

Hybrid Space Suit Simulator (HS3): Development, Characterization, Construction, and Usage

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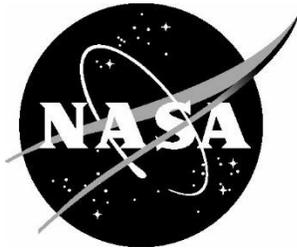
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Acronyms and Abbreviations

%bWt	Percent Body Weight
1G	Normal gravity near the surface of Earth (1G = 32.2 ft/sec ²)
3DPT	3D Printed
ABS	Acrylonitrile Butadiene Styrene
AED	Automated External Defibrillator
APACHE	Assessments of Physiology and Cognition in Hybrid-reality Environments
ARGOS	Active Response Gravity Offload System
BLS	Basic Life Support
BOM	Bill of Materials
CAD	Computer Aided Drawings
CG	Center of Gravity
CO ₂	Carbon Dioxide
ConOps	Concept of Operations
COTS	Commercial Off The Shelf
CPU	Central Processing Unit
CSRM	Crew State and Risk Model
DC	Direct Current
DCU	Display and Control Unit
DOF	Degree-of-Freedom
DSST	Digit Symbol Substitution Task
DTP	Detailed Test Procedure
EEPL	EVA and Environmental Physiology Laboratory
EMU	Extravehicular Mobility Unit
EVA	Extravehicular Activity
EXCON	The EXploration CONops (EXCON) Mockup Suit
F&T	Fatigue and Traverse
FOV	Field of View
FQD	Fluid Quick Disconnect
H-3PO	Human Physiology, Performance, Protection & Operations
HC	Hard Capture
HEPA	High Efficiency Particulate Air
HH&P	Human Health and Performance
HNW	Hydration, Nutrition, & Waste Management
HR	Heart Rate
HRM	Heart Rate Monitoring
HRmax	Maximum Heart Rate
HRP	Human Research Program
HS3	Hybrid Space Suit Simulator
HUT	Hard Upper Torso
IMU	Inertial Measurement Unit
ISS	International Space Station
JETT	Joint-EHP Test Team
JSC	Johnson Space Center
LA	Left Arm

LCG	Liquid Cooling Garment
LEO	Low Earth Orbit
LL	Left Leg
LMM	Linear Mixed-effects Modeling
MCO	Mars Campaign Office
MKIII	Mark III Space Suit
MR	Metabolic Rate
MSK	Musculoskeletal
MST	Mean Skin Temperature
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory
NZGL	NASA Zero Gravity Lever
PACES	Physical and Cognitive Exploration Simulations
PET	Phase-Elapsed Time
PiCO ₂	Partial Pressure of Inspired Carbon Dioxide
PLA	Polylactic Acid
PLSS	Portable Life Support System
POGO	Partial Gravity Simulator
PPE	Personal Protective Equipment
PVT	Psychomotor Vigilance Task
QD	Quick Disconnect
RA	Right Arm
RL	Right Leg
ROM	Range of Motion
RPE	Rating of Perceived Exertion
RTG	Radioisotope Thermoelectric Generator
SC	Soft Capture
TCL	Test Checklist
TCU	Thermal Comfort Undergarments
TLX	Task Load Index
VCO ₂	Volume of Carbon Dioxide (Carbon Dioxide Production)
VO ₂	Volume of Oxygen (Oxygen Consumption)
VR	Virtual Reality
xEMU	Exploration Extravehicular Mobility Unit

1 Executive Summary

As NASA prepares for human exploration missions beyond low Earth orbit, including to the Moon and Mars, addressing critical Human Health and Performance (HH&P) risks associated with surface extravehicular activity (EVA) is essential. The goals of some EVA studies may not require high-fidelity, pressurized space suits in gravity offloaded and/or neutrally buoyant environments but rather can be effectively conducted in space suit simulators in analog environments. As access to pressurized space suits is often limited and costly, the NASA EVA and Environmental Physiology Laboratory (EEPL) developed the Hybrid Space Suit Simulator (HS3), a modular, low-cost, unpressurized space suit simulator designed to support a wide range of EVA research objectives. HS3 enables consistent, quantifiable simulation fidelity while significantly reducing logistical and financial overhead for EVA analog research and testing.

HS3 was designed to be a modular system, allowing for components and/or subsystems to be added or removed based on the goals of specific studies or tests. HS3 consists of seven major subsystems:

1. Hard Upper Torso (HUT) with visor
2. Mock portable life support system (PLSS) with waist offload and thermal control system
3. Electrical system that supplies and manage power
4. Soft goods system with a soft suit and gloves
5. Peripheral systems including communication, range of motion (ROM) ancillary equipment, camera, boots, safety harness, etc.
6. Modular sensor system
7. Donning stand to simulate space suit donning/doffing

The HS3 was designed and developed in an iterative fashion with the final version, HS3 2.5, being detailed in this report. We also describe a human-in-the-loop test series with physiologic and performance data as well as HS3 system capability data as a reference for the performance envelope of the HS3. In addition, full details of HS3 assembly instructions as well as user guidelines are provided.

This report provides a comprehensive overview of the design, development, and construction of the HS3 to enable research use of the HS3. In addition, this report highlights characterization studies of the HS3, demonstrating its ability to be a customizable, modular research tool equipped with integrated physiological sensors. HS3 is a critical tool for advancing EVA-related research by enabling targeted studies that address knowledge gaps including objectives related to physical and cognitive performance during simulated EVA tasks.

2 Introduction

As the National Aeronautics and Space Administration (NASA) transitions to exploration missions beyond low Earth orbit (LEO), a plethora of Human Health and Performance (HH&P) risks and knowledge gaps must be addressed to ensure safe and successful execution of extravehicular activities (EVA) during missions to the Moon and Mars [1]. Some studies, such as those focused on understanding injury mechanisms in the suit, require access to high-fidelity, pressurized space suits and/or mockups; however, many EVA objectives related to HH&P do not necessarily require a full pressurized and/or gravity-offloaded space suit. Examples of these types of studies may include developing and testing novel EVA informatics and decision support systems, biomedical monitoring systems, and assessment of physical and cognitive responses to EVA tasks, timelines and training. Additionally, access to NASA space suits and/or mockup space suits can be limited and costly. Thus, the NASA EVA and Environmental Physiology Laboratory (EEPL) developed the Hybrid Space Suit Simulator (HS3). **The primary goal of the HS3 project was to create a low-cost, unpressurized space suit simulator for use as an EVA research tool with modular capabilities to provide physical and cognitive workload approximations as required by specific study aims during EVA simulations.** A space suit simulator like HS3 significantly simplifies and reduces overhead for EVA analog testing while providing consistent, quantifiable simulation quality and fidelity. **This report describes the design, development and characterization of the HS3 during simulated EVA as a modular, customizable research tool with integrated human physiological sensors to address human health and performance EVA knowledge and technology gaps.**

2.1 Background: Suit Simulators

Space suit simulators are not a new concept and have been used as early as exploration EVA development during Apollo training [2, 3, 4]. Training and research activities for microgravity EVA have been heavily fine-tuned and characterized throughout the Shuttle and International Space Station (ISS) eras; however, exploration-based EVA tasks and simulations are relatively infantile as new space suits, tools, and concepts are just now being developed and characterized for the Artemis program. NASA has a multitude of exploration-based EVA analogs such as the Neutral Buoyancy Laboratory (NBL), the Active Response Gravity Offload System (ARGOS), and various field-testing environments. The NBL and ARGOS facilities provide high-fidelity gravity-offloaded, pressurized suited testing and training environments that will be required for crew to be successful in future exploration-based mission objectives; however, exploration-based EVA training tasks and concepts are actively and continually being defined and developed, initial testing does not always require high-fidelity analogs. Historically, during Apollo-based exploration development, rock yard and field-based training exercises were frequently utilized including volumetric and weighted mock-ups of suit components.

Space suit simulation tools and mock-ups can be categorized into five main categories with increasing cost and complexity [5, 6, 7, 8, 9], ranging from unsuited analogs (shirt-sleeve environments), limited interface (using a limited number of components for simulating specific suit aspects), representational simulation (using visually representative garments to provide immersion during an EVA), unpressurized full-spectrum simulation (may have various suit functions like ventilation or mobility restriction), and full-fidelity pressurized space suits (Figure 2-1).



Figure 2-1. Examples of Space Suit Simulators Used in Human Spaceflight.

(a) Unsuiting EVA analog testing used in the Assessments of Physiology and Cognition in Hybrid-reality Environments (APACHE) facility [6]. (b) Limited interface suit simulator used by Apollo crew to conduct geological training (source: NASA). (c) Representational suit simulator used during public affair events (source: NASA). (d) Unpressurized full-spectrum simulator (Atlas Devices) as ergonomic capabilities simulator of the NASA’s xEMU suit [8]. (e) Fully pressurized suit (Z-2.5) used in the NASA neutral buoyancy laboratory (NBL) for crew training [9].

Focusing on unpressurized full-spectrum suit simulators, there is increasing growth in the usage of EVA analog testing environments through field applications, virtual reality simulations, and controlled lab settings. These analog testing environments provide opportunities to address HH&P and human factors questions or knowledge gaps related to EVA. Additionally, the use of space suit analogs provides workloads more representative of EVA tasks. Each of these unpressurized full-spectrum suit mock-ups provide different applicable lower fidelity workloads through specific focused attributes from the suits. For example, the Exploration ConOps (EXCON) space suit mock-up (based on the exploration extravehicular mobility unit, xEMU) is a higher quality volumetric suit simulation tool that emulates the feel of being in a restricted suit assembly by including rotational bearings and volumetric constraints [8]. Current space suit simulation tools, however, lack key suit capabilities from realistic range of motion (ROM) attributes to cooling loop assemblies that are critical to characterizing exploration EVA workload approximations. Thus, the HS3 project aimed to address the gaps in current analog suit simulators with the development requirements listed below to allow for the modularity in suit applicable assemblies based on study-specific goals.



Figure 2-2. Unpressurized full spectrum suit simulators used in research analog studies. Mock-ups include NASA MK III mockups, vendor volumetric mockups, and academic analog research suits [10]. These suit simulation tools focus primarily on volumetric attributes of the suit including weight components.

HS3 Development Requirements:

- Shall provide suit-like experience and immersion during EVA.
- Shall be modular and reconfigurable based on study specific research objectives.
- Shall provide physical and cognitive workload approximation profiles of exploration EVA.
- Shall be lightweight (backpack-like, less than 40 lbs for loaded weight on hips).
- Shall be capable of recreating various planetary space suit volumetric, field of view (FOV), and similar constraints.
- Shall be able to be donned or doffed in ~20 mins or less.
- Shall include provisions for thermal management.
- Shall have low manufacturing costs.
- Shall have low maintenance overhead (rapid prototype/3D-Print/commercially available items) that allows easy suit maintenance and swapping of hardware.
- Shall provide the following safety measures:
 - Head, elbow, hand, knee pads
 - Fall restraint or positioning devices, as needed (e.g., for virtual reality/treadmill usage)
- Shall accommodate a wide range of anthropometry (target 1st to 99th percentiles) while providing consistent FOV and ROM simulations with consistent results.
- Shall provide helmet ventilation airflow.
- Shall have easy-to-align fasteners, connectors, or mating system for donning/doffing; and allow for self as well as single operator assisted don/doffing.
- Shall provide fast off-nominal doffing (i.e., breaks, emergencies, etc.) to allow airway and chest access in less than 4 minutes for emergency purposes.
- Shall have integrated communications system with wireless connectivity.

- Shall be compatible/configurable to allow for concurrent use of a wearable metabolic system (e.g., COSMED or similar metabolic masks; COSMED masks shall not hinder head/neck mobility).
- Shall be able to integrate with virtual reality headsets.
- Should provide mounting locations for helmet/visor lights as applicable.
- Should provide a camera mount for first-person view.
- Shall support EVA informatics and biosensor technologies, as applicable.
- Shall provide a minimum simulation duration of at least 6 hours continuously.
- Shall support hydration, nutrition, & waste management (HNW) measures.
- Should provide cable management and organization within mock Portable Life Support System (PLSS) enclosure.
- Shall be able to easily implement COSMED mounting/secure COSMED to PLSS and protection from sand/dust.
- Shall have easy access option to PLSS internal hardware for performing hot swaps and troubleshooting.
- Should consolidate power to single power bank.

2.2 Use Cases and Application for Research and Training

As space suit simulators are key tools used in human physiological EVA research, hardware evaluation, EVA training, and generation of mission concepts of operations (ConOps) development, selection of an appropriate suit simulator based on the test goals is critical. Example use cases of HS3 are shown in Section 9.9. NASA has traditionally used volumetric suit simulators in field testing environments to increase the fidelity in generating ConOps. For example, the Joint EHP Test Team (JETT) field test series currently utilizes the volumetric EXCON suit, which uses a backpack hip offloading configuration, to simulate bearing positions and suit interactions during simulated exploration EVA operations in 1G field test environments [11].

The HS3 system has been designed to add various modular components along with volumetric suit applications to enable more realistic EVA-like workloads during analog testing with a lower overall system weight (and thus lower injury risks). A large gap in field-based suit simulators are suit components such as PLSS and thermal control systems which are included in the HS3 design modularity. The HS3 also incorporates biomedical sensors and instrumentation for EVA research studies. In addition, HS3 can be used to test new EVA prototype technologies (e.g., informatics systems) for iterative design updates prior to high-fidelity pressurized suited testing. This enables a lower cost and faster approach by only implementing testing in full fidelity pressurized suited environments once technologies have been tested and improved in lower-fidelity suit simulators. With HS3 being a 3D printed (3DPT) modular system, engineers can test the functionality and ergonomics of a design concept at a lower cost than designing a pressurized system that may not be efficient. Additionally, HS3 can simulate EVA-relevant physical and cognitive workloads in a variety of EVA analog environments including virtual reality (VR), sandbox (lunar simulation), and planetary analogs (rock yard). Assessing performance in various environments can identify trends to be expected during exploration EVAs and assess HH&P implications.

HS3 could also be implemented for EVA training and increasing crew experience with the mobility and workload challenges of surface EVAs. For example, the loaded body weight experienced in the HS3 is similar to what would be expected in pressurized space suits. In addition

to physical workload, HS3 simulates cognitive workload by allowing the crew/subject to practice performing specific tasks, like navigating or operating tools, to prepare for EVAs. When monitoring cognitive workload in HS3, researchers have the opportunity to develop and refine procedures for various EVA tasks, like communication, navigation and emergency responses based on performance with the ultimate intent of reducing crew cognitive demand. Exploration EVA simulated tool usage, task completion, and HS3 suit interactions have been assessed in 1G environments and could also be used for training purposes [12].

Overall, as a modular EVA simulation and research tool, HS3 can be used in custom configurations to meet specific test objectives for exploration EVA tests and studies.

3 HS3 Design

3.1 HS3 System Overview

This section will detail the design of the HS3 version 2.5 and its subsystems. The design evolution of HS3 versions 1.0 through 2.5 is shown in Section 3.2. HS3 consists of seven major subsystems comprised of multiple components:

1. **Hard Upper Torso (HUT)** – HUT and helmet/visor.
2. **Mock portable life support system (PLSS)** – PLSS, spine, waist belt, thermal control system (ventilation, and cooling systems, i.e., bladder & cooling loop.)
3. **Electrical** – Power bank, LCG pump motor speed controller, switches, cables, etc.
4. **Soft Goods** – Soft suit, HUT arm canvas covers, and glove/gauntlet systems.
5. **Peripheral** – Liquid Cooling Garment (LCG) garment only, communication, range of motion (ROM) ancillary equipment, camera, boots, safety harness, Thermal Comfort Undergarment (TCU), treadmill adaptation (i.e., safety harness), lighting, etc.
6. **Sensors** – A modular system for integrating sensors into HS3 on a per-test basis.
7. **Donning stand** – an adjustable, rollable stand with hard capture (HC) and soft capture (SC) mechanisms.

