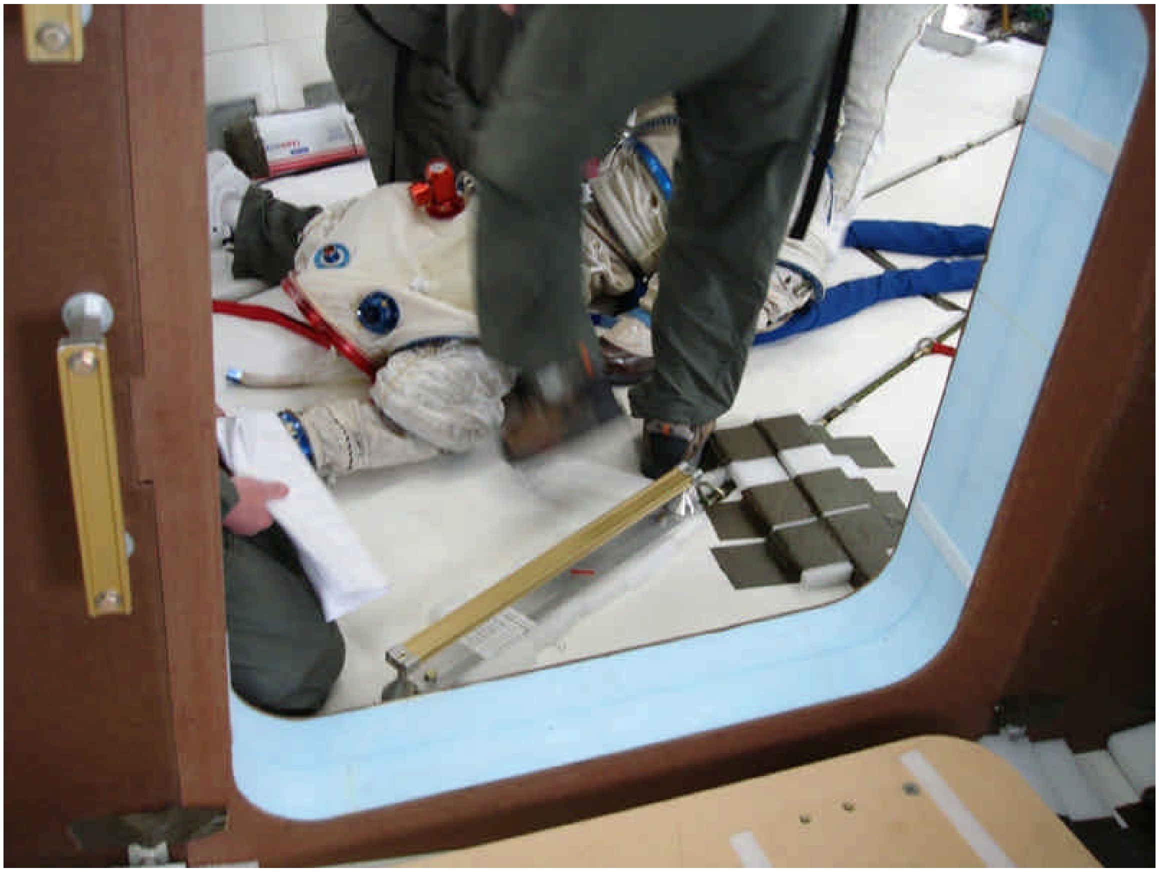


Figure 4-19 Handrail on interior side of CEV mockup

5. Results

5.1 CEV Hatch Egress/Ingress

All of the CEV hatch ingress/egress operations planned for evaluation during this test event were successfully completed over the course of two flight days. Flight day 1 consisted of 62 parabolas and flight day 2 consisted of 52 parabolas for a total of 114 parabolas (at ~25-30 seconds each) dedicated to this portion of the test series. A parabola breakdown giving the details of the testing is included as an appendix to this report All of the subjects were able to safely perform the tested procedures and the test personnel were able to gather clear data regarding the suit/vehicle architecture interface.

Following completion of the test, the test video was compiled and reviewed at the ESPO Systems Engineering Panel (ESPO SEP) on June 25, 2007 in order to form the technical conclusions of the ESPO. In addition to the video, the test team, and test subjects provided their subjective input to the SEP. The following forms the official conclusions reached by the ESPO:

Primary Conclusion: All hatch opening sizes tested (baseline, wide, and wide/short) with both umbilical sizes, and a minimal complement of tools appear to be compliant for in-space EVA ingress and egress operations with the existing ESPO EVA System Reference 1, both the Configuration 1 and Configuration 2 style pressure garments, with the following caveats:

1. Any reduction in the size of the hatch will need to be tested to determine the impacts to the results found during this evaluation.
2. Provisions for the hatch to lock open at 90 degrees and with a handrail on the hatch appear to be one of the prime factors for an acceptable operation. This provision serves as a “porch” and minimizes the flailing associated with ingress and egress operations, and the transition to/from the CEV exterior skin. If these

provisions are not provided, the evaluation will need to be repeated to determine acceptability.

3. Translation aids on the immediate interior of the CEV cabin are required. Engineering runs evaluated prior to official test subject runs without interior translation aids resulted in the subjects having significant difficulty in completion of the ingress and egress translation objectives. Based on these early runs, translation aids were installed for the official test subject evaluations. These interior translation aids do not necessarily need to consist of current ISS or SSP EVA translation aids (handrails/handholds, etc), but do need to consist of structure meeting EVA handling loads with sufficient grip diameter. Additionally, they do not necessarily need to be permanently mounted as considerations may warrant that set-up only for the contingency EVA is acceptable, and possibly even preferable in order to account for the other non-EVA events which CEV must consider. If permanent installation is not pursued, the operational concept for setting up these handrails prior to CEV egress for lunar landing must be assessed in order to ensure that the handrails will be in place prior to the post-lunar ascent contingency EVA crew transfer from the lander to the CEV.
4. The hatch hinges were used repeatedly throughout the evaluation as a translation and stabilization aid even though sufficient translation aids were available on the hatch and exterior skin of the mockups. These hinges appear to be in a location that will be unavoidable for this type of contact due to natural human responses. It is thus recommended that these hinges should be designed for these types of loads and intentional/deliberate contact cases. If the hinges are deemed a “no-touch” area, the evaluation should be repeated to determine if this existing hatch size is adequate for human subjects to deliberately avoid contact.
5. This evaluation demonstrated that the key to success will be translation aid locations, as well as specific hatch opening. The iteration of the type of location of these handrails should be a key focus area between the ESPO and CEV projects during future design efforts to ensure that the existing hatch size and

ESPO system continue to a convergent solution. Although the location and type of translation aids used for this evaluation were not intended to present the only solution for CEV, any significant alterations to those provided during this evaluation should be accompanied by additional early validation testing to assess the feasibility of these proposed solutions, and thus increase the likelihood of subsequent formal verification testing.

6. The subsequent test planned for the Fall ’07 will provide the launch pad ingress/egress evaluation through these hatch size openings. Given the very different nature of body orientation required for the 1-g launch operations, the need of the person to carry the weight of the suit, and the additional hardware that might be necessary for the launch pad operations (such as Ground Operations provided ventilation ducting), it is not possible to extrapolate the results of this test to the launch pad operations. Thus, this test only served to provide conclusions for the “in-space” EVA portion of the flight and only after conclusion of this second test will the full conclusions and evaluation of hatch size and ESPO architecture compliance be forthcoming.

Additional comments have been captured by the execution test team and are contained below. In case of any disagreements between the conclusions documented above from the ESPO SEP and below, the ESPO SEP will take precedence.

All three hatch opening sizes were acceptable for the purpose of translation for both the Mark III and I-suit. The subjects reported that the differences in hatch sizes tested were not significant enough to make a discernable difference in the amount of effort needed to egress/ingress through the hatch opening (Figure 5-1 and Figure 5-2).

Figure 5-1 Mark III suit translation through the baseline hatch opening

Both styles of suits were found to have adequate range of motion and clearance to allow passage through all of the different hatch openings. Suit sizing and crew availability prevented having a single subject perform the test operations using both suits, but based on the comments from the subjects and the suit engineers this did not impact the quality or completeness of the testing.