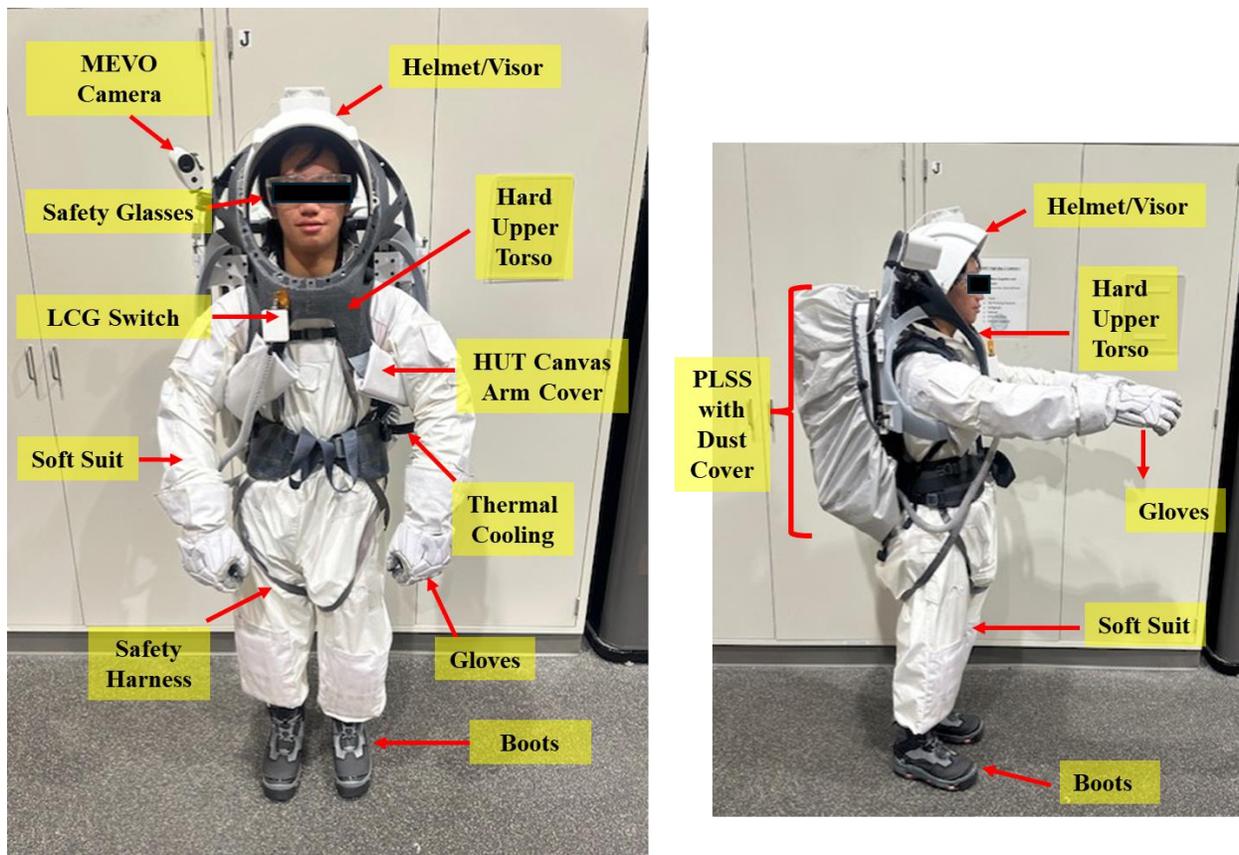


Figure 3-1. HS3 System Overview

The HUT is the portion of HS3 that encloses the upper torso of the body (Figure 3-2). It provides the 3D printed (3DPT) structural mounting interface for the PLSS, helmet/visor, and camera assembly. The mounting interface includes the spine and hip offloading waist strap, similar to a hiking backpack. See Section 4.2 for design details.

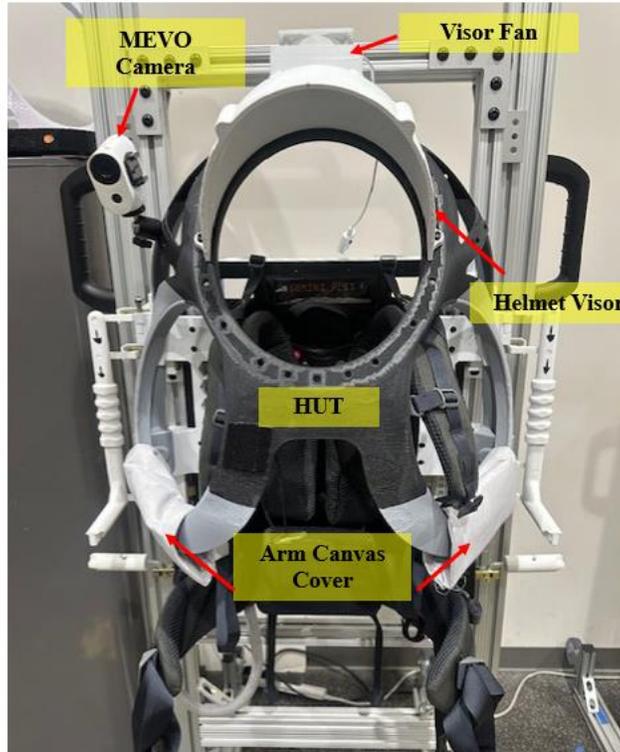


Figure 3-2. HS3 HUT

The PLSS structure couples to the subject via a mounted back-packing spine, shoulder straps, and waist belt assembly. Attached to the PLSS are two rail systems that allow for HUT mounting and adjustable vertical sizing. The PLSS provides the housing for electrical and thermal cooling systems (Figure 3-3). Power for the HS3 is provided by a single battery bank and required for helmet ventilation system (helmet fan), thermal control system (water pump), and various bioinformatics. The thermal control system provides cooling to the subject via a single water pump, bladder, and full-body liquid cooling garment (LCG). The LCG is comprised of an outer layer of stretchy Nylon fabric with embedded tubing allowing water from the bladder to circulate around the subject to enable thermal control during operations. Connections between the LCG and PLSS interface are two quick disconnect (QD) connection points. The LCG cooling system is designed to be used with either a mobile LCG bladder OR a surface supply umbilical. See Section 4.1 for design details.

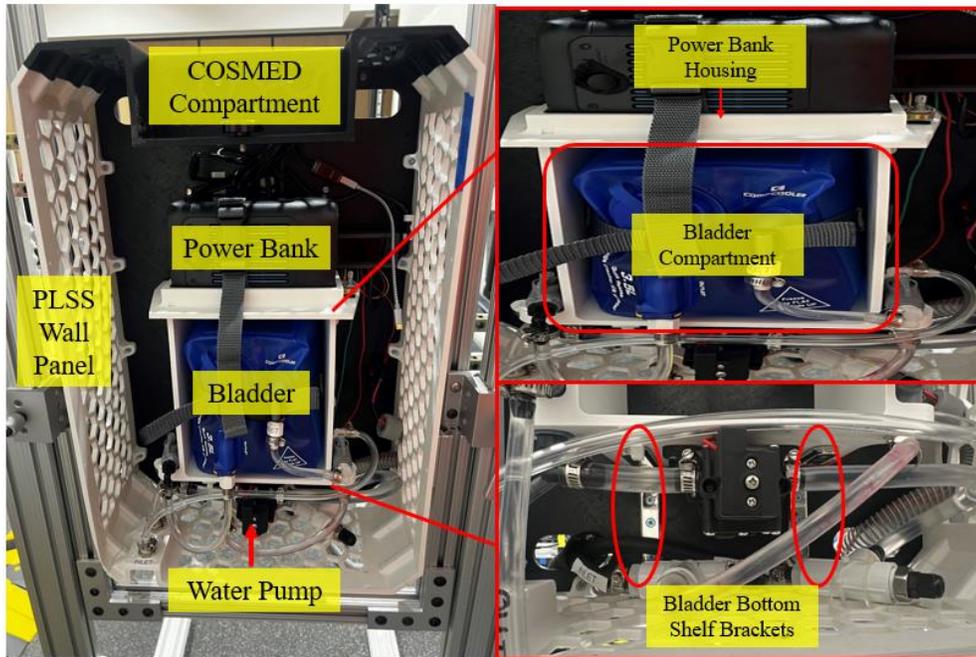


Figure 3-3. HS3 PLSS Components

HS3 has peripheral systems to enhance the simulation experience such as LCG, communication, ROM ancillary equipment, camera, boots, safety harness, TCU (which is made of a COTS athletic base layer) (Figure 3-5), treadmill adaptation (i.e., safety harness), lighting, and bioinformatic sensors. The LCG provides thermal cooling to the subject's body. The communication system can vary per user discretion, but wireless bone conduction headphones have been found to work the best to provide two-way voice interface while performing tasks. HUT mounts for camera access and lighting options enable study specific camera assembly usage which can provide real-time video coverage from the subject's point of view during operations. The PLSS power bank provides flexible powering connections, and the soft suit/PLSS has multiple sensor attachment points for easy integration of additional sensors. See section 4.4 for design details.

Although HS3 is not a pressurized system, ROM ancillary equipment is used to simulate suit-like motion limitations that may be experienced during exploration EVA. ROM ancillary equipment consists of elbow and knee braces, as well as a waist inhibitor. Refer to Figure 3-4 for this layer (2). The elbow and knee braces are used for restriction of motion for the extremities as a simulation of the Extravehicular Mobility Unit (EMU) pressurization. The waist inhibitor and crotch pad assembly are used for creating suit-like restriction motion of the hips and legs. The waist inhibitor limits the subject's ability to bend at the waist while the crotch pad keeps the legs separated during ambulation, similar to the lower torso assembly in exploration space suits. When using ROM ancillary equipment, the subject is expected to experience difficulty executing tasks such as bending extremities, kneeling, and walking. The outer layer of the HS3 consists of a soft suit which provides additional suit-like ROM restrictions, keeps all ancillary equipment in place, and provides an immersive feel of environmental isolation. The soft suit has interfaces with the thermal control system, HS3 gloves, and boots. The thermal control system is accessed via soft suit LCG access ports where the LCG QDs connect to the PLSS. The HS3 gloves are connected via interference fit with removeable 3DPT wrist rings and gauntlets attached to the soft suit arms.

The HS3 boots are hiking boots that provide volume and weight similar to EMU boots. The boots also provide leg and ankle ROM restrictions during kneeling and ambulation. Various sizes are available for all HS3 modular systems to accommodate subject's differing physical anthropometry. See Section 4.4 for design details.

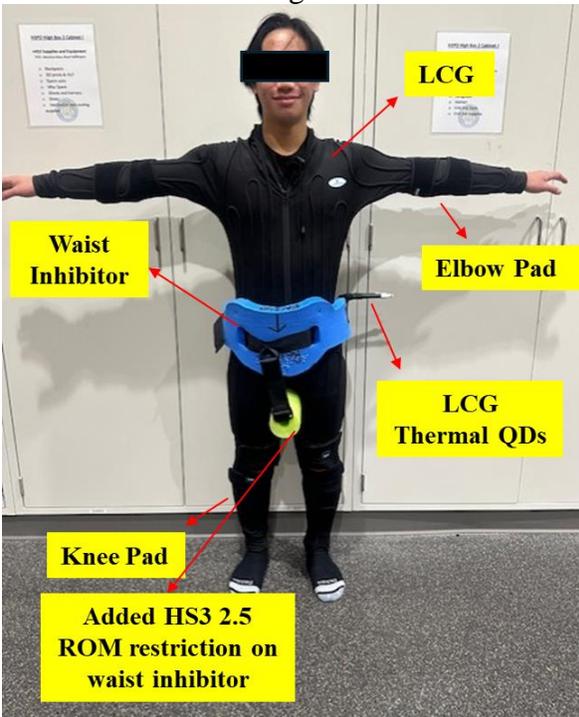


Figure 3-4. HS3 Layer 2



Figure 3-5. Layer 3 – HS3 Under Thermal Comfort Undergarment (TCU) Layer

Note: Orange blocks in the image shows the location of IMU sensor system, which is optional, and it is part of the Sensors System.

3.2 HS3 Development – Design Process and Evolution

This section provides a high-level overview of the HS3 design evolution. The actual performance comparison across different versions of HS3 is detailed in Section 6.3. Through rigorous testing in the Assessments of Physiology and Cognition in Hybrid-reality Environments (APACHE) facility [6] with HS3-focused studies and/or engineering runs, HS3 design has evolved from version 1.0 to 2.5 based on **subjective feedback from subjects with pressurized suited experience, as well as objective measurements**. Subjects were polled on shirtsleeve vs. suit likeness across various HS3 suit systems using a 10-point subjective scale (see suited experience survey, Section 6.1.2.2) with 0 indicating HS3 being shirtsleeve like and 10 indicating HS3 being pressurized suit like. **The overarching goals of the design evolution are captured below:**

- (1) Minimize subject injury and/or discomfort,
- (2) Enhance EVA simulation quality and fidelity, and
- (3) Simplify overhead cost by using a simple design for operation and manufacturing

The 2.5 version is the current state-of-the-art and is the final design detailed in this report. Figure 3-6 highlights the design evolution from HS3 1.0, to 2.0, to the final 2.5 version as an unpressurized 1G suit simulator. Major sub-systems are labeled across the image for reference and comparison.

3.2.1 HS3 1.0 (2021-2023)

The HS3 1.0 design was the first released version in 2023, and it was designed based on the requirements outlined in Section 2.1. The 1.0 design was evaluated during multiple engineering runs as well as the “HS3 Characterization Study” (~2 hr simulated EVA) with n=8 subjects who had previous pressurized suit experience [12]. All subjects completed the study and provided critical feedback as listed below. See Figure 3-6 for HS3 1.0 design.

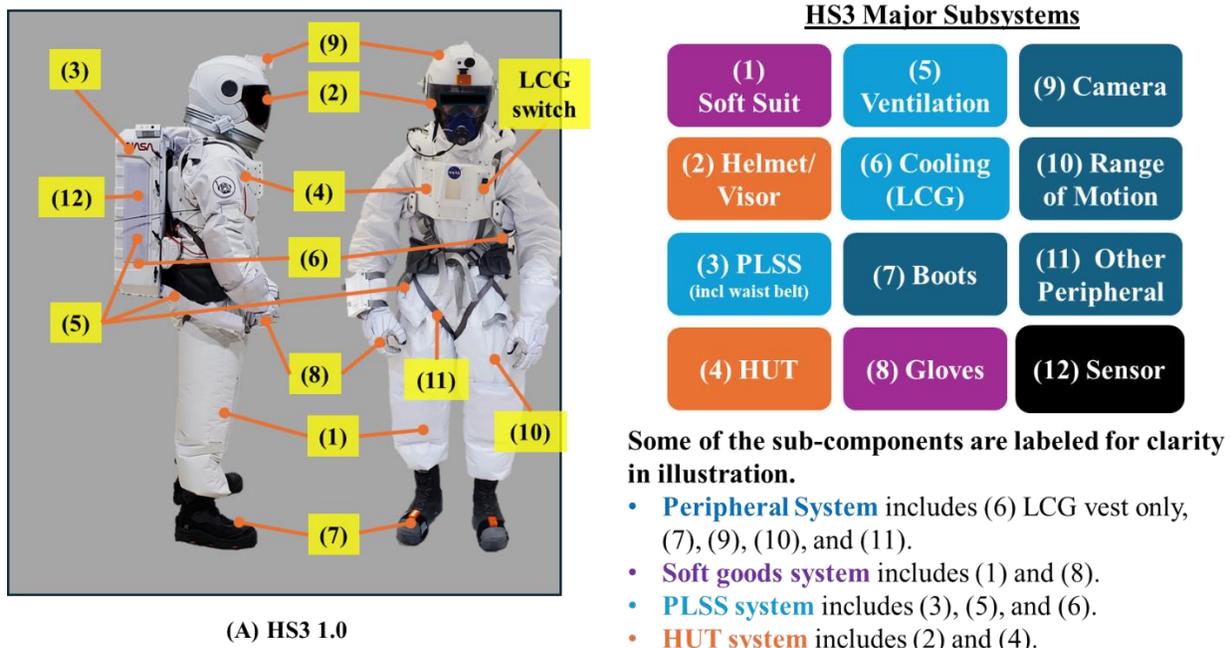


Figure 3-6. HS3 1.0 Design Features.

- **Key Design Features and Feedback during 1.0 Design Evaluation**
 - **Soft Goods** – Included soft suit, glove, HUT canvas cover, and ventilation covers.
 - **Design:**
 - Soft suit was made of a lightweight Nylon Ripstop fabric with waterproof canvas reinforcement around joint areas to restrict ROM.
 - Soft suit had knee and elbow pockets that allow insertion of padding which create ROM restrictions and knee/elbow support during EVA when subject is kneeling or crawling.
 - The soft suit was not a closed loop system (i.e. air leaked out from suit). It creates a barrier layer from external environment which enables a relatively isolated thermal environment for ventilation and cooling, and a physical and mental EVA immersion space for subjects.

- QD access ports for ventilation and LCG inputs were integrated into the soft suit.
 - Bulky modified lacrosse gloves with cotton liner glove inserts reduced finger dexterity and attached to soft suit via 3DPT quick release wrist rings for easy suit-like don/doff.
 - **Feedback:** Subjects reported the gloves provided good immersion but asked for more bulk to increase dexterity restriction. Subjects also reported soft suit provided good EVA simulated immersion. Operators reported access ports on the soft suit are very useful for ventilation/cooling system operation.
- **PLSS (Figure 3-8)** – Included the electrical (battery, sensors, and cables), waist offload (spine and waist belt), ventilation, and cooling systems.
 - **Design:**
 - PLSS was a hard structure that housed the ventilation system and coolant feed water. The PLSS was attached to a backpacking spine for hip offloading.
 - PLSS was powered by 3 isolated batteries, and the electrical connections were scattered through the entire PLSS space.
 - PLSS cover used a modified tote box with magnetic ventilation screen attached. The PLSS backplate used a flat plastic board.
 - The ventilation system provided airflow for cooling (4 body ports, with 2 on arms, 2 on legs) and defogging of the helmet visor (1 port).
 - Ventilation was driven by a 12V DC fan blower that was mounted inside the PLSS and provided 30L/min of airflow to each ventilation path.
 - Ventilation airflow was pulled through a filter on the outside of the PLSS into a secondary High Efficiency Particulate Air (HEPA) filter mounted on the PLSS frame coupled to the fan blower.
 - Cooling was achieved by using a Commercial Off the Shelf (COTS) liquid cooling garment.
 - A half body vest option was used in 1.0. Two pass-throughs for the inlet and outlet LCG ports coupled via two QD fittings with poppet shut-off when released.
 - The LCG was charged (i.e. frozen overnight) via a 3L feedwater bladder that was secured in the PLSS. The pump was fixed near the feedwater to allow flow from the PLSS to the LCG. A LCG on-off control switch was placed on the HUT shoulder strap which allowed either subject or operator to control the LCG on-off state.
 - DI water is used in the cooling loop to minimize build-up of residue in the pump system.
 - **Feedback:** Operators preferred a centralized electrical system with better cable management and protection against LCG bag condensation/leak. Subjects reported HS3 1.0 was slightly warmer than Exploration Extravehicular Mobility Unit (xEMU) and would like to have stronger

cooling options and/or an umbilical/surface supply option. The LCG cooling is short lived, requiring replenishment at least once per hour. Operators preferred a redesigned PLSS shell and backplate for easier PLSS access, better stability, and easier 3DPT processes. An Infinadeck adapter was also needed for omnidirectional treadmill operations in HS3.