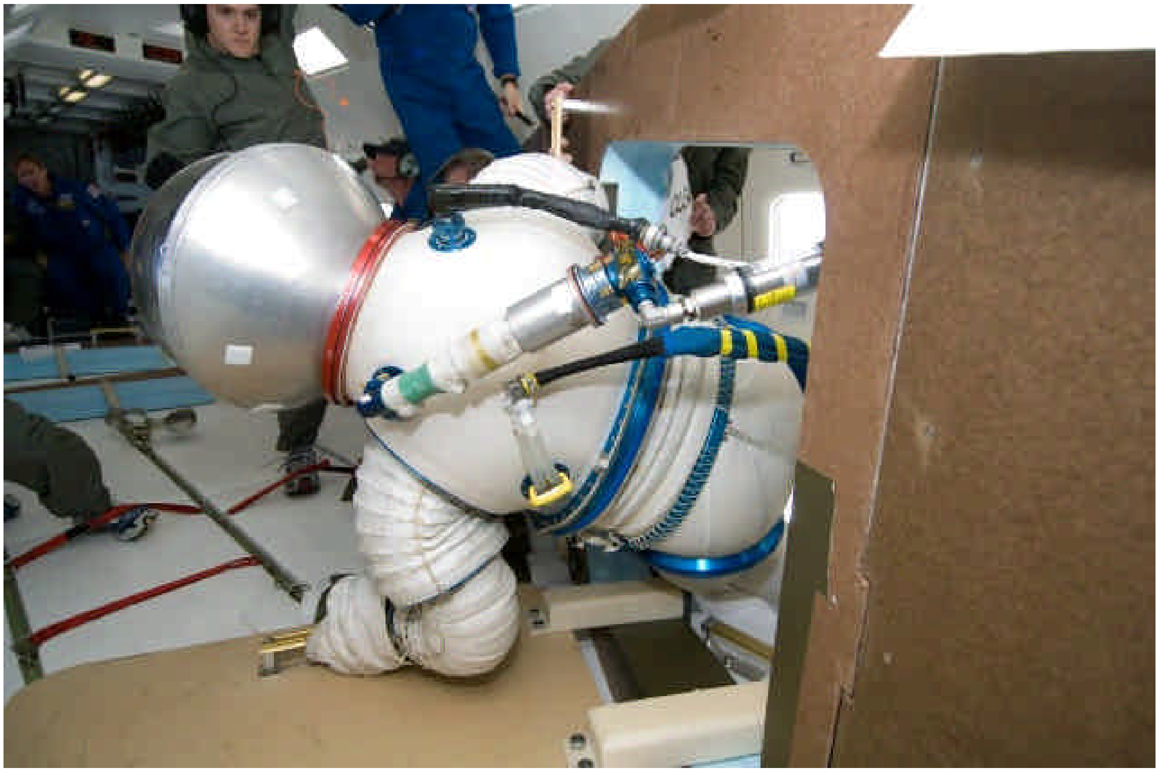


Figure 5-2 I-suit translation through the baseline hatch opening

Adding either of the umbilical mockups to the suits had a small impact on the level of effort required to perform the translation through the hatch opening due to the stiffness of the umbilical, but there was not enough difference in the two mockups to be able to differentiate between them during the operations (Figure 5-3). Likewise the addition of the tool harness to the I-suit did not have a significant impact on the subject mobility with respect to his ability to translate through the hatch, though there was some difference (specifically in the effort required to move the hip bearings and to flex and extend the torso) noted by the subjects in other scenarios with the harness. The addition of the tool complement to the harness complicated getting through the hatch opening by adding more potential snag hazards and requiring the subjects to manage the attached tools, but this was still not enough of a factor to make the translations unacceptable (Figure 5-4).

Figure 5-3 Mark III translation through the wide hatch configuration with small umbilical

Figure 5-4 I-Suit translation through the wide/short hatch configuration with tool harness and tools

It should be noted that video and photographic data recording captured a number of impacts by the suited crewmembers against the sides of the hatch opening during translation, though no serious impacts occurred. It was the general opinion that most if not all of these impacts were the result of test specific effects. The subjects had a limited time for the 0-g operations so they were not able to take the time and care they would under on-orbit conditions. Also the reduced gravity effect was not perfect and mid-parabola turbulence contributed to subject impacts. And in some cases the actions of the test support personnel, acting to maintain test subject safety, may have been a contributing factor to some impacts. None of these issues change the overall acceptable result of the evaluations, but only serve to indicate that there is a high likelihood of significantly reduced contact between the suited subjects and the vehicle in the “real-life” operations.

A number of important observations and comments about the test setup and how it relates to the actual CEV hardware in development were made during the test. Because these details were a factor in the overall success of the evaluation they will be included here to document these findings and convey them to the CEV development group.

During the test development it was decided that the hatch mockup would be set at a 90° relative to the hatch opening. This was thought to represent the worse case scenario with the hatch as close to the translation path as was considered possible. This configuration actually ended up being highly useful for the translation through the hatch opening. The hatch provided a natural path and translation aid for getting in and out of the CEV and for orienting towards the planned translation path on the exterior of the vehicle. It was reported that a slight increase in the hatch angle would not reduce this usefulness, but any significant change in angle would need to be re-tested to determine the impact on these operations. Every effort should be made to include the ability to lock the hatch in the open position in an angle similar to the one tested.

The handhold on the CEV hatch was placed based on similar architecture that was present on the Apollo capsule hatch and has not been fully defined as a design feature for the CEV. All of the test subjects reported that this handhold was necessary to complete the hatch opening translation and that every effort should be made to maintain this feature. Details about location and orientation should be coordinated between the ESPO and CEV communities (Figure 5-5).

Figure 5-5 I-Suit translation using hatch and handhold for egress

It was also evident from the data collected that the hatch hinges were routinely contacted during the subjects maneuvering through the hatch opening. In many if not all cases the subjects used the hinges as an aid to help align and guide themselves as they presented a natural reaction location during the translation (Figure 5-6). It was stated during test development that the hinges were not considered “no-touch” items. If this condition changes due to sharp edge, force application or other concerns it will seriously impact the results of this evaluation.

Lastly, during the first day of testing it was observed that the subjects needed some form of translation aid on the IVA side of the CEV hatch opening. A test specific handrail was added for the second day of testing and this greatly improved the ability of the subjects to

Figure 5-6 Mark III ingress, hinges used as translation aid

control themselves during CEV ingress operations (Figure 5-7). This result highlights the need to inclusion of some form of IVA aid. The specific form (soft-goods straps, dedicated handrails or properly sized structural features) and nature (temporary or permanent) of these aids should be developed in a coordinated effort between the CEV and ESPO communities with consideration given to both nominal and contingency operational scenarios .

An issue that was discussed during the preliminary test development meetings but did not get incorporated into the actual test event was the translation through the hatch opening while carrying a Secondary Oxygen Package (SOP) mockup. However a review of the test video data suggests that the facility umbilical (which provided air and water for all of the suits during the pressurized operations of this test series) presented an acceptable representation of the volumetric impacts the SOP would have for translation through the hatch.

Figure 5-7 I-Suit ingress using simulated IVA translation aid

5.2 0-G Suit Don/Doff

The 0-g donning/doffing in the simulated CEV volume objectives were successfully evaluated during the third day of testing, which consisted of 71 parabolas (a new record for the C-9 aircraft at that time). For these evaluations it was decided that suit donning would be terminated once the respective suit seal (hatch, zipper or body seal closure) was made. Helmet and glove donning and suit pressurization were not included in this test.

A parabola breakdown giving the details of the testing is included as an appendix to this report. The following donning/doffing scenarios were tested during the flight:

- Single suit don/doff, 4 crew in volume, two-person assist
- Single suit don/doff, 4 crew in volume, one-person assist
- Single suit don/doff, 4 crew in volume, unassisted
- Single suit don/doff, 6 crew in volume, two-person assist, 2 suits in volume
- Single suit don/doff, 6 crew in volume, one-person assist, 2 suits in volume
- Single suit don/doff, 6 crew in volume, unassisted, 2 suits in volume
- Single suit don/doff, 4 crew in volume, two-person assist, 2 suits in volume
- Two suit don/doff, 6 crew in volume, one-person assist
- Two suit don/doff, 6 crew in volume, unassisted
- Two suit don/doff, 6 crew in volume, two-person assist

Figure 5-8 Mark III donning with 2 person assist, 4 crew in volume

The volume used for the evaluation was developed from the best information available at the time of the test and was based on the dimension for the inner mold line of the CEV and the vertical clearance between the top of the seat pallet and the ceiling of the CEV. For this test it was assumed that the CEV seats would be completely stowed for the suit operations, providing the greatest amount of free space. The seat pallet support struts were not included in this evaluation as their configuration and location were undefined at the time. The simulated CEV volume provided adequate space for performing the different donning and doffing operations even with six simulated crewmembers present (Figure 5-9 and Figure 5-10). Subject used test specific soft-goods restraints for stabilization and suit restraint. These provided adequate means to complete the tasks and supported the concept that such a system would be acceptable on orbit. Particular details of the restraints should be developed through a coordinated effort between the CEV and ESPO communities.

Figure 5-9 Mark III donning with 2 person assist, 6 crew and 2 suits in the CEV volume

It was generally observed that the one piece suits (Mark III and ACES) were easier to don and doff than the 2 piece suits (I-Suit and D-Suit). Self donning/doffing was possible for all suits with adequate restraints for the suit and handholds for the subject. The Mark III suit was easy to don and doff once a method of restraining the suit via soft-goods strap around the waist bearing was implemented. The I-suit was found to be easier to don than to doff in 0-g. Donning of the I-Suits Soft Upper Torso (SUT) assembly was easy to perform unassisted, but doffing required a two-person assist to be completed in a timely manner (Figure 5-11).

Figure 5-10 Two suit donning with 2 person assist for each

Figure 5-11 I-Suit donning with 2 person assist

Donning and doffing the D-suit was the most complicated and time consuming operation assisted or unassisted due to problems with the suits inner bladder folding, bulging, etc. The ACES was the quickest suit to don or doff even though these actions were complicated by the fact that the subjects were not wearing the liquid cool garment (LCG) designed for the ACES but were instead using the LCG for the other suit configurations (Figure 5-12).

Figure 5-12 ACES donning, unassisted

5.3 LIDS Tunnel Operations

The evaluation of the LIDS tunnel translation by a suited crewmember was conducted on the fourth day of testing, which consisted of 49 parabolas. A parabola breakdown giving the details of the testing is included as an appendix to this report Three different suits configurations were used for the test: the Mark III, the I-suit and the D-Suit. The Mark III and the I-suit were used in both the pressurized and unpressurized conditions. The D-suit was only used unpressurized.

The goal of the test was to assess the reach, access, visibility and range of motion for each suit configuration/condition tested in order to determine the mobility and visibility that will need to be considered for pressure garment requirement and design development for these confined operations and to potentially provide input to the vehicle design group on placement for controls that may need to be accessed by a suited crewmember. Subjects were asked to simulate several different motions that had been suggested as possibilities for control mechanism actuation (overhead wrist rotation, small crank motion, large crank motion, etc.). They were also asked to indicate their preference for control locations based on the mobility in the suit under the different configurations/condition. These assessments were performed at the crew module hatch plane where the tunnel diameter is 36 inches and at the LSAM hatch plane where the tunnel is narrower (32 inches).

Figure 5-13 Pressurized Mark III reach and access at LSAM hatch

It should be noted that the Constellation Program has not levied suited CEV or LIDS tunnel translations and operations on either the ESPO or CEV projects. Data from this test might be useful for the Constellation Program in assessing the feasibility of such a requirement for both the ESPO or CEV projects. At the time of this report, the video resultant from this test has not been compiled and reviewed by the ESPO SEP, as the emphasis has been first placed on review and documentation of the hatch ingress/egress portion of the test and then performance of the subsequent launch oriented test. Any statements and conclusions reached below are based on the test personnel and subjects participating in the test from their valuable first hand experience and actual observations, but should not be construed as representing the conclusions and recommendations of the ESPO at this time. Following video compilation and SEP review completion, this document will be updated with those results if warranted.

It should also be recognized that all the pressure suits participating in this test were not developed and certified to Constellation Program and ESPO flight standards or requirements. Any conclusions reached from the conduction of this test should be tempered with the possibility that future pressure garments fabricated to the Constellation Program flight standards and requirement set may preclude the same mobility as demonstrated during this test. Although this statement could be made for all testing conducted at this time, the suited operations needed while inside the tight confines of the tunnel as simulated in this portion of the test may be more vulnerable to reduced mobility than those associated with other operations simulated in this test series (such as the hatch ingress/egress and donning tests).

All of the subjects were able to complete the requested operations. The subjects were able to place their arms above their head to simulate hatch control actuation even given the tight confines of the smaller diameter tunnel. The unpressurized suit condition demonstrated better mobility and range of motion than the pressurized condition for both the Mark III and the I-Suit. The unpressurized D-Suit showed the greatest mobility in the confined space, with the suited subject being able to execute a 180° turn in the small diameter tunnel (Figure 5-14).

Figure 5-14 D-Suit maneuvering in LIDS tunnel

The addition of the large umbilical mockup to the suits did not impact their ability to perform the desired operations (Figure 5-15). Nor did adding the tool harness to the I-Suit restrict the mobility enough affect its reach and access. The tool harness was used with out a tool complement attached (Figure 5-16).

Another aspect of these operations evaluated was removal of the hatch at the crew module hatch plane. The current design concept calls for the crew to actuate the hatch mechanism which completely releases the hatch from the opening. The hatch is then drawn back into the CEV crew compartment for storage on the bulkhead. Using a low fidelity volumetric hatch mockup the subjects attempted to pass the released hatch back down the tunnel while maintaining their position at the hatch opening. While this task

Figure 5-15 Unpressurized Mark III with large umbilical mockup

Figure 5-16 I-Suit with tool harness in LIDS tunnel

seemed possible, it also added undue risk to damage to the suit when the mass of the hatch and the tight confines of the tunnel where taken into consideration. It was more expedient for the crewmember to back out with the hatch once it was released and then hand it off (Figure 5-17).

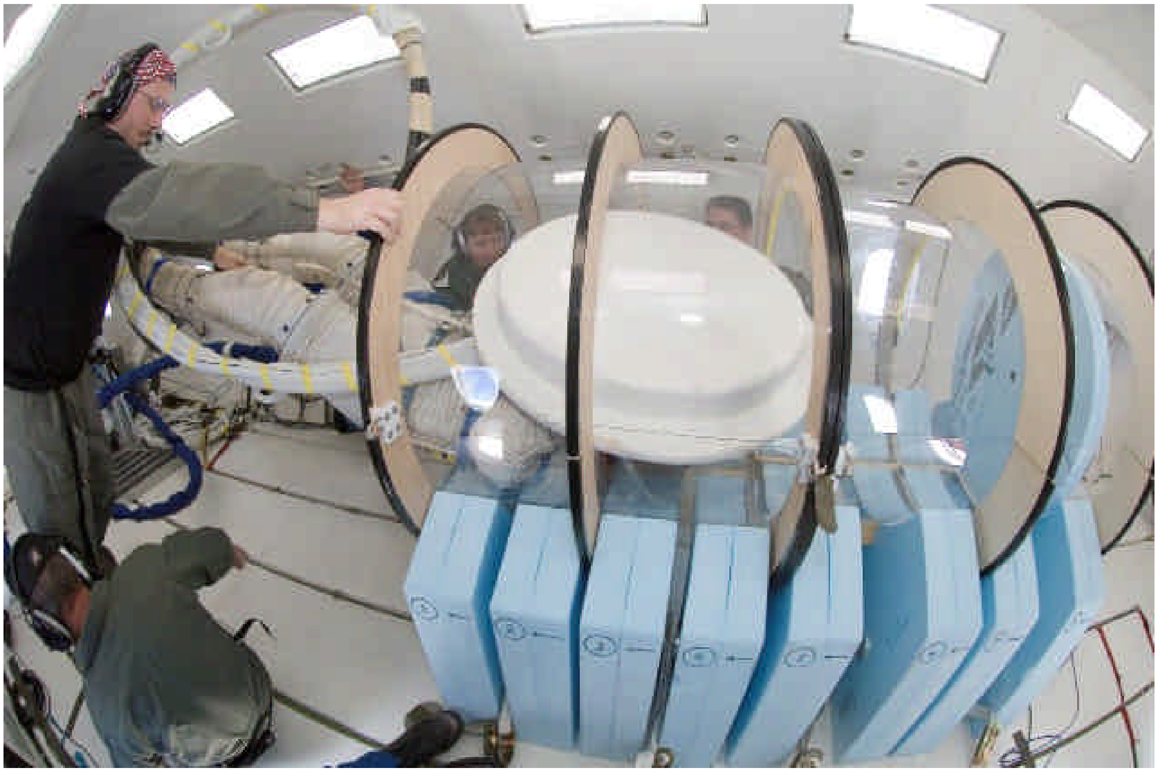


Figure 5-17 LIDS hatch removal

5.4 Tool Harness Evaluation

The subjects demonstrated that a pressurized suit (I suit) can fit through the hatch with the tool harness loaded with tools. All subjects reported that the harness did have a minimal impact on their mobility, but it did not seriously compromise their ability to translate through the hatch opening.