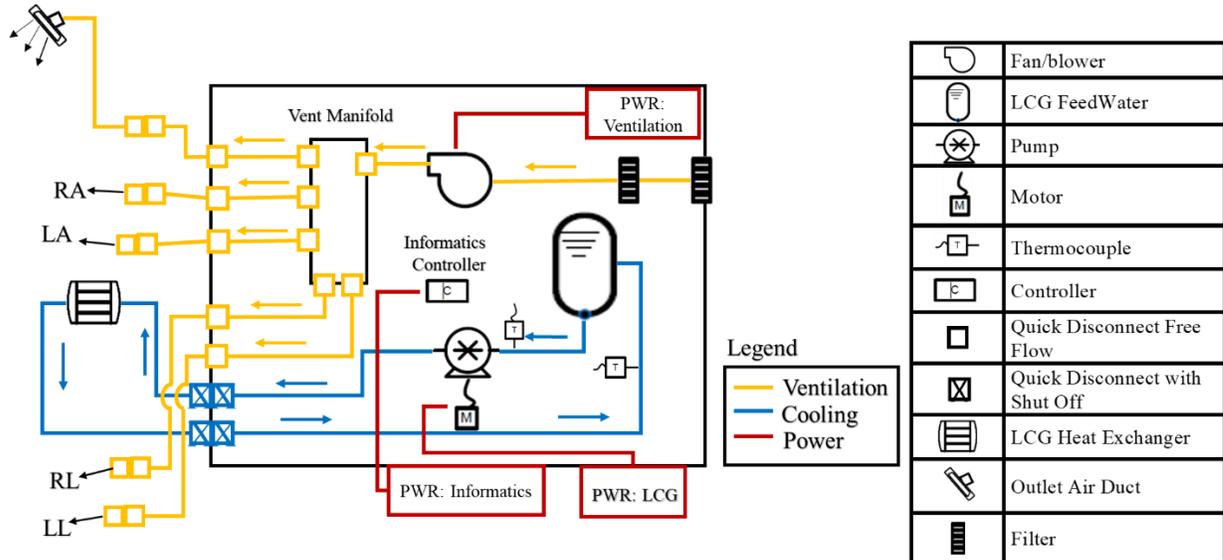


Figure 3-7. The HS3 1.0 PLSS Schematic.

The HS3 1.0 suit is not an enclosed system but allows for air flow via the ventilation loop (Yellow). The air flows into the PLSS via a filter opening. The circulation path feeds into a secondary HEPA filter pulled via COTS fan blower. The outlet of the fan is fed into a ventilation manifold splitting into five paths that fed into the soft suit garment via quick disconnects (QDs) with open flow for the head, right arm (RA), left arm (LA), right leg (RL), and left leg (LL). The open flow feeds into the suit and exits the soft suit garment as it is not fully enclosed. The thermal cooling loop (blue) provides water cooling to the LCG. The LCG is fed via a single 3L feedwater bladder that is pre-cooled prior to donning. A pump pulls the water into the LCG via QDs with poppet with return into the bladder for constant flow that can be turned on or off. The PLSS power (Red) consists of two external COTS batteries that provide power to the ventilation fan blower and informatics controller. There is additional power source inside the PLSS for LCG control.

- **HUT** – Included HUT and helmet/visor.
 - **Design:**
 - A vest shape 3DPT Polylactic Acid (PLA) HUT design (composed of 6 pieces jointed by heat inserts and fasteners) was jointed with quick release pip-pins.
 - The back of the HUT coupled to the PLSS and a backpacking spine for waist offloading.
 - The helmet consisted of a modified COTS motorcycle helmet that was utilized for immersion of the EVA simulation. The helmet is not an enclosed system. A magnetic 3DPT neck ring (w/ quick

- release pins) coupled between the soft suit and the helmet for quick doff.
 - The helmet visor acted as eye protection during geology tasks.
 - **Feedback:** Subjects noted significant neck loading from helmet. Neck pain/loading is not suit like and can result in neck injury for longer EVA. The HUT needed better fit and comfort for small subjects. Subjects also noted the HUT and Helmet should allow neck rotation while keeping reduced FOV and ROM to best emulate suit-like immersion.
 - **Peripheral** – Included LCG garment, communication, ROM restrictor, camera, boots, safety harness, TCU, treadmill adaptation (i.e., safety harness), lighting, etc.
 - **Design:**
 - A COTS half-body LCG vest was equipped with a subject-controlled switch mounted to the front portion of the HUT.
 - COTS wireless earbuds were provided for communication.
 - A COTS camera (Mevo) was secured in a 3DPT housing and mounted on a pivot joint.
 - COTS flashlights could be mounted on the waist belt.
 - COTS hiking boots were used with a quick release for quick don/doff.
 - A TCU made of an athletic clothing base layer was worn under the LCG vest.
 - A easy-to-clean head buff was worn under helmet to keep sweat and hair out of the way.
 - COTS treadmill harness (made from high tenacity nylon, UIAA certified and rated to a minimum breaking strength of 17.8kN) was used with fireman knot to create a low-profile safety harness for positioning subjects on treadmill.
 - **Feedback:** Subjects preferred more cooling and a full body LCG with stronger cooling. Subjects indicated that HS3 1.0 was more shirtsleeve-like when considering freedom of motion in the arms/legs. Subjects recommended more large padding between legs/forearms and around the thigh to help limit ROM (e.g., hockey goalie). Subjects preferred less communication delay and better comm quality.
 - **Sensor** – Included all integrated sensors for HS3.
 - **Design:**
 - A COSMED metabolic mask was worn under the helmet with a COSMED K5 (COSMED USA) unit secured to PLSS via Velcro straps.
 - Thermal skin temperature sensors (iButtons) were worn on the skin for mean skin temperature calculations. These were powered internally at the sensor.
 - Resistive temperature detectors were used to collect LCG water inlet and outlet temperatures. These sensors were connected to a Raspberry Pi 3B+ and secured in the PLSS via Velcro.
 - **Feedback:** LCG sensor data became corrupted likely due to accidental cable disconnection from environment vibration and poor cable

management. Operators recommended better solution to secure COSMED unit on PLSS.

- **Donning stand for HS3 (Figure 3-9)**

- **Design**

- Donning/Doffing was conducted in a seated position for subject ease and safety.
- The donning stand used tightening handles and a sliding plate to adjust PLSS donning height to accommodate different subject heights.
- Subjects could not self-don/doff in this design, and it required two operators to perform don/doff.
- The PLSS interfaced with the donning stand via 4 pip-pins manually guided through holes on the PLSS mini-T frame structure.

- **Feedback:** Operators recommended updates to donning stand for improved adjustment of height for subjects. PLSS mounting positions were not conducive to self-donning and were difficult for operators to manage. PLSS mounting hole clearance and locations were difficult to control during manufacturing process.

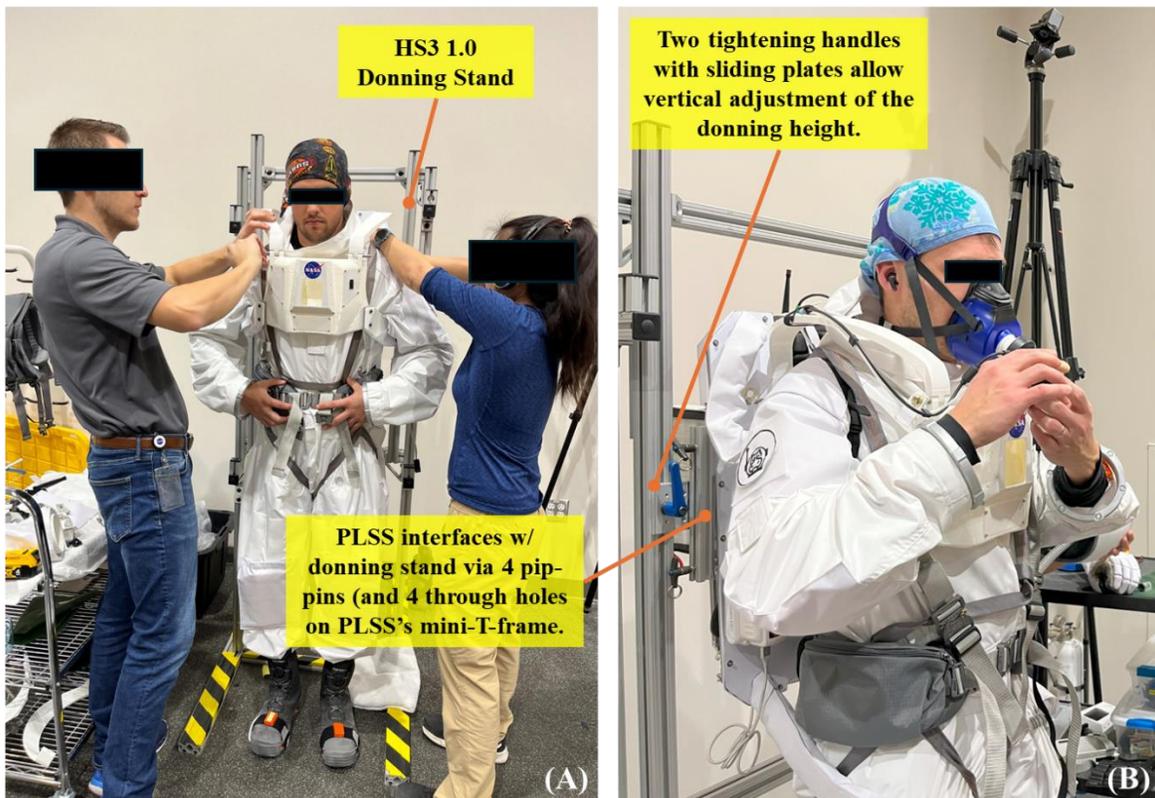


Figure 3-8. HS3 1.0 Donning Stand.

(A) Operators Assist Subject Donning, (B) Subject Doffing.

- **Summary of 1.0 Design Evaluation**
 - Subjects indicated that HS3 1.0 is a reasonable simulator in most simulation areas (scores averaged 4 to 6, out of 10, in suited experience survey, Section 6.1.2.2).
 - HS3 1.0 provides good simulation in overall physical workload/comfort. Subjects described the overall feel of HS3 1.0 is very similar to xEMU, but individual body part contributions are different in HS3 1.0. For example, it was noted that xEMU had more lower body workload and restrictions.
 - The applicability of HS3 1.0 for EVA simulation when compared to suited experience in other analogs:
 - Subjects noted no one analog will contribute 100% of EVA immersion, but HS3 is a step towards being more suit-like during 1G simulations.
 - Strongest simulation areas: thermal environment, visibility (field of view (FOV) restriction), and communication
 - Good simulation areas: Cognitive/physical workload, comfort, restricted dexterity, and EVA immersion
 - Weakest simulation areas: balance, ROM, and motion
 - Common hotspots/injury locations identified: Neck, Hip, Spine (based on subjective suited experience, the hip & neck loading is not suit-like).
- **Objective Suit Performance:**
 - Short average LCG hotswap time (1 hr), System weight (44 ± 2 lbs), ventilation (30 L/min), average system battery life (2 to 2.5 hrs), communication range (60-100’).

3.2.2 HS3 2.0 (2023-2025)

The HS3 2.0 design was the second iterated released version and was upgraded from HS3 1.0 based on subject and operator feedback listed in section 3.2.1. HS3 2.0 design was then evaluated in a shorter point validation HS3 configuration assessment study (“Config Study”). This assessment aimed to characterize changes in workload/subjective experience due to suit hardware upgrades between HS3 1.0 and 2.0 design iterations. The Config Study was conducted as a short point verification test series (n=3) including repeat subjects from the original 1.0 cohort using the same test protocol.

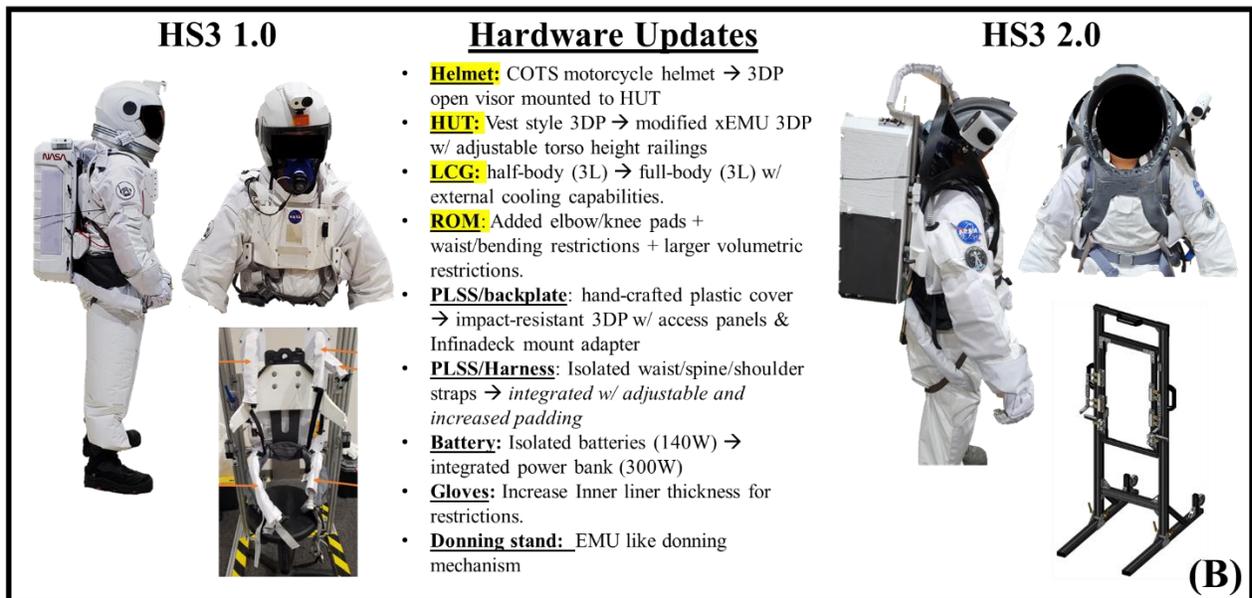
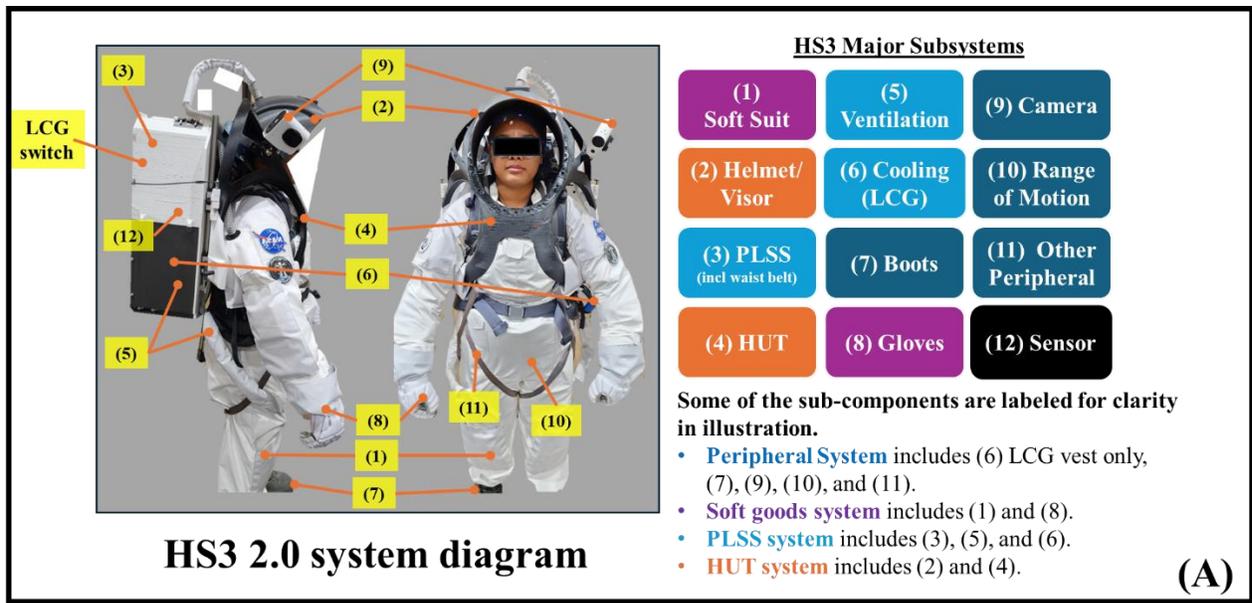


Figure 3-9. HS3 2.0 Design Update Summary.
 (A) HS3 2.0 System Design Diagram, (B) HS3 1.0 and 2.0 Design Update Summary: Yellow Highlighted Areas Indicate Key Updates from 1.0 to 2.0.