During the stand alone evaluation on the fourth day of testing, the BRT base plate functioned well and provided a stable attachment interface between the suited subject and the test handrails. It was noted that the location of the base plate on the leg strap for the harness restricted the leg movement. Also, the location of the BRT adaptor and base plate was difficult for the suited subject to see and, as a result, the subject could not connect the BRT to the adaptor in a timely manner unassisted. After two parabolas of the subject trying to connect the BRT, a suit engineer connected it for him to allow continuation of the rest of the evaluation. The lack of visibility could have been due to the body orientation of the test subject. The D-ring extenders on the leg straps performed well with the harness. By extending the leg loops with the D-ring extenders, the test subject was able to see what he was tethering to. Some comments that were recorded concerning the harness configuration included a suggestion to add a second chest strap to take the V-rings off the shoulder, have the D-rings/loops stand up more so it is easier for the subject to feel, move the rings/loops more towards the center of the chest so it is easier for the subject to reach, and re-evaluate the tethers because they were not in the best condition for use.

In all, the tool harness was evaluated through approximately 12 parabolas for this test. The complete set of tool harness test objectives were not achieved, however it is the judgement of the test team that sufficient objectives were completed in the tool harness stand-alone test to determine that the use of the tool harness for the ingress/egress test was appropriate (i.e. the hatch test results are valid). The test subject was able to add all four tools via tethers to the harness, and was stabilized by the BRT. The incompleted test objectives consisted of: tool removal from the harness, subject attaching himself to the BRT, and complete subject stabilization by the BRT (which did not occur because a suit technician was holding him in preparation for the 2G loads).

6. Conclusions

This test indicates that there appears to be a converging solution for the CEV in-space EVA ingress and egress operations between the ESPO architecture ERS 1 and the CEV/Orion Project hatch size. This test also highlighted the importance of translation aids for the success of this task and, thus, the implication that insufficient translation aids may require an increase in hatch size. The ESPO and CEV/Orion communities should use this test data as the first of many iterations of a continued effort to define the appropriate translation aid locations and types for EVA-related operations. Although the translation aids assumed for this test were only a first estimate by the test team, and it is recognized that a particular design solution is forward work for the CEV/Orion project, any significant alterations made in future work in this area may require revisitation to the conclusions made from this test. The conclusions were formed by the EVA SEP panel based upon a review of the test video data supplemented with test subject and test team subjective comments.

The subsequent 1-g test planned for the Fall '07 will provide the second part of the evaluation, that for suited ingress and egress launch pad operations. It is intended that this test should include the launch pad hardware as well as a configuration 2 suit to help ascertain whether a single suit architecture might be viable. This test is planned to be conducted with a similar test team makeup, although with the addition of Constellation Program Ground Operations Project (GOP) personnel, specifically in the area of “white room” design knowledge.

The data gathered during the don/doff and LIDS tunnel evaluations will be shared with the ESPO and CEV communities and will be used to guide the continuing development of the suit and vehicle hardware and can serve as a springboard for additional testing as requested by either community.

Appendix A: Quick-Look Report

Quick-Look Test Report

Test Title: EVA Systems Project FY'07 SE&I Test 4

Objectives:

1. CEV Side Hatch Translation Evaluation (0-g EVA)
2. Pressure Suit Donning in confined volume (0-g)
3. LIDS Corridor Dimension Pressure Suit Evaluation (0-g)

Dates Performed: May 8-11, 2007

Facility Used: C-9 Parabolic Aircraft

This memo serves to document the testing accomplishments for the CEV Hatch, Suit Don/Doff and LIDS Tunnel C-9 Evaluation conducted on May 8-11, 2007. This report does not provide formal EVA System Project or CEV Project recommendations or conclusions. A complete report documenting the EVA System and CEV Project recommendations stemming from this test will be forthcoming following review of test data.

Flight Day 1:	CEV Hatch Translation Test (5/8/07)
Test Conductor:	Amy Ross
Subjects:	Mark III Suit – M. Dub (EC)
	I-Suit – B. Daniel (EC)

This was the first of two days of CEV side hatch egress/ingress testing conducted during the evaluation. Both subjects were engineers chosen for their familiarity and compatibility with the suits being used for the evaluation. All of the planned test configurations were evaluated during the flight. Variables assessed during the flight included CEV hatch sizes (baseline size, extended width with baseline height, and extended width with decreased height), umbilical configuration (no umbilical and two different umbilical concept mockups) and on the I-suit the mockup for the tool harness was added with different tool configurations for several passes through the hatch. Impacts against the sides of the hatch opening were noted during the evaluation, but many of these could be attributed to the subjects having a limited amount of time to complete their translation through the opening, flight turbulence and interaction with spotters working to maintain the safety of the suited subjects. In general the subjects seemed to be very successful in navigating their way in and out of the CEV hatch regardless of the configuration of the opening and the suit.

The CEV hatch mockup performed well and reconfiguration was easily accomplished as planned.

Some problems with the communication system were identified during the flight, though there was never a safety hazard or loss of communication with the suited subject. Changes to the communication system layout and with some hardware in the C-9 eliminated these problems.

Post test discussion led to a decision to have all suit configuration changes done during level flight on subsequent test days to eliminate the risk and difficulty of making these changes during parabolic flight. Also a handrail was added on the floor of the plane on the IVA side of the CEV hatch to aid subject ingress.

Flight Day 2:	CEV Hatch Translation Test (5/9/07)
Test Conductor:	Amy Ross/Jessica Vos
Subjects:	Mark III Suit – M. Gernhardt (CB)
	I-Suit – A. Ross (EC)

This was the second of two days of CEV side hatch ingress/egress testing and the first evaluation conducted with a crew subject. Again all of the planned test configurations were evaluated. Mike Gernhardt stated that the baseline hatch size seems acceptable and that there was little perceived difference between the hatch configurations as far as impact to translation was concerned. This reflects the sentiments expressed by the other suited subjects as well. The two umbilical mockups evaluated also did not seem to have an impact on the translation of the suited subjects.

There was a minor problem pressurizing the I-suit for its evaluation, but this was corrected. The suit techs planned a post-test inspection of the thigh bearings as this seemed to be the source of the problem.

The communication problems from the first day of the flight were not present on this flight. The decision to reconfigure the suit during level flight caused a small reduction in the number of parabolas completed but made the reconfiguration much faster and safer. Parabolas lost would only have been used to reconfigure the suit anyway and would not have expanded the scope of the evaluations.

Flight Day 3:	Suit Don/Doff in CEV Volume (5/10/07)
Test Conductor:	Amy Ross / Jessica Vos
Subjects:	Mark III Suit – P. Sellers (CB), R. Watson (EC)
	I-Suit – B. Daniel (EC), L. Aitchison (EC)
	D-Suit – B. Daniel (EC), L. Aitchison (EC)
	ACES – P. Sellers (CB), R. Watson (EC), L. Aitchison (EC), B. Daniel (EC)

The objective of this day of testing was to evaluate the donning and doffing of several different configurations of suits in 0-g. Four different suits were evaluated singly and in pairs within a designated CEV volume under different crew complement conditions (four or six crew) and under assisted (with one or two helpers) and unassisted conditions. Additional 0-g donning/doffing evaluation was conducted separate from the CEV volume evaluation to gain additional information about technique and restraints needed to aid crew during donning/doffing. All evaluations were conducted without pressurizing the suits, donning was considered complete once a suit was sealed, not including helmet and gloves. Results for particular suits will be detailed in the final test report.

Flight Day 4: LIDS Tunnel Evaluation and Tool Harness Evaluation (5/11/07)

Test Conductor: Amy Ross / Jessica Vos

Subjects: Mark III Suit – D. Wolf (CB)

I-Suit – M. Dub (EC)

D-Suit – B. Daniel (EC)

During this flight we evaluated a suited crewmember's ability to translate through a mockup of the LIDS tunnel created based on the current design concepts for the CEV and LIDS. The evaluation included manipulation of a simulated hatch between the CEV and LIDS and was performed by suited subjects with the suits pressurized and unpressurized to examine the impact that condition could have on suit mobility in tight confines. The D-Suit was only tested under the unpressurized condition. In general, the unpressurized suits were more mobile than the pressurized suits. Dexterity and reach access were better for unpressurized suits. The large umbilical mockup was added to the Mark III, I-Suit and D-Suit for several parabolas, but it did not seem to impact the reach and access of the suited subject. The D-Suit showed the most mobility in the tight confines and the subject was actually able to perform a 180 degree turn inside the tunnel.