- **Key Design Update from HS3 1.0 to 2.0**
 A series of hardware augmentations were implemented into the updated HS3 2.0 based on experienced suited subject and crew feedback from the HS3 1.0 characterization study. Hardware updates are shown in Figure 3-9.
- **Helmet/HUT:** The Helmet and HUT interface design was modified from an independent helmet to an xEMU-like HUT design to reduce neck loading for subject comfort and more suit-like motion. The new HUT design features improved ROM and

FOV restriction by limiting head down motion, and increasing suit-like head rotation, and was coupled with more flexible vertical height adjustment (railing).

- **Feedback:** Subjects reported that neck pain and discomfort was relieved, and motion/FOV was more suit-like overall.
- **Range of Motion (ROM) (Figure 3-10):** The following items were added between the LCG suit and the soft suit layers: (1) Elbow and knee pads/wraps and (2) a waist inhibitor (to inhibitor bending motion).
 - **Feedback:** Subjects reported significant improvements in ROM restriction, making it more suit-like; however, subjects indicated that ROM restrictions between the thigh similar to a suit's lower torso assembly was still lacking.



Figure 3-10. HS3 2.0 and 2.5 Waist inhibitor Design Evolution
(A) HS3 2.0, (B) HS3 2.5 (included additional ROM restrictions between legs).

- **Soft Goods – Glove:** The 2.0 design maintains a two-layer glove configuration, but the inner liner thickness was increased by switching to a GORE-TEX liner.
 - **Feedback:** Subjects indicated the glove assembly provides great simulation. Overall, subject responses averaged a 7 out of 10 (0 = shirtsleeves and 10 = pressurized suit) for glove simulation. Further recommendations were given from crew subjects to add sew-on turtle skin on the palm for further reduction of dexterity to best emulate suit-like feeling.
- **PLSS:**
 - **Battery:** Switched from isolated batteries (140W) to an integrated power bank (300W). This modification centralizes the electrical system and provides improved electrical management.

- **Thermal:** Improved thermal cooling capability and increased duration between recharges by increasing the LCG bladder size from 1.5 L to 3 L. A full body LCG garment was implemented to replace the vest LCG. External cooling (surface supply) connections were also included in the 2.0 update.
 - **Feedback:** Subjects reported significant thermal comfort and cooling performance increase. The mean skin temperature (MST) measurements also show improvement in thermal regulation during high workload events (See Section 6.3 for data). The improved cooling loop redesign also improved the LCG longevity from needing a hot swap every 60 minutes to every 90 minutes or longer.
- **PLSS harness:** Switched from isolated waist/spine/shoulder straps to an integrated adjustable COTS waist/spine/shoulder combination with increased padding.
 - **Feedback:** Subjects reported significant comfort and functional improvement in ergonomic weight loading of HS3 system on the hip. This augmentation simplified strap operations and improved the center of gravity (CG) of the system.
- **PLSS structure:** Switched from hand-crafted plastic cover to impact-resistant 3DPT assemblies with access panels & Infinadeck mount adapter.
 - **Feedback:** Significantly improved the manufacturability of the PLSS. The new design also provided better loading and stability of the CG loading onto hip.
- **Donning stand:** Improved simulation fidelity with self-assisted donning
 - **Feedback:** Subjects were able to do self or assisted don/doff. Subjects and operators reported the design updates improved EVA simulation quality and donning/doffing processes. Operators reported that hard capture handles and interfaces to the PLSS structure were fragile and prone to breakage.
- **Summary of 2.0 Design Evaluation**

The 2025 HS3 Configuration Study showed significant improvements in HS3 2.0 performance and subjective suited experience compared to the HS3 1.0.

 - Physical workload was comparable between HS3 1.0 and 2.0. HS3 2.0 trended slightly higher, likely due to increased system weight (~ +10lb from 1.0 to 2.0); however, subjects reported the same or lower subjective fatigue despite increased weight, presumably due to better hip/spine/shoulder offloading.
 - Subjects reported better CG loading of the PLSS weight in 2.0.
 - Cognitive workload was comparable between HS3 1.0 and 2.0.
 - HS3 2.0 was more suit-like based on experienced suited subject surveys.
 - Thermal responses improved significantly for HS3 2.0 based on subject thermal comfort and objective skin temperature measures.

- The LCG bladder hot swap was recommended to occur every 60 to 90 minutes. This was improved from every 60 minutes in HS3 1.0.
- Mean skin temperature was also lower for majority of the EVA timeline.
- Subjects indicated at least 5 min/hour “offloading” (rest) break is needed for a 6-hr long EVA.

3.2.3 HS3 2.5 (2025)

The HS3 2.5 design is the final HS3 version that is released in this technical report, and it is upgraded from HS3 2.0 based on subject and operator feedback compiled from the HS3 2.0 Config Study detailed in Section 3.2.2. While the HS3 2.5 design was not evaluated formally in a standalone study, the physical and cognitive workload of version 2.5 is expected to be enveloped by HS3 1.0 and 2.0 performance bands due to the relatively benign nature of suit design updates. The minor modifications in HS3 2.5 were implemented to improve subject acceptability for longer EVA (up to 6 hr) and operation efficiency based on feedback received during testing of the HS3 2.0.

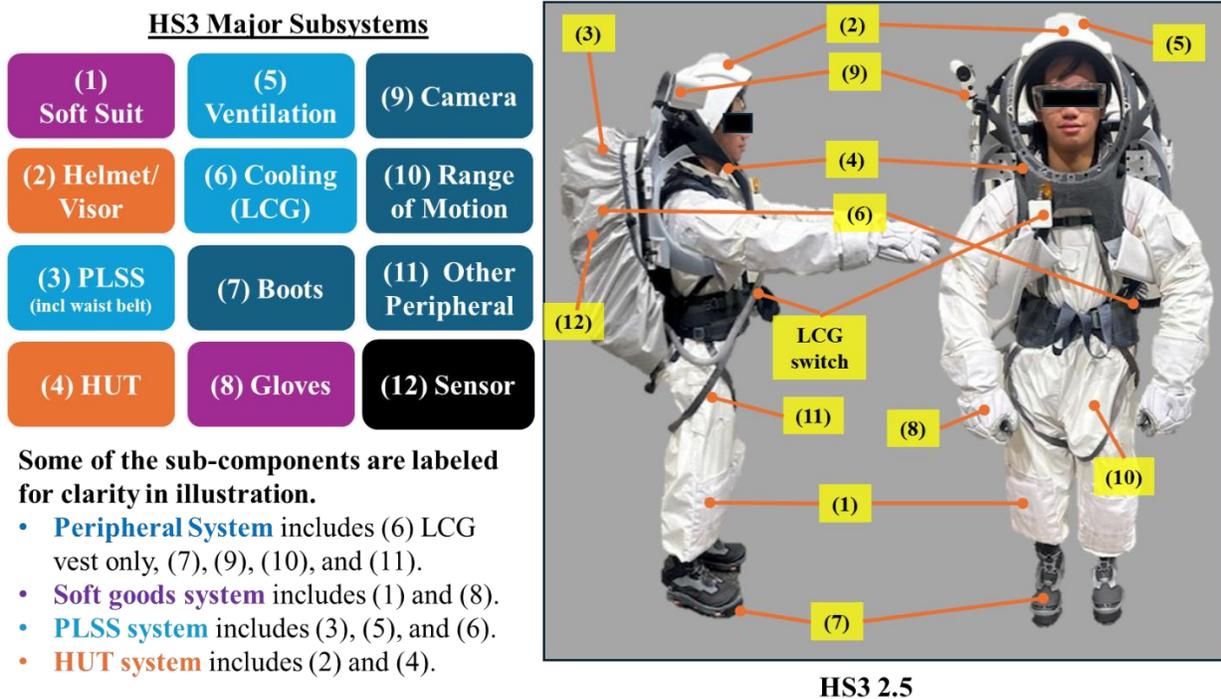


Figure 3-11. HS3 2.5 System Diagram.

- **Key Design Updates from HS3 2.0 to 2.5**
 - **Improved Suit Simulation Experience:**
 - Added ROM crotch pad assembly to the waist inhibitor to increase gait challenges during ambulation.
 - Moved LCG control switch from back (assisted operator control) to front (for subject control) with future ability to adapt into a display and control unit (DCU). (Note: HS3 1.0 LCG control was subject controlled, but 2.0 was operator controlled only since it is located in the PLSS.)
 - A bone conduction headset was incorporated for better communication.

- Added a dual camera adapter on the PLSS to allow integration for 2 cameras (for future face facing camera integration, if applicable to research study).
- Replace thermal comfort undergarments (TCU) with thinner equivalent to enhance cooling effectiveness.

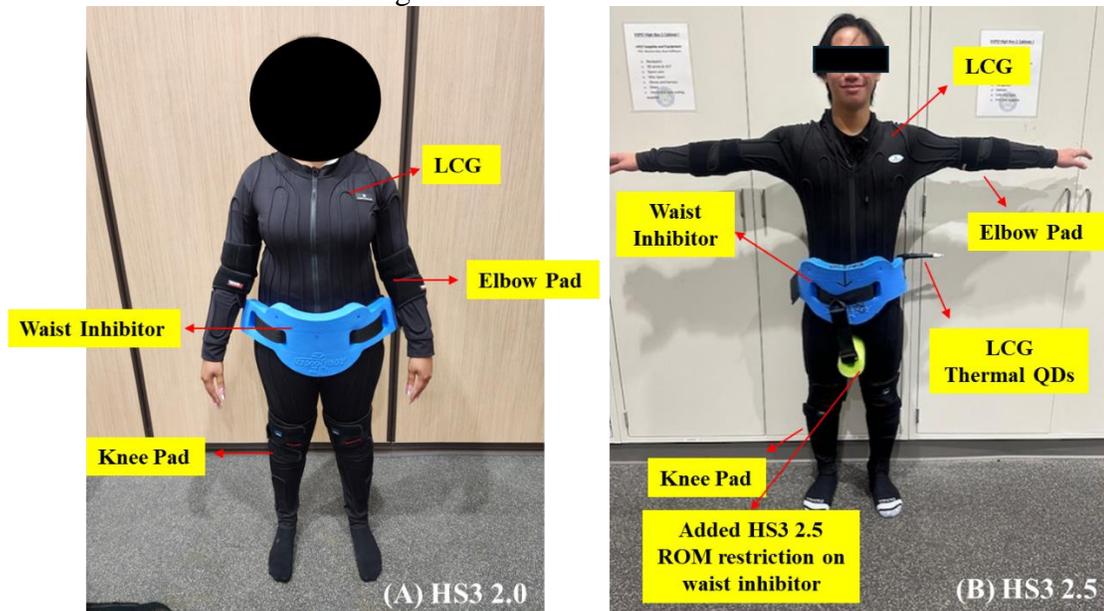


Figure 3-12. HS3 2.0 and 2.5 Waist inhibitor Design Evolution
(A) HS3 2.0, (B) HS3 2.5 (included additional ROM restrictions between legs).

- **Reduced system weight**

- HS3 was reduced from 55 lbs to no less than 45 lbs depending on modular configuration to reduce 1G analog suit injury risk, increase HS3 accessibility to wider subject anthropometry (smaller subjects), and extend HS3 usage duration while maintaining the physical workload envelope.
- Ventilation system was removed due to primary cooling of the full body LCG providing main thermal control. Head ventilation was retained using a small central processing unit (CPU) type fan to conserve weight.
- The solid PLSS wall (HS3 2.0) was replaced with honeycomb design to reduce overall weight and material.
- Mini aluminum T-frame for PLSS shelving support was replaced with light weight L-bracket mounted shelves.
- Weight was reduced by cutting excess HUT rail length.
- Reduced 3DPT infill from 100% to 20-25% for HUT (easier to print, similar structural integrity, and more cost efficient). This reduced the same print weight by 50% and reduced weight.
- Replaced dual LCG bladder (1.5L x 2) with a single 3.5L LCG bladder that takes less space and reduced plumbing connections (Figure 3-12). HS3 1.0 used a 3L bladders, HS3 2.0 used dual 1.5L bladders, and HS3 2.5 settled with a single 3.5L bladder for best weight vs. cooling efficiency and trade-off.
- Removed PLSS top access panel and hinges so PLSS components are more accessible from single direction.

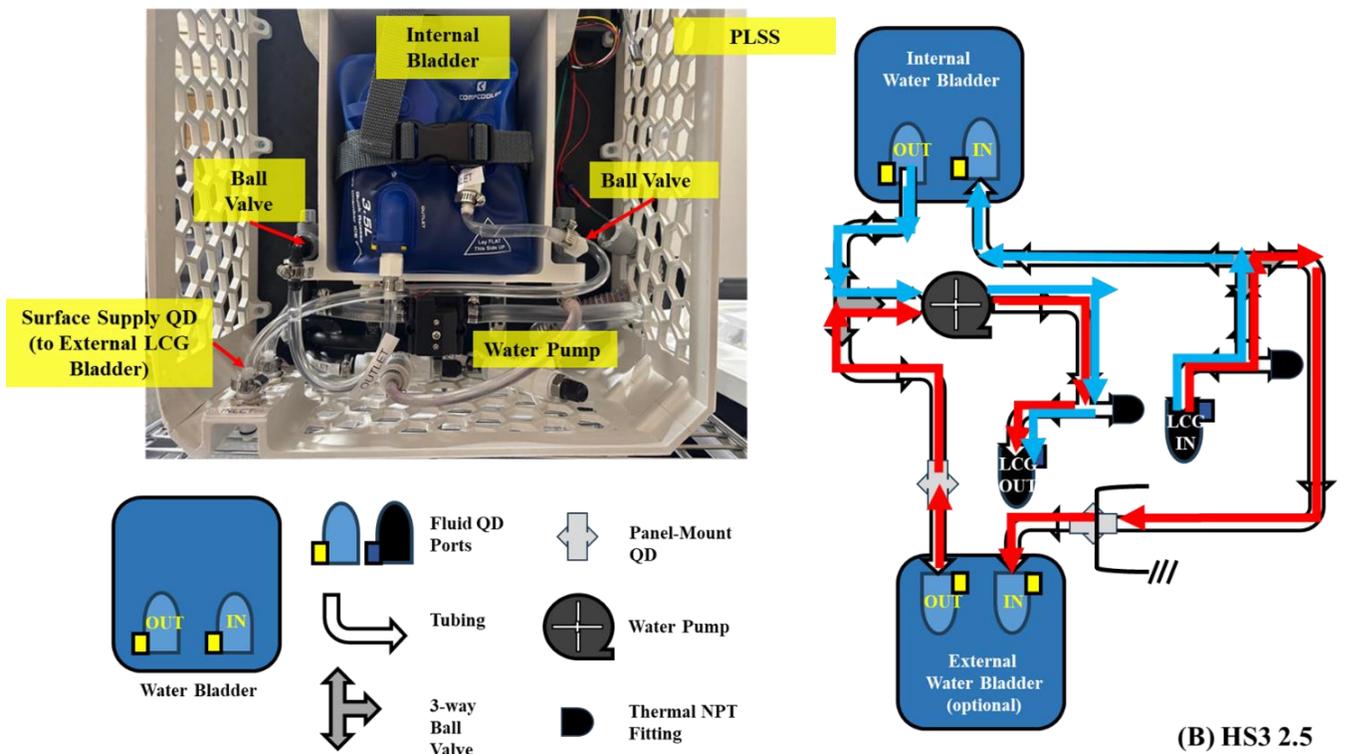
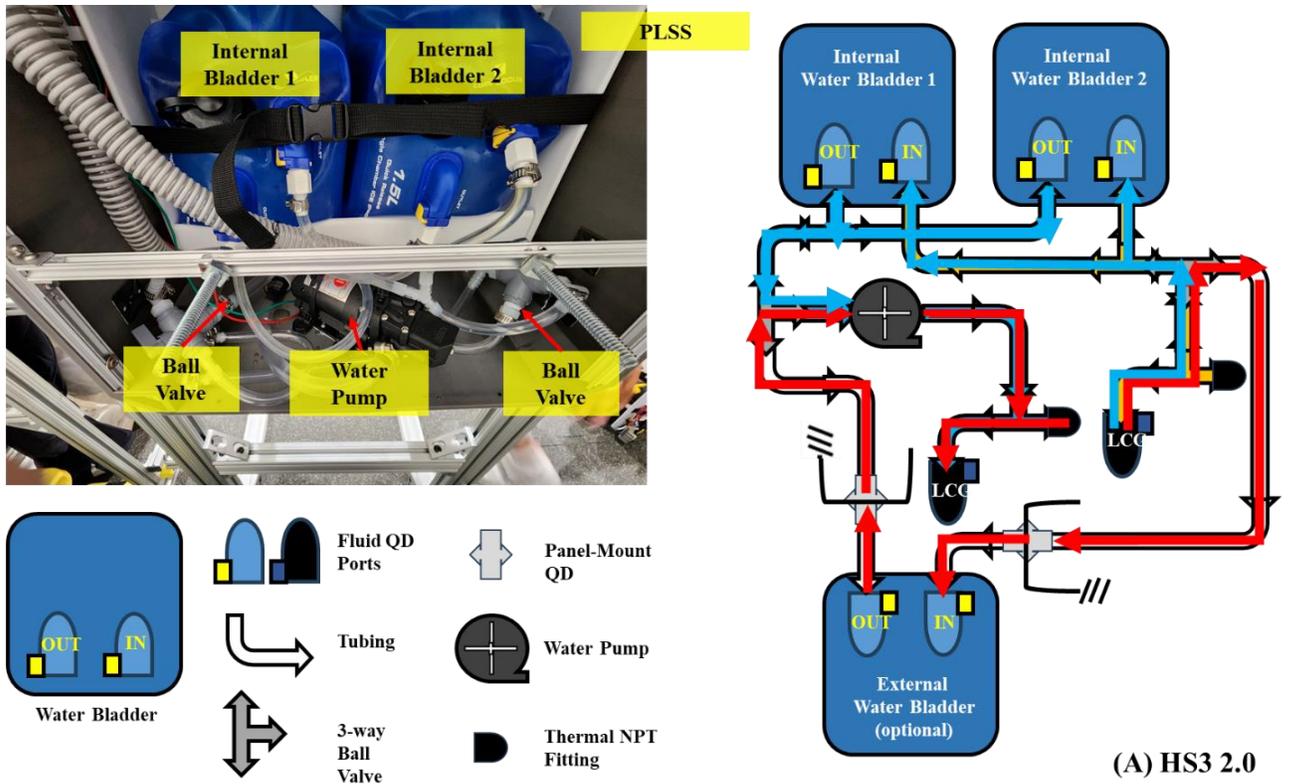


Figure 3-13. Cooling System Update from HS3 2.0 dual bladder design to HS3 2.5 single bladder design.