After the I-Suit subject was complete with the LIDS evaluation, the tool harness was added to the suit and a brief evaluation of the operability of the tool harness was conducted. The harness did impact the range of motion in the I-suit hip bearing and there was not much time to evaluate stowing and unstowing tools. The evaluation lasted about ten parabolas.

Summary

All the test objectives planned for this test were completed without significant incident. The recommendations and conclusions from this test will be documented in the final test report following video review and debriefs with the SE&I teams from the EVA System and CEV projects.

Questions concerning this quick look report can be directed to the EVA Systems Test Lead (Jessica Vos at jessica.r.vos@nasa.gov, 281-483-1483), the primary Test Conductor for this test (Amy Ross at amy.j.ross@nasa.gov, 281-483-8235), or the EVA Systems Test and Facilities Lead (Jeff Patrick at jeffrey.a.patrick@nasa.gov, 281-483-3143).

Appendix B: Parabola Breakdown

Flight Day 1

P#	Suit	Subject	Activity	
1	MKIII	Dub	Suit donning	
2			Suit Donning	
3			**Baseline Hatch**	Clean
4				Clean
5				Clean
6				Clean
7				Clean
8				Clean
9			Suit reconfiguration	
10			Suit reconfiguration	
11			Suit reconfiguration	
12			**Baseline Hatch**	Large Umbilical
13				Large Umbilical
14				Large Umbilical
15				Large Umbilical
16			Suit reconfiguration	
17			**Wide Hatch**	Small Umbilical
18				Small Umbilical
19				Small Umbilical
20				Small Umbilical
21			**Wide/Short Hatch**	Clean
22				Clean
23			Suit reconfiguration	
24			Suit reconfiguration	
25			**Wide/Short Hatch**	Large Umbilical
26				Large Umbilical
27			Suit Doffing	
28	I-Suit	**Daniel**	**Baseline Hatch**	Clean
29				Clean
30			No Test	
31				Clean

P#	Suit	Subject	Activity	
32				Clean
33				Clean
34				Clean
35			**Baseline Hatch**	Small Umbilical
36				Small Umbilical
37				Small Umbilical
38				Small Umbilical
39			Suit reconfiguration	
40			**Baseline Hatch**	Large Umbilical
41				Large Umbilical
42				Large Umbilical
43				Large Umbilical
44			Suit reconfiguration	
45			Suit reconfiguration	
46			**Wide/Short Hatch**	Tool harness w/o tools
47				Tool harness w/o tools
48				Tool harness w/o tools
49				Tool harness w/o tools
50			Suit reconfiguration	
51			Suit reconfiguration	
52			**Wide/Short Hatch**	Tool harness w/ tools
53				Tool harness w/ tools
54				Tool harness w/ tools
55				Tool harness w/ tools
56			Suit reconfiguration	
57			**Wide/Short Hatch**	Tool harness w/ tools, Large Umbilical
58				Tool harness w/ tools, Large Umbilical
59			Suit reconfiguration	
60			**Wide Hatch**	Tool harness w/ tools, Large Umbilical
61				Tool harness w/ tools, Large Umbilical
62			No test	

Flight Day 2

P#	Suit	Subject	Activity
1	MKIII	**Gernhardt**	Suit Donning

2			**Baseline Hatch**	Clean
3				Clean
4				Clean
5				Clean
6				Large Umbilical
7				Large Umbilical
8				Large Umbilical
9				Large Umbilical
10			**Wide Hatch**	Large Umbilical
11				Large Umbilical
12				Large Umbilical
13				Large Umbilical
14			**Wide Hatch**	Clean
15				Clean
16			**Wide/Short Hatch**	Clean
17				Clean
18				Clean
19				Clean
20			**Wide/Short Hatch**	Large Umbilical
21				Large Umbilical
22				Large Umbilical
23				Large Umbilical
24			Suit Doffing	
25			Suit Doffing	
26	I-Suit	**Ross**	**Baseline Hatch**	Clean
27				Clean
28				Clean
29				Clean
30			**Baseline Hatch**	Large Umbilical
31				Large Umbilical
32				Large Umbilical
33				Large Umbilical
34			**Wide Hatch**	Large Umbilical
35				Large Umbilical
36			**Wide Hatch**	Clean
37				Clean

38			Clean
39			Clean
40			**Wide/Short Hatch** Clean
41			Clean
42			**Wide/Short Hatch** Tool harness w/ tools
43			Tool harness w/ tools
44			Tool harness w/ tools
45			Tool harness w/ tools
46			**Wide Hatch** Tool harness w/ tools
47			Tool harness w/ tools
48			Tool harness w/ tools
49			Tool harness w/ tools
50			Tool harness w/ tools
51			Tool harness w/ tools
52			Suit Doffing

Flight Day 3

P#	Crew	Assistance	Activity
1.	4	2	Mark III donning
2.	4	2	Mark III doffing
3.	4	2	Mark III donning
4.	4	2	Mark III doffing
5.	**No test**		
6.	4	2	Mark III donning
7.	4	2	Mark III doffing
8.	4	1	Mark III donning, one knee backwards
9.	4	1	Mark III doffing
10.	**No test**		
11.	4	0	Mark III donning
12.	4	0	Mark III doffing
13.	4	0	Mark III donning – lost bootstrap, suit unrestrained
14.	4	0	Mark III doffing
15.	6	2	Mark III donning, 2 suits in volume
16.	6	2	Mark III donning, 2 suits in volume
17.	6	2	Mark III doffing, 2 suits in volume
18.	6	2	I-Suit donning, 2 suits in volume
19.	6	2	I-Suit donning, 2 suits in volume
20.	6	2	I-Suit donning, 2 suits in volume
21.	6	2	I-Suit donning, 2 suits in volume
22.	6	2	I-Suit doffing, 2 suits in volume
23.	6	2	I-Suit doffing, 2 suits in volume
24.	6	2	Mark III donning, 2 suits in volume
25.	6	2	Mark III doffing, 2 suits in volume
26.	6	2	Mark III donning, 2 suits in volume
27.	6	2	Mark III doffing, 2 suits in volume
28.	6	2	I-Suit donning, 2 suits in volume
29.	6	2	I-Suit donning, 2 suits in volume
30.	6	2	I-Suit doffing, 2 suits in volume
31.	6	2	I-Suit doffing, 2 suits in volume
32.	6	1	Mark III donning, I-suit donning
33.	6	1	Mark III doffing, I-suit donning
34.	6	1	Mark III donning, I-suit doffing

P#	Crew	Assistance	Activity
35.	6	1	Mark III doffing, I-suit doffing
36.	**No test**		
37.	6	0	Mark III donning, I-suit donning
38.	6	0	Mark III doffing, I-suit donning
39.	6	0	Mark III donning, I-suit donning
40.	6	0	Mark III doffing, I-suit doffing
41.	6	0	Mark III donning, I-suit doffing
42.	6	0	Mark III doffing, I-suit donning
43.	6	0	Mark III donning, I-suit donning
44.	6	0	Mark III doffing, I-suit doffing
45.	6	0	Mark III no test, I-suit doffing
46.	**No test**		
47.	6	0	D-suit donning, 1 suit in volume
48.	6	0	D-suit donning, 1 suit in volume
49.	6	0	D-suit donning, 1 suit in volume
50.	6	0	D-suit donning, 1 suit in volume
51.	6	0	D-suit doffing, 1 suit in volume
52.	6	0	ACES donning, 2 suits in volume (ACES and D-suit)
53.	6	0	ACES donning, 2 suits in volume (ACES and D-suit)
54.	6	0	ACES donning, 2 suits in volume (ACES and D-suit)
55.	6	0	ACES doffing, 2 suits in volume (ACES and D-suit)
56.	6	0	ACES doffing, 2 suits in volume (ACES and D-suit)
57.	6	0	ACES donning, D-suit donning
58.	6	0	ACES donning, D-suit donning
59.	6	0	ACES doffing, D-suit donning
60.	6	0	ACES doffing, D-suit doffing
61.	6	2	ACES donning, D-suit donning
62.	6	2	ACES donning, D-suit donning
63.	6	2	ACES doffing, D-suit doffing
64.	6	2	ACES donning, D-suit donning
65.	6	2	ACES donning, D-suit donning
66.	6	2	ACES donning, D-suit donning
67.	6	0	ACES doffing, D-suit donning
68.	6	0	D-suit donning, 2 suits in volume (ACES and D-suit)
69.	6	0	D-suit donning, 2 suits in volume (ACES and D-suit)

P#	Crew	Assistance	Activity
70.	6	0	D-suit donning, 2 suits in volume (ACES and D-suit)
71.	**No test**		

Flight Day 4

P#	Suit	Subject	Activity
1	MKIII	Wolf	Subject moved to test area
2			Pressurized suit, clean, mid-tunnel hatch removal
3			Pressurized suit, clean, translation through tunnel
4			Pressurized suit, clean, translation through tunnel
5			Pressurized suit, clean, end hatch reach and access
6			Pressurized suit, clean, translation through tunnel
7			Pressurized suit, clean, translation through tunnel
8			Pressurized suit, clean, mid-tunnel hatch removal
9			Pressurized suit, large umbilical, mid-tunnel hatch removal
10			Pressurized suit, large umbilical, mid-tunnel hatch removal
11			Pressurized suit, large umbilical, end hatch reach and access
12			Unpressurized suit, large umbilical, mid-tunnel hatch removal
13			Unpressurized suit, large umbilical, end hatch reach and access
14			Unpressurized suit, large umbilical, end hatch reach and access
15			Unpressurized suit, large umbilical, end hatch reach and access
16			Unpressurized suit, large umbilical, end hatch reach and access
17			No Test
18			Unpressurized suit w/ helmet, large umbilical, end hatch reach and access
19			Unpressurized suit w/ helmet, large umbilical, end hatch reach and access
20			Mark III moved to donning stand
21	I-Suit	Dub	Pressurized suit, clean, mid-tunnel hatch removal
22			Pressurized suit, clean, translation through tunnel
23			Pressurized suit, clean, end hatch reach and access
24			Pressurized suit, clean, end hatch reach and access
25			Pressurized suit, clean, translation through tunnel
26			Pressurized suit, large umbilical, mid-tunnel hatch removal
27			Pressurized suit, large umbilical, end hatch reach and access
28			Pressurized suit, large umbilical, mid-tunnel hatch removal

P#	Suit	Subject	Activity
29			Pressurized suit, large umbilical, end hatch reach and access
30			Pressurized suit, large umbilical, end hatch reach and access
31			Vent P, large umbilical, end hatch reach and access
32			Vent P, large umbilical, mid-tunnel hatch removal
33			Vent P, large umbilical, mid-tunnel hatch removal and translation through tunnel
34			Vent P, large umbilical, end hatch reach and access
35			Pressurized suit, tool harness w/o tools, mid-tunnel hatch removal
36			No Test
37			Pressurized suit, tool harness w/o tools, end hatch reach and access
38			No Test, I-suit moved to aft of plane
39	D-Suit	Daniel	Unpressurized suit, no gloves or helmet, clean, mid-tunnel hatch removal and translation through tunnel
40			Unpressurized suit, no gloves or helmet, clean, end hatch reach and access
41			Unpressurized suit, no gloves or helmet, clean, end hatch reach and access
42			Unpressurized suit, no gloves or helmet, clean, translation through tunnel and flip
43			Unpressurized suit, no gloves or helmet, clean, translation through tunnel and flip
44			Unpressurized suit, no gloves or helmet, large umbilical, end hatch reach and access
45			Unpressurized suit, no gloves or helmet, large umbilical, mid-tunnel hatch removal and translation through tunnel
46			Unpressurized suit, no gloves or helmet, large umbilical, mid-tunnel hatch removal and translation through tunnel
47			Unpressurized suit, no gloves or helmet, large umbilical, translation through tunnel and flip

Appendix C: Test Equipment Data Package

CTSD-ADV-634
JSC 65552

TEST EQUIPMENT DATA PACKAGE

for the
C-9 Facility Space Suit and CEV Hatch Test

Prepared by:

Drew Manning EC/ESC

Jessica Vos/EC5 and Amy Ross/EC5

Crew and Thermal Systems Division

March 12, 2007

TABLE OF CONTENTS

SYNOPSIS

Advanced space suit system functional mobility in conjunction with the current CEV side-hatch and LIDS tunnel design will be evaluated in a reduced gravity environment during a series of flights aboard the C-9 Reduced Gravity Aircraft. Two advanced space suits (I-suit and either the MK III or the REI-suit) will be used to assess the possible impacts of the Constellation Program's planned and possible EVA scenarios on the Suit Element's current suit configuration. In particular this test will investigate suit compatibility with the anticipated CEV architecture with regards to suit donning/doffing and translation through the CEV side hatch and the LIDS tunnel. The data obtained from this test will be used to support the EVA Systems Project's analysis tools and provide input to the design requirement of the new suit system as a result of the CEV architecture.

TEST OBJECTIVES

The overall objectives for the “C-9 Space Suit and CEV Hatch Evaluation” are as follows:

1. 0-G CEV Side Hatch ingress/egress - suited subjects will demonstrate egress and ingress through a simulated CEV hatch. Test variables will include:
    a. Rear-entry vs Waist-entry configurations (Mark III suit versus I-suit)
    b. CEV hatch size (2-3 configurations)
    c. Tool harness and tool configuration
2. 0-G suit donning/doffing - provide input into suit architecture feasibility study by understanding the ease/difficulty of and techniques for 0-G suit donning and doffing in the anticipated volume available in the CEV. These tests will not be pressurized.
    a. Rear-entry vs Waist-entry configurations (Mark III suit versus I-suit)
    b. Solo donning versus assisted donning (1 or 2 person assist)
    c. Simultaneous donning of two suits in CEV volume with six person complement
    d. Simultaneous donning of two suits with 4 person complement (Lunar-g)
3. 0-G LIDS Tunnel operations - further investigate the capabilities of a suited crewmember to perform a LIDS tunnel translation and mechanism manipulation, including the hatch actuation
    a. Rear-entry vs Waist-entry configurations (Mark III suit versus I-suit)
    b. Pressurized suit versus unpressurized suit.
4. Tool harness evaluation - suited subjects (I-suit only) will evaluate use of the new design for the EVA tool harness.
    a. Tool harness configuration and mobility
    b. Tool retrieval and stowage
    c. BRT operations

TEST DESCRIPTION

The test will be conducted over a 4-day period with one 60 parabola flight per day, conditions allowing. All parabolas during the flights will be 0-G except for Flight Day 3, which has Lunar simulated gravity parabolas also. Table 1 shows the breakdown of the parabolas per flight day**.

TABLE 1: PARABOLA REQUIREMENTS

FLIGHT DAY 1

# of parabolas per activity (in order – 60 total)	Gravity (Lunar, Martian, or Zero)	Suit/Subject	Hatch Configuration	Activity
15	0-g	Mk III (TBD1)	Baseline Hatch	Hatch ingress/egress - subjects will begin with a full compliment of tools on the tool harness. Tool configuration will be varied to evaluate impact on hatch ingress/egress.
LEVEL FLIGHT	Swap out hatch mockup			
15	0-g	Mk III (TBD1)	Hatch 2	Hatch ingress/egress - subjects will begin with a full compliment of tools on the tool harness. Tool configuration will be varied to evaluate impact on hatch ingress/egress.
LEVEL FLIGHT	Swap out hatch mockups and suits – extra time may be needed			
15	0-g	I-suit (TBD2)	Baseline Hatch	Hatch ingress/egress - subjects will begin with a full compliment of tools on the tool harness. Tool configuration will be varied to evaluate impact on hatch ingress/egress.
LEVEL FLIGHT	Swap out hatch mockup			
15	0-g	I-suit (TBD2)	Hatch 2	Hatch ingress/egress - subjects will begin with a full compliment of tools on the tool harness. Tool configuration will be varied to evaluate impact on hatch ingress/egress.

FLIGHT DAY 2

# of parabolas per activity (in order – 60 total)	Gravity (Lunar, Martian, or Zero)	Suit/Subject	Hatch Configuration	Activity
15	0-g	Mk III (TBD2)	Baseline Hatch	Hatch ingress/egress - subjects will begin with a full compliment of tools on the tool harness. Tool configuration will be varied to evaluate impact on hatch ingress/egress.
LEVEL FLIGHT	Swap out hatch mockup			
15	0-g	Mk III (TBD2)	Hatch 2	Hatch ingress/egress - subjects will begin with a full compliment of tools on the tool harness. Tool configuration will be varied to evaluate impact on hatch ingress/egress.
LEVEL FLIGHT	Swap out hatch mockups and suits – extra time may be needed			
15	0-g	I-suit (TBD1)	Baseline Hatch	Hatch ingress/egress - subjects will begin with a full compliment of tools on the tool harness. Tool configuration will be varied to evaluate impact on hatch ingress/egress.
LEVEL FLIGHT	Swap out hatch mockup			
15	0-g	I-suit (TBD1)	Hatch 2	Hatch ingress/egress - subjects will begin with a full compliment of tools on the tool harness. Tool configuration will be varied to evaluate impact on hatch ingress/egress.