- **Summary of 2.5 Design Evaluation**

- During HS3 usage as part of an external study for the Crew State and Risk Model (CSRM) work in EEPL – the CSRM study engineering run subjects indicated that the waist inhibitor and crotch pad assembly provide intended function in “keeping the legs apart” while walking and thus added suit-like range of motion challenges during traverse tasks.
- Operators reported more efficient operation with new power bank location, donning stand handles, and front HUT detachable LCG switch.
- HS3 2.5 weight was reduced from 55 lb to approximately 45 lb.

4 Construction of HS3 2.5

This section outlines the design details, construction, manufacturing, and assembly of the HS3 version 2.5.

4.1 HUT System

This section documents the design, construction, and assembly of the HS3 2.5 mock HUT structure including interfaces, carriage rail struts, pip pin mounts, visor, and ventilation fan assemblies (BOM #H-1 to #H-27).

4.1.1 Design details

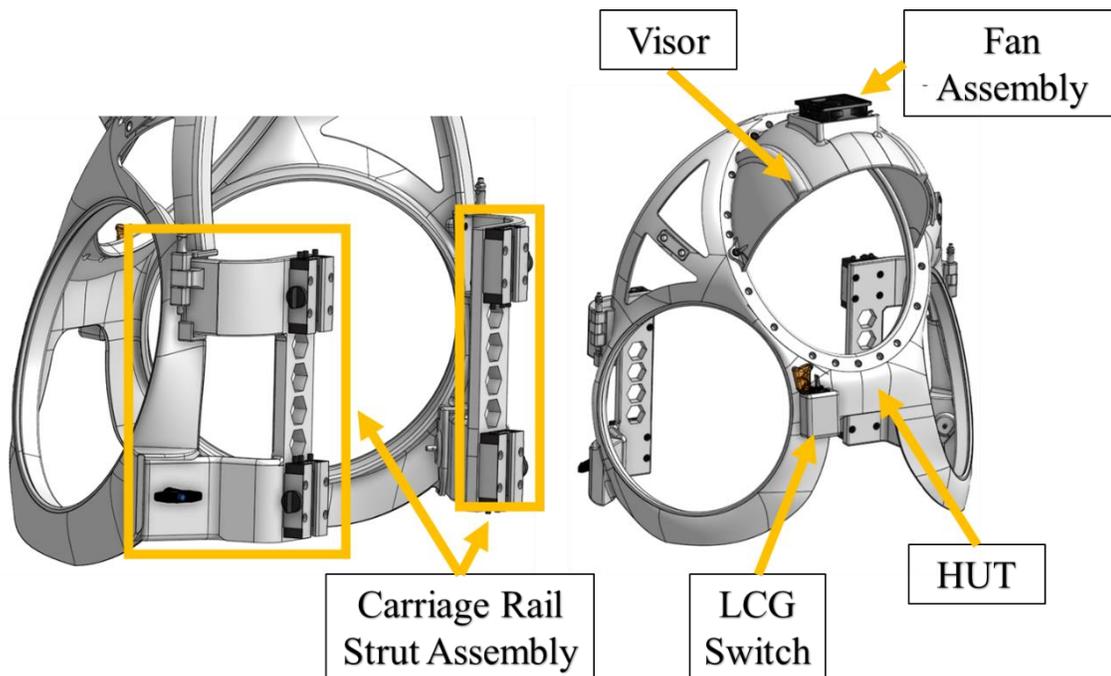


Figure 4-1. Hard Upper Torso (HUT) Assembly and Subsystems

The HUT is a slightly modified EMU suit hard upper torso, which provides some volumetric restrictions to the wearer's arms and shoulder mobility by confining the range of motion to the arm rings. The HUT – along with the PLSS - innately also increases the volume of the wearer, adding some suit-like immersion with increased volumetric depth as well as cognitive perception of surroundings for the wearer in relation to the suit's construction. Additionally, the HUT allows for mounting of any additional equipment, such as a first-person wireless camera or lighting rails, in addition to the LCG toggle switch assembly and visor. The HUT has two size options, small and large, in which the primary difference is the decrease in depth of the arm rings in the small HUT compared to the large HUT, shrinking the chest breadth; the chest and torso depth, width, and height are the exact same.

Attached to the HUT are two carriage rail assemblies. The carriages themselves mount to the aluminum carriage rails installed on the PLSS in Section 4.2 and are braked. These carriages can be connected to the HUT through a series of rail struts and spring-loaded pip-pin mounting

adapters fastened altogether on the back of the HUT. This carriage rail system allows for easy, fine-tunable height shifting and adjustment of the HUT and visor in relation to the wearer’s head, torso, and chin encompassing a wide distribution of anthropometries and torso widths and heights. Furthermore, small-medium and large-XL sizing options for the rail struts can increase the chest depth for larger, ‘barrel-chested’ wearers, increasing HS3’s sizing capabilities for different Anthro ranges.

The visor mounted onto the HUT provides a few suit-like characteristics of a space suit helmet bubble, including providing cooling via ventilation to the wearer and reducing the wearer’s field-of-view. An 80mm USB-powered fan (~30 cubic feet per minute) and mesh filter mounted to a slot in the visor provides cooling and thermal regulation to the wearer’s head and optimizes the headspace environment conditions despite being an open-air system.

4.1.2 Construction: Assembly Instructions

This section will detail the construction of the HUT assembly including structural setup and size adjustments, visor and fan subsystems installation and mounting, and carriage rail strut assemblies and installation. The construction will be described in a linear process starting with the basis of the HUT structure and heat inserts required for mounting and fastening components. Construction of the PLSS and HUT requires all 3D printed components to be fully printed, sanded, cleaned, etc., before full assembly.

4.1.2.1 Heat Inserts

Heat inserts are used in the PLSS and HUT structures to allow for component mounts in the 3D printed parts. Each structural item and component subassembly will have letters that are tied to the part or fastener to detail placement as well as refer to you to the part in the BOM.

4.1.3 Carriage Rail Strut Assembly

Fasten the rail carriages **BN** to the carriage rail struts **BP** using screws **BO** (8 on each rail strut, 16 total for a pair for struts) Figure 4-2. When fastening the carriages onto the struts, be sure the finger screw on the carriages faces the outside of the HUT/away from the wearer – if looking straight at the front of the HUT, the finger screws on the carriages of the left strut point outward left while the finger screws on the carriages of the right strut point outward right. This is to ensure the carriages can be loosened or brake while the wearer is actively in the HS3 suit so on-the-fly adjustments can be made without doffing the suit entirely. One pair of assembled rail struts consists of a left and right rail strut and is needed for mounting both sides of the HUT.

Table 4-1. Carriage Rail Strut Assembly – Parts List

Item	BOM ID	Qty.	Part #	Description
BN	H-4	4	3249K2	Locking Sleeve Bearing Carriage for 15 mm Wide Rail
BO	H-5	16	91290A248	Alloy Steel Socket Head Screw Black-Oxide, M5 x 0.8 mm Thread, 22 mm Long

BP	H-6/7	1	N/A	Carriage Rail Strut - Left, S/M or L/XL
BP	H-8/9	1	N/A	Carriage Rail Strut - Right, S/M or L/XL

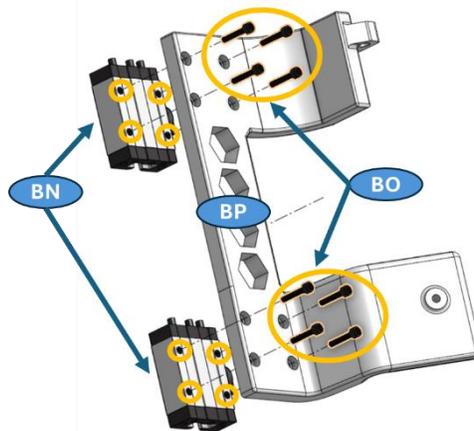


Figure 4-2. Carriage Rail Strut Assembly. Right XL Strut shown as example.

Table 4-2. HUT Pip-Pin Adapter Assembly – Parts List

Item	BOM ID	Qty.	Part #	Description
BQ	H-10	1	N/A	HUT Pip Pin Adapter (left)
BQ	H-11	1	N/A	HUT Pip Pin Adapter (right)
BR	H-12	4	93365A132	Brass Tapered Heat-Set Inserts for Plastic 6-32 Thread Size, 0.25" Installed Length
BS	H-13	4	90357A120	Ultra-Low-Profile Socket Head Screw Alloy Steel, 6-32 Thread Size, 5/16" Long

Using a heat insert tool, install heat inserts BR (Table 4-2) into the allocated holes on the edge of the back of the HUT (two on each side, four total) Figure 4-3. Fasten the left and right pip-pin adapters BQ onto the HUT by threading screws BS into the heat inserts. One pair of pip-pin adapters consists of installing the left and right pip-pin adapter onto both sides of the HUT and is needed for mounting the HUT to the carriage rail strut assembly.

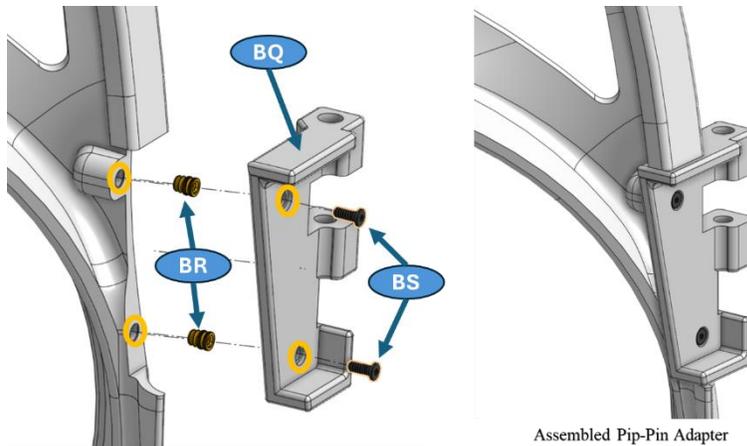


Figure 4-3. HUT Pip-pin Adapter Assembly. Right adapter shown as example.

Table 4-3. HUT and Spring-Loaded Pip-Pins – Parts List

Item	BOM ID	Qty.	Part #	Description
BT	H-14	2	93871A250	Locking Quick-Release Pin for Tight Spaces 6 mm Diameter, 50 mm Usable Length
BU	H-15	2	93750A205	T-Handle Locking Quick-Release Pin with Lanyard, 3/16" Diameter, 1" Usable Length
BV	H-16/17	1	N/A	Hard Upper Torso (HUT) – S/M or L/XL

To fasten the HUT to the carriage rail strut assemblies (left and right), use pip pins BT and to interlock the top of the rail strut to the top pip-pin adapter and pip pins BU to interlock the bottom of the rail strut to the indented hole in the HUT BV (1 of each spring-loaded pip-pin on each side, 2 total of each) Figure 4-4. This connection of the HUT to the rail strut assembly happens on both the left and right sides of the HUT.

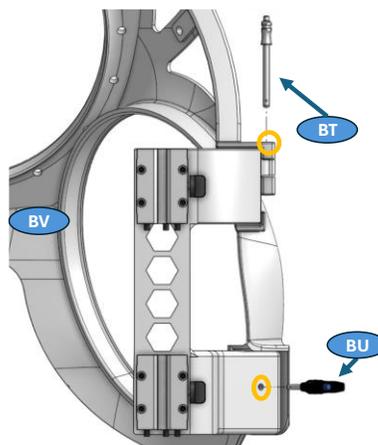


Figure 4-4. Mounting the HUT to the Carriage Rail Strut Assembly via Pip-Pins.

Table 4-4. Visor and Ventilation Fan – Parts List

Item	BOM ID	Qty.	Part #	Description
BW	H-18	1	N/A	Hard Upper Torso (HUT) - Visor
BX	H-19	4	97334A535	Nylon Socket Head Screws 1/4"-20 Thread Size, 3/8" Long
BY	H-20	4	93365A160	Brass Tapered Heat-Set Inserts for Plastic 1/4"-20 Thread Size, 0.3" Installed Length
BZ	H-21	4	94180A351	Brass Tapered Heat-Set Inserts for Plastic M4 x 0.7 mm Thread Size, 4.7 mm Installed Length
CA	H-22	4	91304A113	Alloy Steel Hex Drive Flat Head Screws Blue-Dyed Zinc-Plated, M4 x 0.7 mm Thread, 12 mm Long
CB	H-23	1	B0CX2ZLTKS	PC Case Dust Mesh Filter, 80x80mm
CC	E-26	1	B0BZVDP3PY	USB Computer Fan, 80mm (White)

Using a heat insert tool, insert heat inserts **BY** into the allotted holes on the neck ring of the HUT (Figure 4-5). Then, use nylon screws **BX** to fasten the visor at the mounting indentation holes to the HUT by threading the screws into the heat inserts. To mount the fan and mesh filter, first use a heat insert tool to insert heat inserts **BZ** into the allotted holes in the square opening on the top of the visor. For the fan, remove the pre-assembled metal wiring shield from the fan itself by unscrewing its fasteners and spacers at each corner (the only thing you need is the fan and its USB cable – all other accessories and fasteners are not needed). Place the mesh filter **CB** on top of the square opening, then use fasteners **CA** to fasten the fan **CC** (and sandwich the mesh filter between the wearer’s head and the fan blades) to the heat inserts in the square opening of the visor at each corner of the fan.

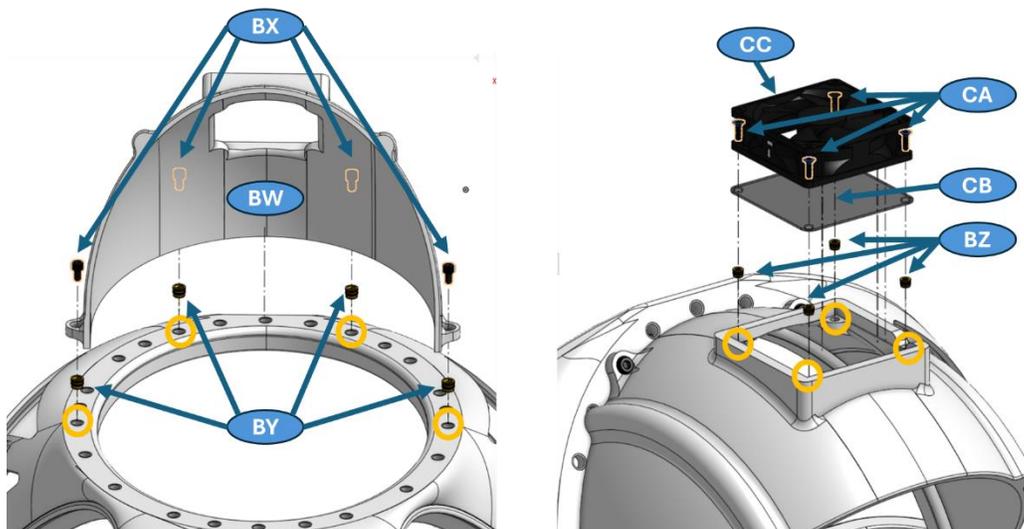


Figure 4-5: Visor Mounting and Visor Ventilation Fan Assembly and Mounting

Table 4-5. Rail End Cap – Parts List

Item	BOM ID	Qty.	Part #	Description
CD	H-25	4	N/A	Carriage Rail End Caps
-	H-24	AR	B00AQ6IS1G	3M Dual Lock Reclosable Fastener Adhesive Tape

Once the HUT and visor w/ fan are fully assembled, loosen the finger screws on the carriages then slide the HUT onto the aluminum carriage rails installed on the backplate via the carriages attached to the rail struts. Once placed in the desired place along the rail, tighten the finger screws on the carriages to lock the HUT and visor assembly in place.

Friction-fit cap the ends of the two aluminum rails using the end caps **CD** to mitigate any sharps or rough edges at the rail ends Figure 4-6. Also, place two strips of dual lock adhesive side by side (to form a square) on the front left side of the side – if you are looking straight at the front of the HUT – as to allow the LCG toggle switch assembly to snap fasten to the HUT.