FLIGHT DAY 3 – Suit Donning/Doffing

# of parabolas per activity (in order – 60 total)	Gravity (Lunar, Martian, or Zero)	Suit/Subject	Activity
10	0-g	Mark III suit	Solo donning/doffing
10	0-g	Mark III suit	Assisted donning/doffing (1 person)
10	0-g	I-suit	Solo donning/doffing
10	0-g	I-suit	Assisted donning/doffing (1 person)
10	0-g	I-suit and either the Mark III, REI-suit or D-suit	2 suit donning/doffing, assisted (6 person)
10	Lunar-g	Mark III and I-suit	2 suit donning/doffing, assisted (4 person)

FLIGHT DAY 4 – LIDS operations and Tool Harness evaluation

# of parabolas per activity (in order – 60 total)	**Gravity (Lunar, Martian, or Zero)**	**Suit/Subject**	**Activity**
6	0-g	Mark III unpressurized	LIDS hatch access
6	0-g	Mark III pressurized	LIDS hatch access
6	0-g	D-suit unpressurized	LIDS hatch access
6	0-g	I-suit unpressurized	LIDS hatch access
6	0-g	I-suit pressurized	LIDS hatch access
30	0-g	I-suit	Tool Harness evaluation • Handrail installation • Translation along handrails • Tool removal from harness (tethering) • Tool stowage onto harness • Attach BRT to handrail • Tool removal from harness (tethering) • Tool stowage onto harness • Release BRT • Handrail removal

***NOTE: Table 1 is a reflection of our desired plan for each of the 60 parabolas, however we are flexible and willing to work around the requirements of the C-9 aircraft and personnel for the best arrangement of gravity levels, turnarounds, and other activities.*

The primary test activities will involve a single suited test subject performing repeated iterations of the tasks being evaluated (i.e. egress/ingress CEV Hatch, suit donning/doffing, etc.) with support personnel providing direction and collecting feedback on the actions performed.

All pressurized testing will be conducted at a suit operating pressure of 4 psig. Two suit technicians spot the suited subject and manage the suit umbilical. A third suit technician is responsible for monitoring and managing the breathing air supply, communication, and liquid cooling system. A suit engineer is also present for each active suited subject to ensure the safety of the subject.

TEST HARDWARE DESCRIPTION

Mark III Advanced Space Suit Technology Demonstrator

The Mark III Suit represents a hybrid space suit configuration in that it is composed of hard elements such as a hard upper torso and hard brief section and of soft components such as the fabric elbows and knees. Another feature of the suit is its use of bearings at mobility joints. The Mark III has bearings at the shoulder, upper arm, waist, upper hip, mid-hip, upper leg (3 bearing hip), and ankle joints. The suit is entered through a hatch on the backside of the hard upper torso (rear-entry suit). Suit subjects are integrated to the suit by a waist belt weight relief system and shoulder straps. The Mark III suit weighs approximately 120 pounds.

I-Suit

The I-Suit is a soft suit and represents a compromise between a hard/hybrid suit and an all soft suit like the Apollo A7LB Suit. The I-Suit incorporates a limited number of bearings at the shoulder, upper arm, upper hip, and upper leg (2 bearing hip) joints. The suit also has a body seal closure and a rigid frame for backpack integration. The I-Suit weighs 64 pounds.

Rear-entry I-Suit

The REI-Suit is designed to be a partial-gravity walking suit. However, in contrast to the Mark III, the I-Suit utilizes a soft upper torso and soft hip and brief elements. The REI-Suit incorporates a limited number of bearings which are located at the shoulder, upper arm, upper hip, and upper leg (2-bearing hip) joints. The boots of the I-Suit consist of the lower portion of an off-the-shelf work boot and a patterned convolute ankle joint. The size 11 boot incorporates straps at the instep that can be adjusted to anchor the feet with the boot. The soft upper torso of the I-Suit was modified to incorporate a rear-entry system. The soft upper torso, on the suit-side of the system, incorporated metal structure. Mating hardware on the hatch-side of the system interfaced with the suit via a two hinges and a locking mechanism. The hatch hardware outlined the shape of the hatch. The majority of the hatch was constructed from softgoods to minimize the weight impact of a hatch. The REI-Suit also retained the body seal closure. The REI-Suit weighs 84 lbs.

D-Suit

The D-Suit represents an soft suit configuration. The D-Suit does incorporate a body seal closure ring and upper arm bearings, but all other components and mobility joints are fabricated of soft goods. Pulley/cable and sliding cables systems are used at the shoulder and waist/hip joints to supplement patterned soft goods joints. The D-Suit weighs 26 pounds.

Mark III Donning Stand

The Mark III donning stand supports and secures the Mark III suit in an upright attitude during suit don and doff. The subject may also rest in the stand during nominal aircraft flight periods. The stand is a tube structure and is bolted to the floor of the plane.

CEV Hatch Mockup

A simulated CEV wall with hatch opening will be created for the hatch egress/ingress portion of the evaluation. The design for the mockup is still in work, but will be reviewed with the RGO for their input and will be presented at the TRR.

LIDS Tunnel and Hatch Mockup

A simulated LIDS tunnel and hatch will be created for the hatch egress/ingress portion of the evaluation. The design for the mockup is still in work, but will be reviewed with the RGO for their input and will be presented at the TRR.

Umbilicals Mockup

Two volumetric mockups of the new umbilical design concepts will be used to increase the fidelity of the egress and ingress operations performed by the suited crewmembers. The mockups will be incorporate simulations of the hoses for oxygen and water as well as electrical conductors for power, data and comm. The water and oxygen hoses will be Teflon with Kynar braid and the power, data and comm cables will be bundles of 6, 12 and 14 conductors with Teflon braid covering. The connectors will be fabricated from SLA resin, aluminum or stainless steel. The umbilical mockups will be about 10 feet long to allow for evaluation of their impacts to ingress and egress. These mockups will be non-functional and will not replace the suit support umbilical.

Tool Harness

A mockup of the new EVA tool harness will be used during this evaluation to assess the impact of the tool harness and anticipated tool complement on egress/ingress by suited crewmembers. We will also perform an assessment of tool usage operations with regard to the tool harness design. The tool harness will be constructed from a off the shelf parachute harness with retractable tethers, bayonet receptacles and O, D and V rings sewn onto it. A selection of EVA tools will be flown for use during these evaluations. A list of the specific tools will be provided to the RGO in advance of the test.

Space Suit Support Hardware

The hardware required to support the suited subject will be provided by the CTSD and will include:

K-Bottles of breathing air; manifold support for 6 bottles total

Breathing air pressurization system; provides 6 acfm minimum

Breathing air and cooling water umbilical

Liquid Cooling Garment water cooling system

Communication system

EVA Handrails

We will make an attempt to borrow handrails from the EVA tools group that have previously flown on the KC-135 and the C-9 to conduct a simple “ease of use” evaluation. However, this is dependant upon the availability of the hardware and is currently unknown.

STRUCTURAL LOADS ANALYSIS

The MK III donning stand has previously been approved to and have flown on the KC-135 Reduced Gravity Aircraft. All new mockups and hardware will have a structural analysis completed as part of their design and development. This information will be provided the RGO and Test Safety as soon as it is complete. **Refer to Tables 3 and 4 below.**

ELECTRICAL LOADS ANALYSIS

110 V, 4 amps, AC for suit support, 2 amp per suit.

PRESSURE VESSEL CERTIFICATION

None required for this evaluation.

IN-FLIGHT TEST PROCEDURES

See Attachment 1, “Test Procedures”.

PARABOLA REQUIREMENTS

For our 4 planned flights, we desire to perform the above stated suit mobility evaluations in 0G simulated gravity environment with the exception of approximately 10 parabolas of Lunar G on flight day 3. **Refer to Table 1** for an outline of each parabola activity/gravity level. All suits except the MK III must be donned during level flight, and can be completed within the normal (5 min) turn around time. However, on Flight Day 1 and 2, we’ll need extra turn around time (per the table) to allow time for both a suit doff and a suit don (10-15mins).