Lastly, wire the USB fan cable and switch to the back of the PLSS and plug in the cable into any of the USB Type A ports. To test the power to the fan, turn on the power bank then use the in-line fan switch to turn the fan to ‘H’ (high) power; observe for air flow and spinning blades. This completes the PLSS and HUT assemblies of HS3.

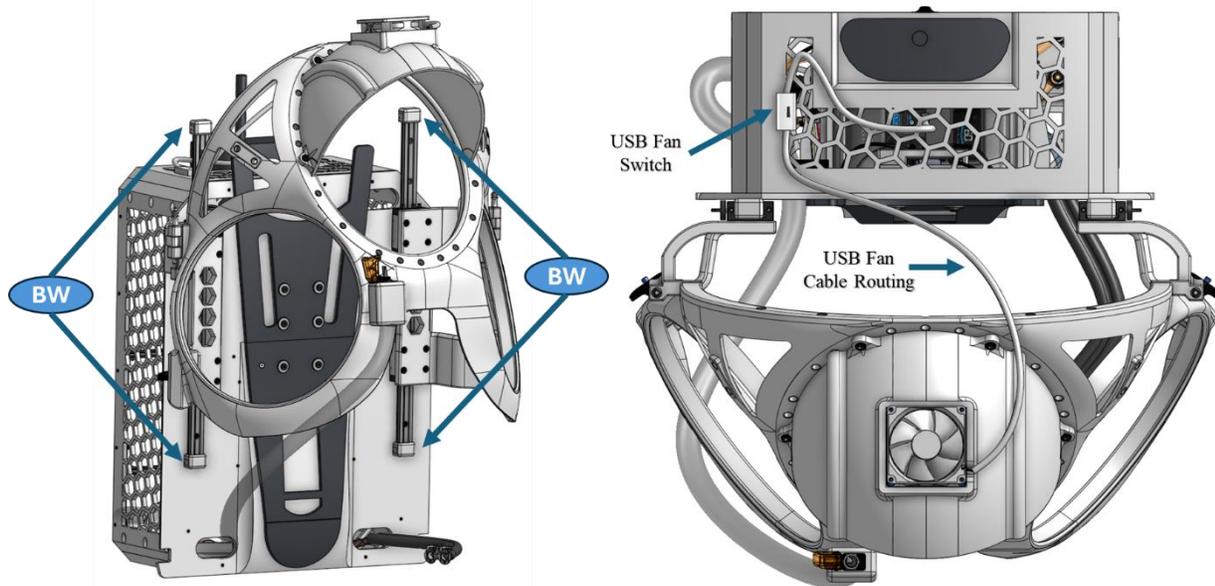


Figure 4-6: Rail End Caps and USB Fan Cable Routing.

4.2 Portable Life Support System (PLSS) and Electrical System

This section documents the design, construction, and assembly of the HS3 2.5 mock PLSS structure including interfaces, thermal cooling loop, spine and waist assemblies (BOM #P-1 to #P-48 and #E-1 to #E-26).

4.2.1 Design details

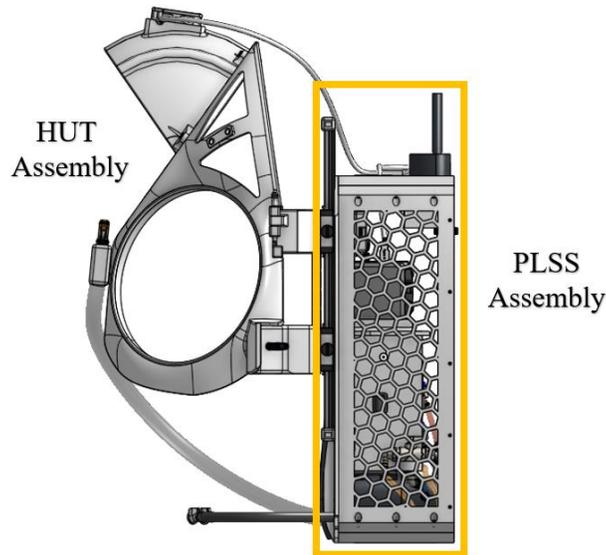


Figure 4-7. Side View of HS3 2.5 HUT and PLSS Assembly

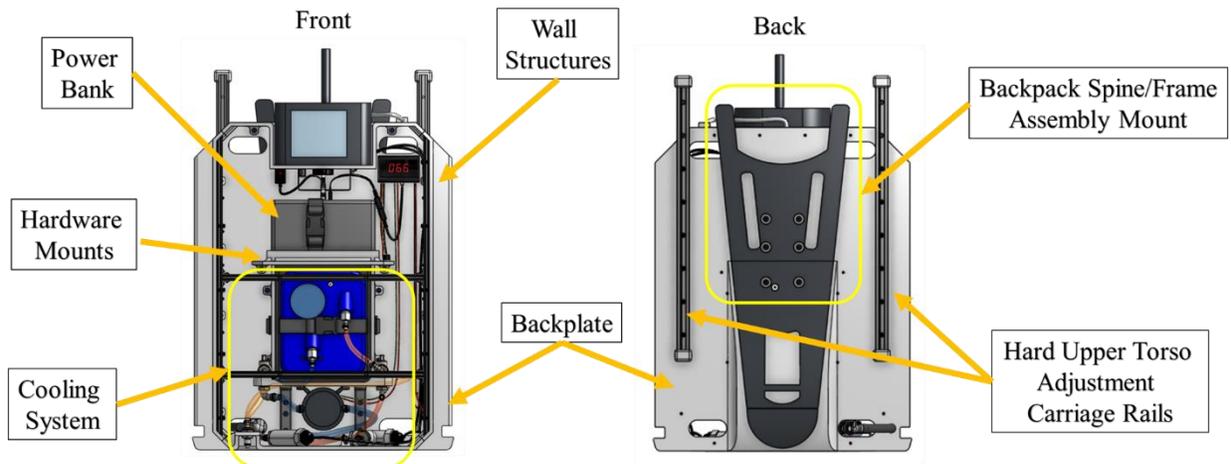


Figure 4-8. Overview of the HS3 2.5 PLSS Assembly

The mock portable life support system (PLSS) structurally houses the electronics, hardware, and ancillary equipment and mounts necessary to power the liquid cooling system and pump as well as provides the capability to power additional equipment (i.e., lights, toggle switches, microcontrollers, displays, etc.) or biomedical sensors (i.e., thermowell probes, temperature-humidity probes, etc.) as required by testing and facility environmental needs. From a high-level

overview, the PLSS consists of multiple assemblies, to which the first is the structural volume that holds the primary electrical components and liquid cooling system hardware composed of four outer walls fastened together and reinforced. Second, the backplate of the PLSS acts as the primary mounting point for all the internal shelving resting hardware, the backpacking frame and padded harness/hip belt, the HUT adjustment carriage rails, and parts of the liquid cooling system plumbing. Third, the liquid cooling system housed in the PLSS feeds frozen/chilled water from a 3.5L bladder reservoir into the liquid cooling garment to provide thermal cooling to the wearer freely un-tethered from an umbilical-based cooling system for simulated tasks. In the same regard, the PLSS and liquid cooling system have panel-mounted fluid disconnects on the PLSS walls and inline diverting valves should a study want to supply the liquid cooling system from a tethered umbilical or fluid line with a constantly chilled/compressor-cooled supply of deionized water instead of the internal, limited supply by the chilled bladder during a simulated task. Fourth, the PLSS houses all the electronics and batteries, in addition to the Raspberry Pi setup with temperature probes collecting inlet-outlet water temperature data from the liquid cooling garment as well as feeding out a wired toggle switch assembly to the water pump for subject control at any point and a cable for the ventilation fan connected to the visor mounted on the HUT for subject cooling. Overall, the HS3 PLSS houses and powers all the critical liquid cooling system hardware, sensors, and any additional equipment as needed by the study. The structure of the PLSS is completely modular in construction and can accommodate easily to fit a test team's [and hardware's] needs and thus achieve desired outcomes of any study utilizing.

4.2.2 Construction: assembly instructions

This section will detail the construction of the PLSS assembly including structural setup, cooling system and plumbing, electrical subsystems, and wiring for those subsystems. The construction will be described in a linear process starting with the basis of PLSS structure and heat inserts required for mounting and fastening components. Construction of the PLSS and HUT requires all 3D printed components to be fully printed, sanded, cleaned, etc., before full assembly.

4.2.2.1 Heat Inserts

Heat inserts are used in the PLSS and HUT structures to allow for component mounts in the 3D printed parts. The basis of the PLSS structure is the backplate which couples the individual to the PLSS assembly. Each structural item and component subassembly will have letters that are tied to the part or fastener to detail placement as well as refer to you to the part in the BOM.

4.2.3 Backplate and PLSS Structure

Once the backplate **A** is printed, using a heat insert tool, insert heat inserts **B**, **C**, and **D** (Table 4-11) into their respective holes as indicated in Figure 4-3 by the orange circles and blue arrows.

Table 4-6. Backplate - Parts List

Item	BOM ID	Qty.	Part #	Description
A	P-1	1	N/A	PLSS Backplate
B	P-11	28	94180A351	Brass Tapered Heat-Set Inserts for Plastic

				M4 x 0.7 mm Thread Size, 4.7 mm Installed Length
C	P-15	12	94180A363	Brass Tapered Heat-Set Inserts for Plastic M5 x 0.8 mm Thread Size, 11.1 mm Installed Length
D	P-40	6	93365A160	Brass Tapered Heat-Set Inserts for Plastic 1/4"-20 Thread Size, 0.3" Installed Length

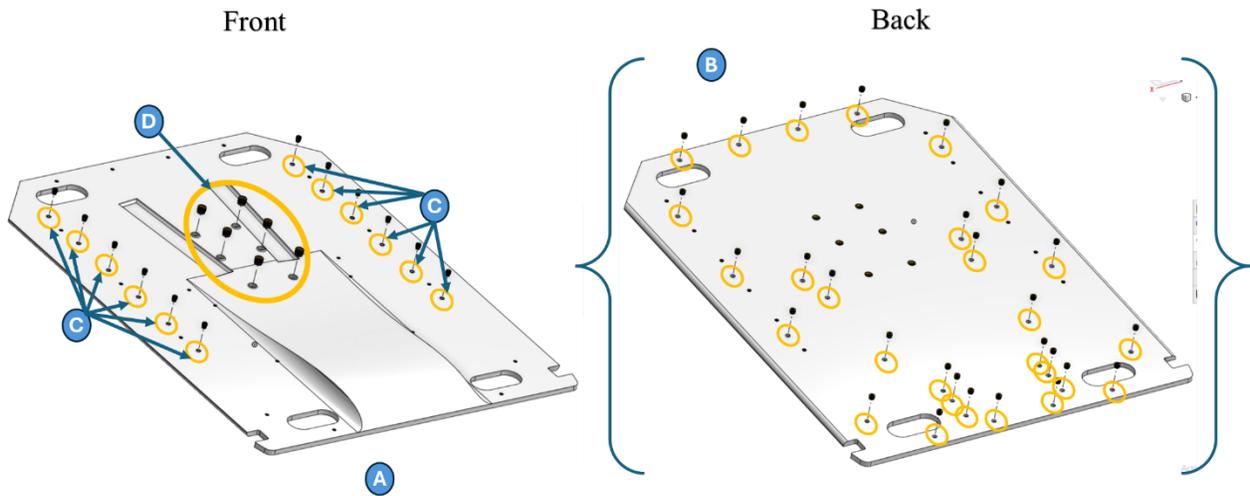


Figure 4-9. Heat Insert Positions for Backplate

Table 4-7. LCG Bladder Compartment – Parts List

Item	BOM ID	Qty.	Part #	Description
D	P-6	1	N/A	PLSS Bladder Compartment Shelf
A	P-11	10	94180A351	Brass Tapered Heat-Set Inserts for Plastic M4 x 0.7 mm Thread Size, 4.7 mm Installed Length
E	P-9	AR	B07WVRQ59Q	Neoprene Foam Roll Adhesive

Next, use the heat insert tool to insert heat inserts **A** (Table 4-7) into the bottom of the LCG bladder compartment shelf **D** as seen in Figure 4-4. Additionally, cut out two 6" x 8", two 6" x 7" and one 7" x 8" sheets of neoprene foam **E**. Where there are slits in the LCG bladder compartment's walls, also cut slits in the foam at the same spot using scissors. At this point, you do not need to remove the adhesive – lay aside the cut sheets of foam from now.

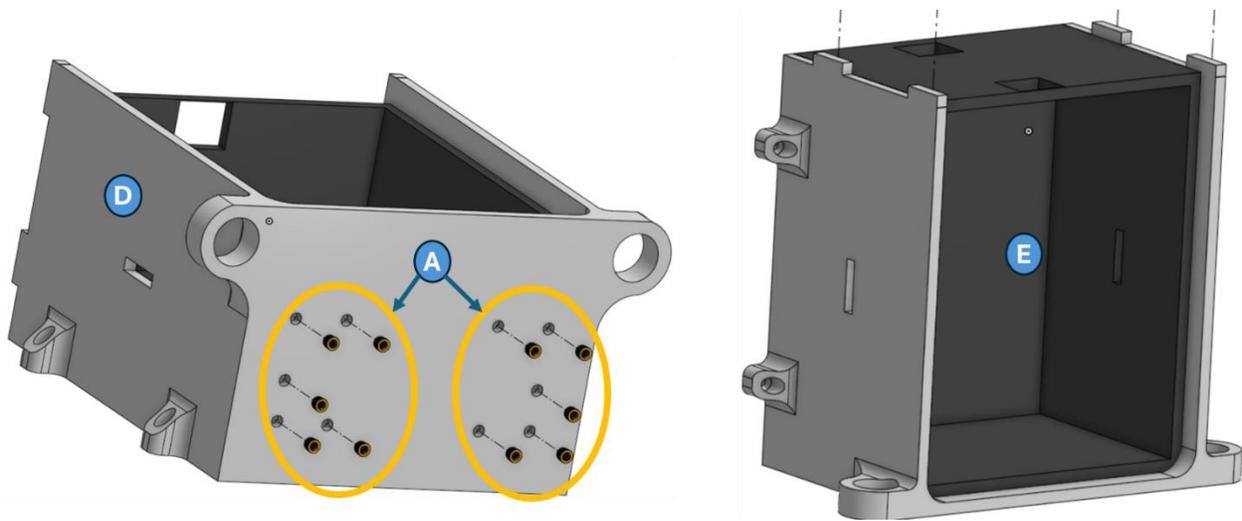


Figure 4-10. Heat Inserts and Foam Cutouts for LCG Bladder Compartment.

Table 4-8. Battery Compartment Shelf and Corner Brackets – Parts List

Item	BOM ID	Qty.	Part #	Description
F	P-7	1	N/A	PLSS Battery Compartment Shelf
G	P-12	2	15655A72	Corner Bracket 304 Stainless Steel, 3-9/16" x 3-9/16" x 13/16"
H	P-14	18	91304A113	Alloy Steel Hex Drive Flat Head Screws Blue-Dyed Zinc-Plated, M4 x 0.7 mm Thread, 12 mm Long

Mount the battery compartment shelf **F** (Table 4-8) to the LCG bladder compartment as seen in Figure 4-11 by friction-fitting the two together at the four rectangular notches on the LCG bladder compartment. Next, mount the assembled shelves/compartments into the PLSS by fastening the six screws **H** into the screw mounts on the LCG bladder compartment shelf (two on each side) and on the bottom of the battery compartment shelf (one on each side). After, support the shelves by fastening the corner brackets **G** to their respective heat inserts on the backplate (3 on each bracket, 6 total) and on the underside of the bladder compartment shelf (3 on each side, 6 total). The battery and bladder compartments should now be firmly mounted into the PLSS/onto the backplate. Once mounted, you may now remove the adhesive from the foam cutouts and place them into the LCG compartment, on the backplate where the LCG compartment fits, and on the underside of the battery compartment (Figure 4-11 (left)).

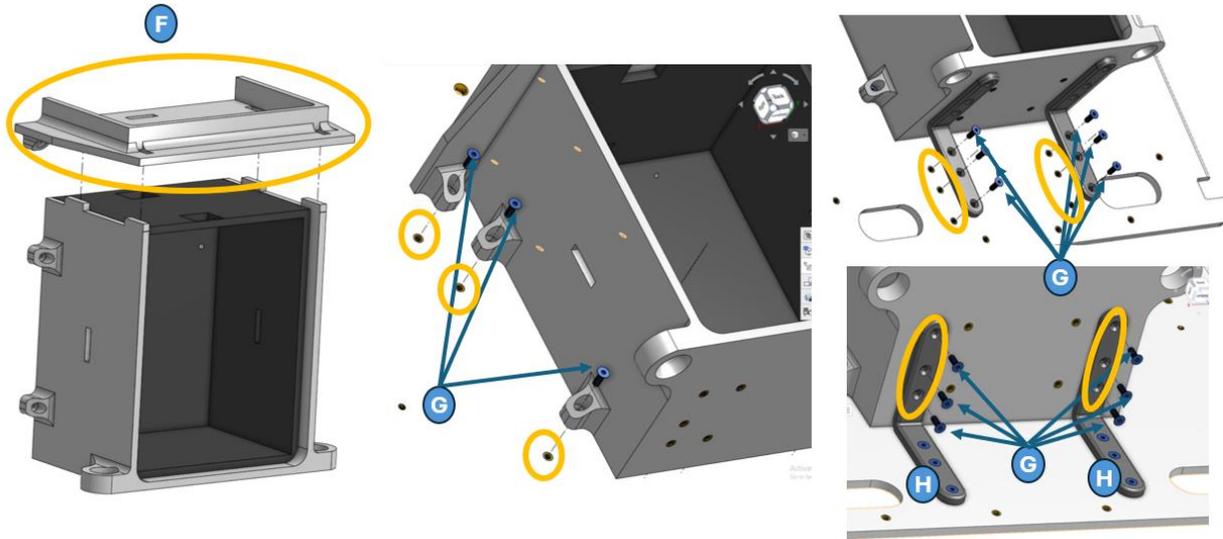


Figure 4-11. Battery Shelf and LCG Compartment Installation.

Mount the battery shelf onto the LCG compartment (left). Fasten the assembled compartment shelves into the middle of the backplate on the back side (middle). Firmly mount the assembled compartment shelves into the PLSS with corner brackets and fasteners near the bottom middle of the back of the backplate (right top, right bottom).

Table 4-9. LCG Pump and Corner Brackets – Parts List

Item	BOM ID	Qty.	Part #	Description
I	P-13	1	B07F35PTFR	36W Flow/Water Pump
H	P-14	4	91304A113	Alloy Steel Hex Drive Flat Head Screws Blue-Dyed Zinc-Plated, M4 x 0.7 mm Thread, 12 mm Long

Using the same fastener screws **H** (Table 4-9), mount the water pump's rubber feet (with screw holes) to the underside of the LCG bladder compartment (two screws on each side, four total) (Figure 4-12).

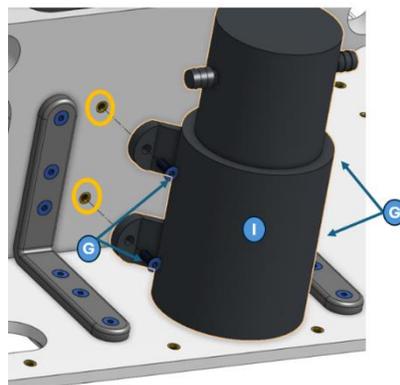


Figure 4-12. Mounting the Water Pump to the LCG Bladder Compartment.

Table 4-10. Heat Inserts for Top and Bottom PLSS Walls – Parts List

Item	BOM ID	Qty.	Part #	Description
J	P-4	1	N/A	PLSS Bottom Wall
K	P-5	1	N/A	PLSS Top Wall
L	P-15	12	94180A363	Brass Tapered Heat-Set Inserts for Plastic. M5 x 0.8 mm Thread Size, 11.1 mm Installed Length

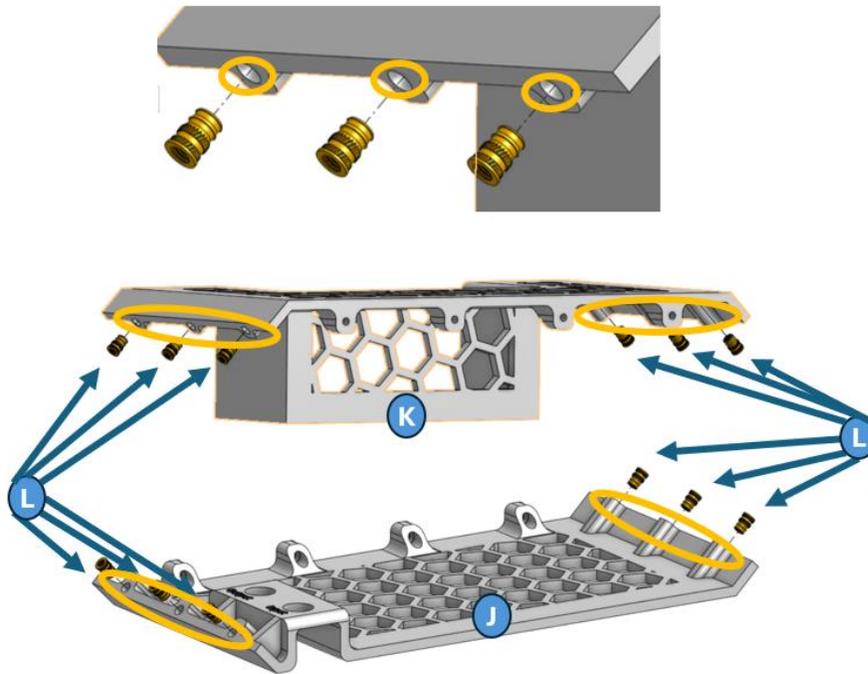


Figure 4-13. Heat Inserts for PLSS Top (top, middle) and Bottom Walls (bottom).

Using the heat insert tool, insert heat inserts **L** (Table 4-10) into the 6 holes at the 45-degree screw holes at the ends of each PLSS walls **J** and **K** (3 on each side, 12 total) as show in Figure 4-13.

Table 4-11. Left and Right PLSS Walls and Backplate – Parts List

Item	BOM ID	Qty.	Part #	Description
J	P-4	1	N/A	PLSS Bottom Wall
K	P-5	1	N/A	PLSS Top Wall
M	P-2	1	N/A	PLSS Left Wall
N	P-3	1	N/A	PLSS Right Wall
H	P-14	16	91304A113	Alloy Steel Hex Drive Flat Head Screws Blue-Dyed Zinc-Plated, M4 x 0.7 mm Thread, 12 mm Long
O	P-16	12	91290A248	Alloy Steel Socket Head Screw

				Black-Oxide, M5 x 0.8 mm Thread, 22 mm Long
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Using fastener **H** (Table 4-11), mount the PLSS Walls **J-N** at their screw holes onto the backplate as seen in Figure 4-14 (4 screws each wall, 16 total). Then, using fastener **O**, fasten the adjacent ends of the PLSS walls together through these holes into heat insert **L** (3 on each end/joint, 12 total).

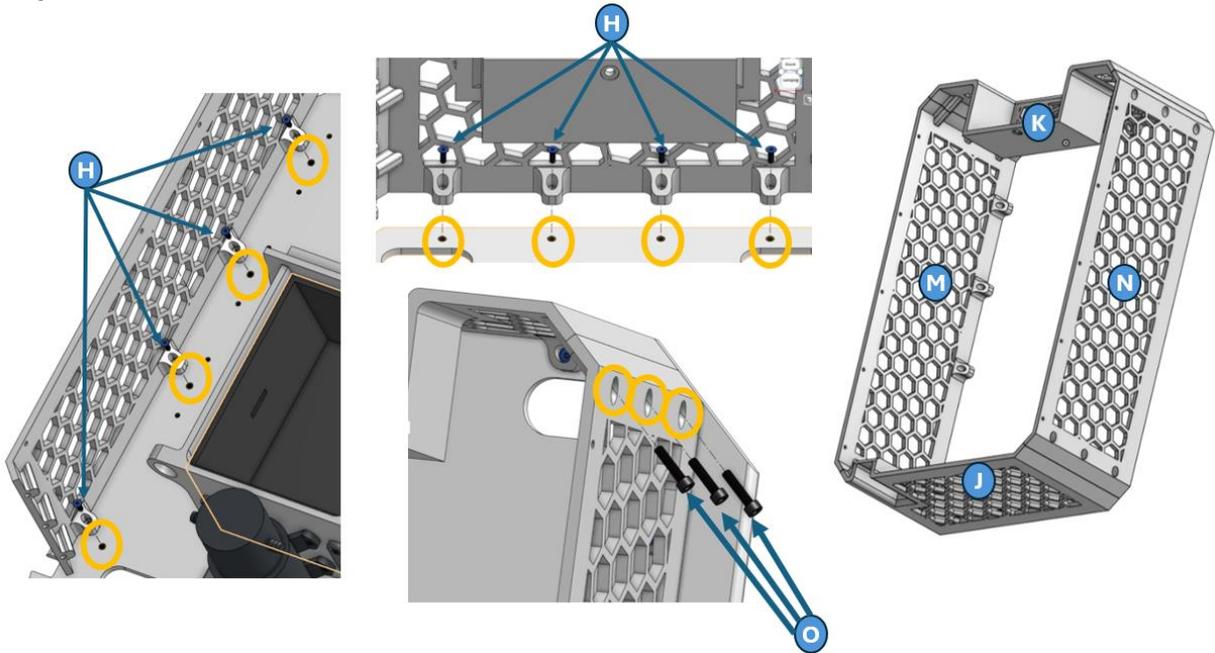


Figure 4-14. PLSS Wall to Backplate Installation.
Mounting the PLSS Walls onto the Backplate (left, top). Fastening the PLSS Walls together (bottom, right).

Table 4-12. Left and Right PLSS Internal Frame and Corner Fasteners – Parts List

Item	BOM ID	Qty.	Part #	Description
P	P-32	2	5969N15	Miniature T-Slotted Framing Single Rail, 10 mm High x 10 mm Wide (18" Lg.)
Q	P-33	2	5969N16	Miniature T-Slotted Framing Single Rail, 10 mm High x 10 mm Wide (24" Lg.)
R	P-34	10	93365A132	Brass Tapered Heat-Set Inserts for Plastic
S	P-35	10	90344A135	6-32 Thread Size, 0.25" Installed Length Socket Head Screws with Flat Washer Black-Oxide Alloy Steel, 6-32 Thread Size, 1/2" Long
T	P-36	16	5969N21	M3 Self-Aligning Nut, for Single Rail Miniature T-Slotted Framing

U	P-37	8	5969N42	Corner Bracket for Single Rail Miniature T-Slotted Framing
V	P-38	16	5969N23	5mm Long, Button Head Screw for Single Rail Miniature T-Slotted Framing

Cut T-slotted framing **P** (Table 4-12) into 14.2” lengths using a rotating belt saw. Cut T-slotted framing **Q** into 21-1/8” lengths as well as cut a 45-degree angle off each end of **Q**. Next, using a drill press, drill a 1/4” hole exactly 1.25” away from the longest edge of **Q**, then drill four more holes alike exactly 4.5” apart from each other down the length of the T-slotted framing. Once done, assemble the T-slotted framing corners as shown in Figure 4-## with nut **T**, bracket **U**, and screw **V** to make an H-shaped frame.

Using a heat insert tool, insert **R** into the left and right PLSS walls as shown in Figure 4-15 (5 on each side, 10 total). Lastly, fasten the T-slotted framing assembly into the PLSS walls with screw **S** (5 on each side, 10 total).

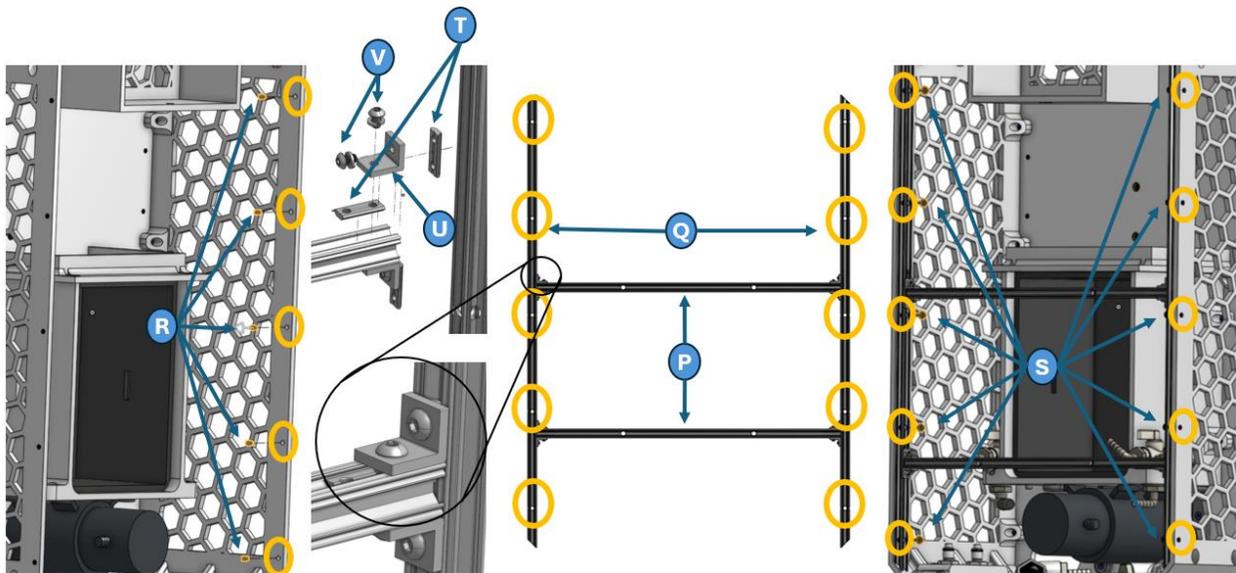


Figure 4-15. PLSS Internal Frame to Wall Installation.

Mounting the heat inserts into the PLSS walls (left); making the corner brackets, cutting the miniature T-slotted framing and assemble using the fasteners in Table 4-12. Fasten the T-slotted frame into the PLSS Walls.

Table 4-13. Carriage Rail Mounting – Parts List

Item	BOM ID	Qty.	Part #	Description
X	H-1	2	9867K12	15 mm Wide Guide Rail for 47 mm Wide Sleeve Bearing Carriage (500mm length)
Y	H-2	12	91864A086	Black-Oxide Alloy Steel Socket Head Screw 6-32 Thread Size, 9/16" Long
-	H-3	2	19425A49	Half-Measure Adhesive-Back Ruler

				Vertical, Top-to-Bottom Reading Direction, 1-1/2 Feet Length
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Using fastener **X** (Table 4-13), mount the carriage rails **Y** onto the PLSS backplate as shown in Figure 4-16. The top two screw holes of **Y** should be left empty/jutting above the PLSS and backplate. Additionally, on the inside of each rail, adhere the back ruler evenly along the vertical length of the rail; this will allow for easy and incremental sizing adjustments of the HUT along the rails. This completes the assembly of the structural parts of the PLSS and backplate!

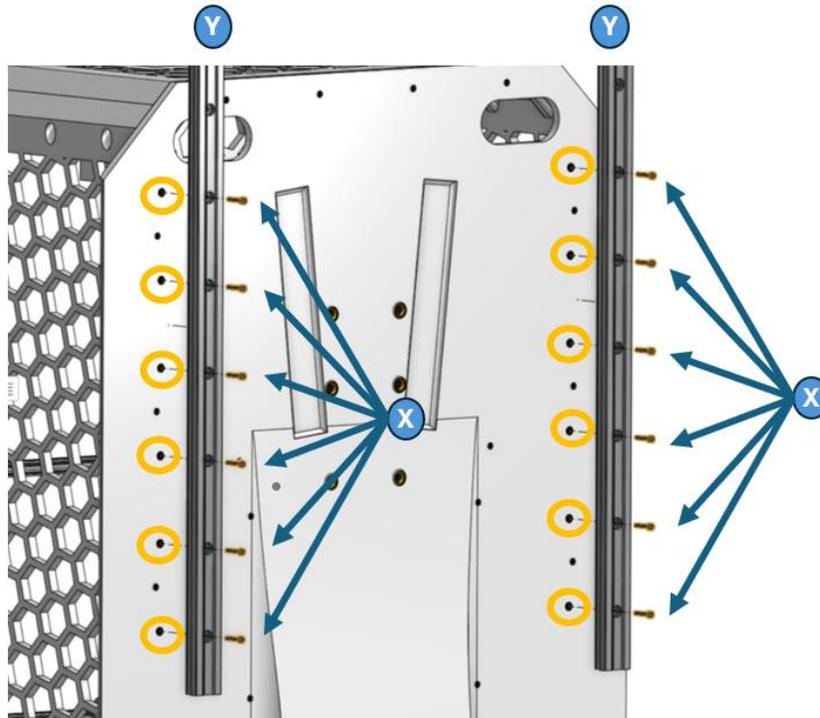


Figure 4-16. Mounting Carriage Rails to Backplate

4.2.4 Liquid Cooling System – Plumbing Installation

Assemble the diverting valves (parts lists in Table 4-14 to Table 4-17), inlet and outlet, and the PVC T-adapter branches, inlet and outlet as shown in Figure 4-17. Prior to threading the plastic barbed hose fittings into the valve and T-adapter, be sure to wrap Teflon tape **AD** around the threads in the direction that you are turning to tighten the barbed hose fittings, so the Teflon tape does not chafe/get damaged. Once threaded, tighten snugly with a wrench. Reference the DTP and the CAD assembly for ensuring the barbed hose fittings are rotated in the proper direction:

- Z** - Leftmost diverting ball valve (outlet):
 - AB** - (x1) Surface Supply Outlet [backward]
 - AB** - (x1) Bladder outlet port [forward]
 - AC** - (x1) Pump-to-LCG outlet [downward]
- Z** - Rightmost diverting ball valve (inlet):
 - AB** - (x1) Surface Supply Inlet [backward]
 - AB** - (x1) LCG inlet [downward]

- AB** - (x1) Internal Bladder inlet port [forward]
- AE** - Leftmost PVC T-adapter (outlet):
 - AG** - (x1) LCG outlet
 - AH** - (x1) Pump-to-PVC T-adapter
 - AF** - (x1) 50mm Thermowell for DS18B20 sensor
- AE** - Rightmost PVC T-adapter (inlet):
 - AG** - (x1) LCG inlet
 - AG** - (x1) PVC T-adapter-to-diverting valve (inlet)
 - AF** - (x1) 50mm Thermowell for DS18B20 sensor