TEST SUPPORT REQUIREMENTS

Cargo straps, 4-bottle K-bottle rack and 2-bottle K-bottle rack (for a total capacity of 6 K-bottles per flight), fasteners, comm. headsets, Test Directors, Aircraft personnel, photographers, aircraft power supply to cooling pump.

DATA AQUISITION SYSTEM

No data acquisition required for this evaluation.

TEST OPERATIONS LIMITATIONS

No operating limits or restrictions have been identified.

PROPOSED MANIFEST

The names of test personnel manifested to fly each day will be delivered Flight Day 1 plus two weeks. The boarding orders list and personnel assignments list for each flight will be delivered Flight Day 1 plus one week. Test personnel will be selected from the list below:

TABLE 2: Test Team for Suit Mobility Evaluations (subject to change)

C-9 Flight Day 1 Manifest List		**C-9 Flight Day 2 Manifest List**	
TC:	Amy Ross	**TC:**	Amy Ross
Subjects:		**Subjects:**	
Prime MK III	Michael Gernhardt	Prime MK III	TBD – Crew Member
Back up MK III	TBD	Back up MK III	TBD
Prime I-Suit	TBD – Crew Member	Prime I-Suit	TBD – Crew Member
Back up I-Suit	Brian Daniel	Back up I-Suit	TBD
Technicians:	Kevin Groneman Edward Ehlers John Harris	**Technicians:**	Kevin Groneman Edward Ehlers John Harris
Suit Engineers:	Jessica Vos Barbara Janoiko Lindsay Aitchison Dustin Gohmert Jayleen Guttromson	**Suit Engineers:**	Jessica Vos Barbara Janoiko Lindsay Aitchison Dustin Gohmert Jayleen Guttromson
Others:	Drew Manning Nicole Jordan Felix Soto Toro (sound guy) Richard Watson Eric Falconi	**Others:**	Drew Manning Nicole Jordan Richard Watson Eric Falconi

C-9 Flight Day 3 Manifest List		**C-9 Flight Day 4 Manifest List**	
TC:	Amy Ross	**TC:**	Amy Ross
Subjects:		**Subjects:**	
Prime MK III	TBD	Prime MK III	TBD
Back up MK III	TBD	Back up MK III	TBD
Prime I-Suit	TBD	Prime I-Suit	TBD
Back up I-Suit	TBD	Back up I-Suit	TBD
		Prime D-suit	TBD
		Back D-suit	TBD
Technicians:	Kevin Groneman	**Technicians:**	Kevin Groneman
	Edward Ehlers		Edward Ehlers
	John Harris		John Harris
Suit Engineers:	Jessica Vos	**Suit Engineers:**	Jessica Vos
	Barbara Janoiko		Barbara Janoiko
	Lindsay Aitchison		Lindsay Aitchison
	Dustin Gohmert		Dustin Gohmert
	Jayleen Guttromson		Jayleen Guttromson
Others:	Drew Manning	**Others:**	Drew Manning
	Richard Watson		Jessica Nelson
	Eric Falconi		Joe Gensler

Proposed Personnel Manifest

Test Conductor (CTSD)	1
Test Subject(s)	2 (back ups will be addn'l suit engineers or test team folks)
Suit Technicians	3
Suit/Test Engineers	5 (with some serving as subjects on FD3 & 4)
Others	5
Photographer (FCOD)	3 on flight days 1 and 2, 2 on days 3 and 4
Flight Surgeon	1
TOTAL	**20**

PHOTOGRAPHIC NEEDS

1 Photographer with a digital camera and 2 Videographers with handheld video cameras with wide angle lenses will be required. Products will be four DVDs of video footage, four CDs of selected digital pictures, selected digital pictures posted on the Imagery Online website, and 8" x 10" prints of selected views.

HAZARD ANALYSIS

TABLE 3: Applicable HA documents

Document Title	Document Number	Revision Date
Hazard Analysis for Class III SSA, ORLAN-DMA/M-HL/DL, Mark III Space Suit and Ancillary Support Equipment	JSC 33069 FEMU-G-504	Rev D May 2005
Hazard Analysis for Prototype Suit Suits: I-Suit and D-Suit	JSC 39205 CTSD-ADV-356	Rev D June 2006
Hazard Analysis for Mark III Space Suit Communication System	FEMU-G-521	

The only change to previously flown hardware will be the use of a new communications system for the suits. This new hardware will be tested a reviewed with the RGO in preparation for use onboard the airraft.

The hardware that has not been flown previously (CEV Hatch mockup, LIDS tunnel mockup, tool harness) will all be reviewed with RGO and Test Safety in advance of the test and applicable hazards identified and controlled. A Hazard Analysis will be prepared for each piece of equipment still in development and will be delivered when it is complete.

SAFETY CERTIFICATION

Safety inspection of the test hardware and interface plates will take place prior to the flight.

OTHER APPLICABLE DOCUMENTS

- **EC5 Internal TRR package – includes comm. loop diagram and test hardware layout schematic**

TABLE 4: Applicable Suit Operation, Stress Analysis, and Emergency Documents

Document Title	Document Number	Revision Date
Test Equipment Data Package: C-9 Facility Space Suit Testing Evaluation	JSC 65656 CTSD-ADV-xxx	Baseline October 2006
Checkout Procedures for Mark III Space Suit Used in 1-G and KC-135 Reduced Gravity Aircraft Evaluations	JSC 33497	Rev A June 2003
Stress Analysis – Zero Gravity Ops for P/N 300 (Donning Stand)	N/A	Initial November 1988
Interface Control Document NASA 932 C-9B	AOD33912	Rev A August 2005
Test Equipment Data Package Requirements and Guidelines NASA JSC RGO	AOD 33896	Rev B PCN 1 August 2005
JSC Reduced Gravity Program User's Guide	AOD 33899	Rev A PCN 1 August 2005

ATTACHMENT 1: TEST PROCEDURES

Pre-flight:

Lab:

- Size suit and verify test readiness
- Bag and deliver to RGO subject preference items (TCUs, socks, etc.)

C-9:

- Perform any required safety inspections
- Load suit(s)
- Load K-bottle rack/K-bottles
- Load suit support equipment:
  - Mark III donning stand (only on day Mark III flies)
  - LCG cooler
  - Pressurization system
  - Communication system
  - Umbilical
- Load simulated CEV wall and hatch (Flight Days 1 and 2)
- Load and secure for takeoff LIDS mockup (Flight day 4)
- Load EVA handrails (Flight Day 4)
- Pre-flight briefing

In-Flight:

- Assemble simulated CEV wall and hatch (Flight Days 1 and 2)
- Unstow/ prep LIDS mockup (Flight Day 4)
- All test personnel don comm. units
- Subject dons suit during flight to test area (except for Mark III, which is donned during parabolas)
- Subject performs activities outlined per Table 1 (walking, kneeling, lopeing, handrail translation, etc.).
- Photographers document motions with digital camera and video at test conductor’s direction
- Subject performs specific motions at test conductor’s direction
- Test conductor, Suit Engineers, and other Test Support Personnel record subject comments and ratings on their data tables
- Following completion of parabolas, secure rock panels with straps and doff/secure suit

Post-Flight:

- Unload used K-bottles
- Unload suit
- Unload suit support equipment (including Mark III donning stand when applicable)
- Debrief

Post Test Series:

- Unload K-bottle rack
- Unload all suit hardware, support equipment, tools, etc.
- Return cargo straps, K-bottle rack, fasteners, etc. to the RGO.

CTSD-ADV-634
JSC 65552

Addendum to the Test Equipment Data Package for the C-9 Facility Space Suit and CEV Hatch Test

This addendum covers the addition of the ACES suit to flight day 3. This hardware has been flown previously on the C-9.

Advanced Crew Escape Suit (ACES)**
The Shuttle ACES is manufactured by the David Clark Company. It's is a full-pressure suit assembly that consists of a coverall assembly, gloves, helmet, communications carrier, thermal underwear, liquid cooling garment (LCG), bubble helmet, an anti-gravity suit, and boots. The outer layer of the suit is flame retardant Nomex and the inner bladder is constructed from one layer of Gortex. The gloves must be connected to the suit in order to provide the pressurization (3.5 psid). The ACES improves upon the mobility of the Launch/entry Suit (LES) originally used by the Shuttle program and provides vent flow to the torso, hands, and thighs, which was not available in the LES. The total ACES suit weight with all crew escape equipment is 91.0 lbs.

This suit will not be pressurized during the evaluations.

Advanced Crew Escape Suit (ACES)