Table 4-14. Diverting Valve (Outlet) – Parts List

Item	BOM ID	Qty.	Part #	Description
Z	P-18	1	4757K52	Compact Diverting Valve, 1/4 NPT Female x Female
AB	P-19	2	5218K782	Plastic Barbed Hose Fitting for Water, Elbow, 1/4" Hose ID, 1/4 NPT Male, 150 PSI
AC	P-20	1	5218K789	Plastic Barbed Hose Fitting for Water, Elbow, 3/8" Hose ID, 1/4 NPT Male, 150 PSI
AD	P-31	AR	B0DY5ZMRGF	Teflon Tape

Table 4-15. Diverting Valve (Inlet) – Parts List

Item	BOM ID	Qty.	Part #	Description
Z	P-18	1	4757K52	Compact Diverting Valve, 1/4 NPT Female x Female
AB	P-19	2	5218K782	Plastic Barbed Hose Fitting for Water, Elbow, 1/4" Hose ID, 1/4 NPT Male, 150 PSI
AD	P-31	AR	B0DY5ZMRGF	Teflon Tape

Table 4-16. PVC T-Adapter (Outlet) – Parts List

Item	BOM ID	Qty.	Part #	Description
AE	P-21	1	4880K154	Standard-Wall PVC Pipe Fitting for Water Tee Connector, 1/2 NPT Female
AF	P-22	1	B08QV4F8FF	50mm Thermowell
AG	P-23	1	5218K688	Plastic Barbed Hose Fitting for Water, Adapter, 1/4" Hose ID, 1/2 NPT Male, 150 PSI
AH	P-24	1	5218K698	Plastic Barbed Hose Fitting for Water, Adapter, 3/8" Hose ID, 1/2 NPT Male, 150 PSI
AD	P-31	AR	B0DY5ZMRGF	Teflon Tape

Table 4-17. PVC T-Adapter (Inlet) – Parts List

Item	BOM ID	Qty.	Part #	Description
AE	P-21	1	4880K154	Standard-Wall PVC Pipe Fitting for Water Tee Connector, 1/2 NPT Female
AF	P-22	1	B08QV4F8FF	50mm Thermowell
AG	P-23	1	5218K688	Plastic Barbed Hose Fitting for Water, Adapter, 1/4" Hose ID, 1/2 NPT Male, 150 PSI
AD	P-31	AR	B0DY5ZMRGF	Teflon Tape

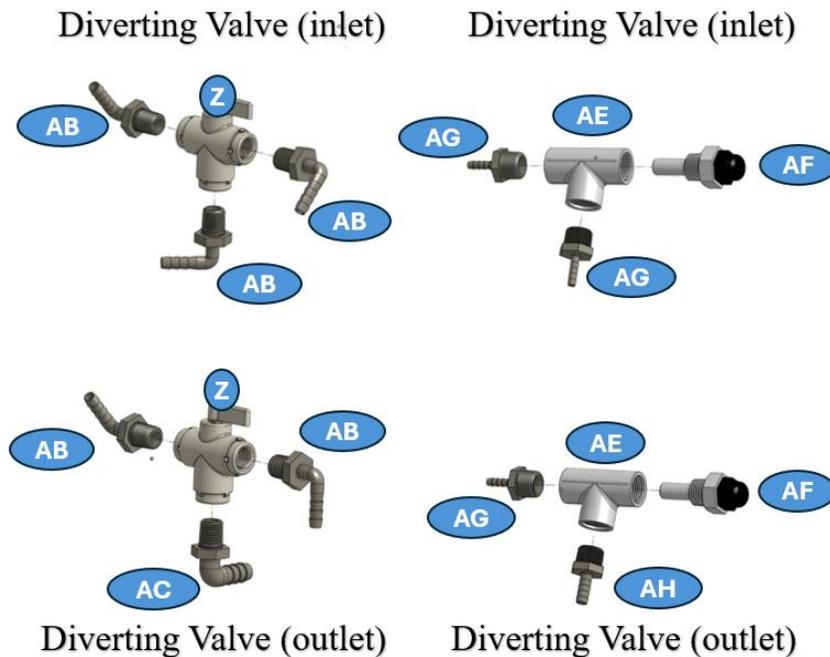


Figure 4-17: Diverting Valves Assembly Instruction.

Insert the assembled diverting valves into the open circular protrusions on the LCG compartment shelf. Reference the DTP and Figure 4-18 to ensure the barbed hose fittings are rotated in the proper direction. Stage the PVC T-adapters on the PLSS bottom wall as seen in Figure 4-19.

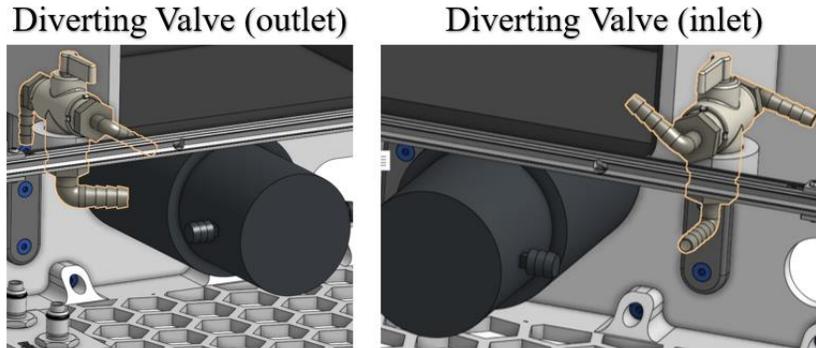


Figure 4-18. Diverting Valves Installed in LCG Bladder Compartment.

Table 4-18. Panel-Mounted Fluid QDs – Parts List

Item	BOM ID	Qty.	Part #	Description
AI	P-17	2	5012K94	Plastic Quick-Disconnect Tube Coupling for Air and Water Thru-Wall Plug, Shut-Off, 1/4 Size, for 1/4" Barbed Tube

Unscrew the hex nut that is mated with the panel-mounted fluid disconnect (Table 4-18) **AE**. In the PLSS bottom wall, feed the two items **AI** through the 13/16" holes on the left side of the bottom wall (where it is printed "inlet" and "outlet"). Screw the hex nut onto the fluid QD with a wrench or socket as to mount it to the bottom wall, ensuring the barbed hose fitting is pointing inside of the PLSS and not outside/outwards.

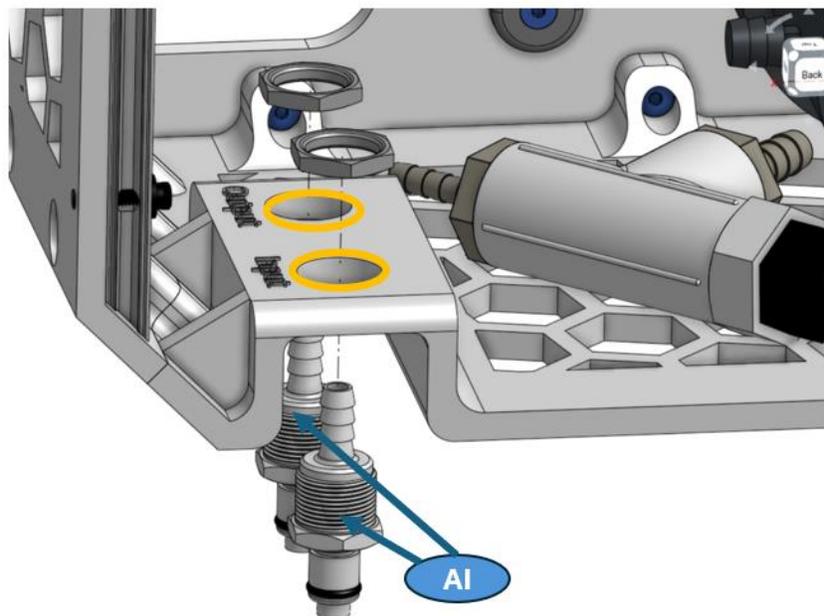


Figure 4-19: Panel-Mounted Fluid QDs being installed.

Table 4-19. Hoses and Clamps – Parts List

Item	BOM ID	Qty.	Part #	Description
AJ	P-25	2	N/A	CPC male fitting 1/4" (two pcs)
AK	P-26	AR	5233K56	Soft Masterkleer PVC Tubing for Air&Water 1/4" ID, 3/8" OD
AL	P-27	AR	5233K64	Soft Masterkleer PVC Tubing for Air&Water 3/8" ID, 9/16" OD
AM	P-28	1	N/A	COMPCOOLER Extension Tubing with sleeve protection Screw-in Connector (3ft and 6ft)
AN	P-10	1	N/A	COMPCOOLER Single Chamber Quick Release Detachable Cuboid Bladder (3.5L) 0.4mm TPU Film
AO	P-45	16	B09BM1MNFx	25 Pack Stainless Steel Hose Clamps, 1/4 inch to 1/2 inch

Once all the barbed hose fittings, diverting valves, water pump, and PVC T-adapters are in place, next comes the plumbing for the liquid cooling system.

For the tubing: simply cut an approximately length of ¼” or 3/8” hose (Table 4-19) using scissors, loop on two hose clamps that have not been tightened yet, and securely connect the hose ends to their appropriate barbed fittings. Once connected to their correct fittings, move the hose clamp midway onto the barb and securely tighten the hose clamp with a flathead screwdriver once placement and length of tubing is adequate and optimal. Use Figure 4-20 and Figure 3-13(B) as a reference for where the tubing should connect and how water should flow through the system when the pump is turned on.

For visual reference, in the CAD assembly: blue tubing indicates outlet/”cold” water, and red tubing indicates inlet/”warm” water. The orange tubing is the connection between the external cooling supply via the panel-mounted fluid disconnects AI and the diverting valves in the internal cooling system.

The hosing connecting to the LCG bladder from the inlet and outlet diverting valves has a male fluid disconnecting fitting **AJ** on it to allow connection to the water bladder.

For the LCG hose extension **AM**, the commercial item comes with screw/Luer lock fittings. This hose extension connects at the female ends to the wearer’s LCG garment to the liquid colling system where then the PLSS can supply cold water and return warm water back into the bladder. To install this hose extension, cut off the screw-on fittings from the tubing using scissors, and then cut away a few inches of foam insulation to expose the tubing underneath. Then, connect the tubing to the PVC T-adapters and clamp down as shown to connect the inlet and outlet of the LCG garment to the internal liquid cooling system and supply.

Once all hosing has been connected, fill the water bladder with DI water, plug the male fluid QDs inside the PLSS/at the diverting valves into the outlet and inlet ports of the bladder (refer to

the DTP for detailed steps for checking for leaks), then power on the liquid cooling system/water pump. It is recommended to wait to test for leaks until all electronics hardware is installed and connected as described in this report since the pump needs to be wired into the DC motor controller and toggle switch before it will power on sufficiently.

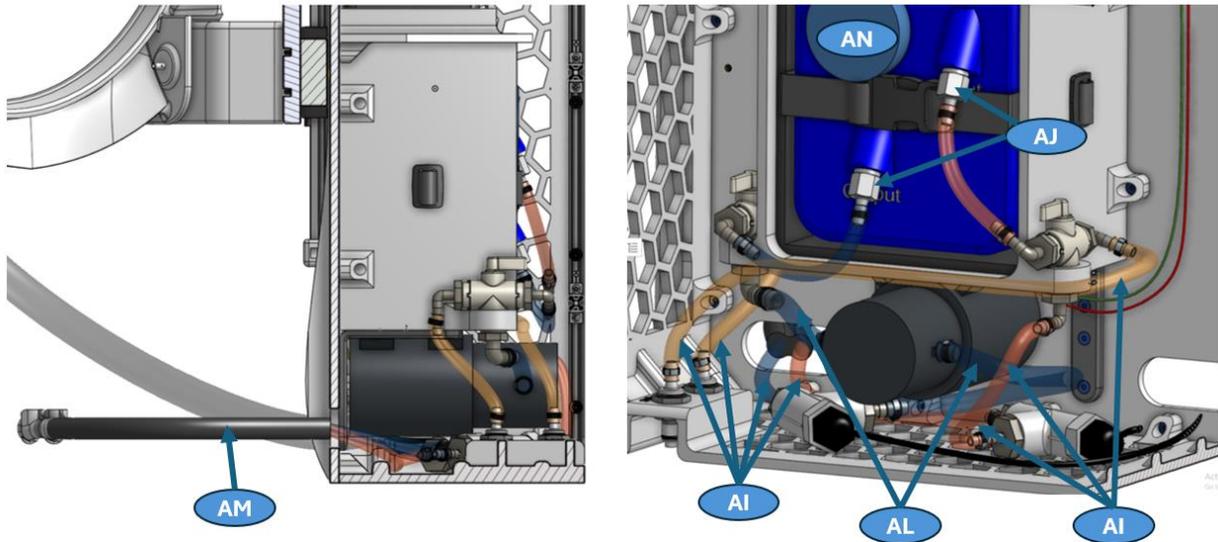


Figure 4-20: LCG Hosing and Connections in PLSS.

4.2.5 Backpacking Frame/Padded Harness

To begin, our HS3 unit utilizes a backpacking frame and padded suspension harness to offload the weight of the PLSS and HUT components onto mostly the wearer's hip/ilic crest as well as a slight bit on the shoulders and upper back.

To mount this backpacking frame and harness system on our HS3, we first must use a drill press to drill six holes into the frame **AR** (Table 4-20) itself so we can use fasteners, washers, and heat inserts to fasten it to the backplate. To do so, you will need to draw a sketch template on the back of the flat part of the frame as seen in Figure 4-21. For the extra tall frame, the middle holes line up directly with the open channels that allow the shoulder straps to slide up and down for easy adjustment for the wearer. Whereas the regular and tall frame sizes do not line up with the extra tall hole template/drawing. Though, the carbon fiber texture pattern on the frames is a perfect horizontal, allowing the test team to easily measure across the frame and draw out their hole markers between these frame sizes. For example, the extra tall spine has a textured line that lies exactly at the bottom of the open channels for the shoulders while the regular and tall frames lie about six textured lines above the extra tall hole template. Keep this in mind when drilling into the frames and plan carefully. The reason for this template difference is to mount the frame to the backplate consistently for wearer offloading in the same spot on the lower back and hips as to not cause shifts in center-of-gravity or awkward offloading at higher vertebrae of the spine with various anthropometric subjects of different torso heights whilst wearing HS3 and performing simulated tasks.

Table 4-20. Backpacking Frame/Padded Harness and Mounting Fasteners – Parts List

Item	BOM ID	Qty.	Part #	Description
AP	P-41	6	92220A185	Alloy Steel Low-Profile Socket Head Screw Hex Drive, Black Oxide, 1/4"-20 Thread Size, 3/4" Long
AQ	P-42	6	91860A029	17-7 PH Stainless Steel Washer for 1/4" Screw Size, General Purpose, 0.312" ID, 0.750" OD
AR	P-43	1	N/A	KUIU Carbon Fiber Frame
N/A	P-44	1	N/A	KUIU PRO Suspension Padded Harness

The hole template is a 2.35" x 4.5" rectangle across the upper middle of the frame where the Velcro patches built into the spine and the open channels for the shoulder straps are located with another line drawn at 2" below the top horizontal of the hole template. With this drawn on the back of the spine, you should now have six vertices where you will mark 'x's to then drill through with a 1/4" drill bit. Other reference measurements are shown below for trying to align the template to the middle of the frame; unfortunately, the manufacturer does not provide the CAD for this frame so only hand-taken measurements and dimensions were captured and drawn.



Figure 4-21. Hole Template Drawing for Drilling into the Frame.
Note the difference in heights of the template between the extra tall and the tall sized frame.

Before drilling, wear the proper PPE since this frame has carbon fiber in it and fine powder will aerate once drilled into. To drill into the frame, clamp the flat part of the frame down to a wooden block or surface, then align the drill bit into the center of the 'x' mark for your holes. After six holes are drilled, use a Dremel or sandpaper/sanding strips to remove any flaking or sharp bits from the holes. Rinse the holes with a small amount of water and paper towel dry to help release any fine plastic/fiber material from the frame before use or touching with your bare hands.

Once the frame is ready, it is now time to strap the padded harness to the frame before mounting to the backplate of HS3. Since the harness and frame are sold separately, the padded harness and frame system must be put together and are not one unit.

1. Undo the lower lumbar pad from the Velcro on the back of the hip belt. Slide the bottom part of the frame into this 'pocket' in the hip belt. Ensure the large vertical Velcro strap is behind and above the middle support of the frame (orange rectangle in Figure 4-22).
2. Flip the large Velcro strap down onto the Velcro patch at the back of the hip belt.
3. Align the bottom of the lumbar pad with the bottom of the hip belt and Velcro to the hip belt.
4. Wrap and Velcro the left and right straps on the lumbar pad around the frame to hold it in place and fasten it to the Velcro on the back of the lumbar pad.
5. Rotate the shoulder horizontally to align and guide the plastic T-shaped tab on the back of the shoulder pad into the open channels of the frame. Rotate the shoulder pad 90 degrees counterclockwise to lock the shoulder pads to the frame.
6. Velcro the back of the shoulder pad to the Velcro patch on the frame. Adjust as necessary for subjects.



Figure 4-22. Visual Instructions for Attaching the Padded Harness to the Frame.

To mount the harness and frame to the backplate of the PLSS as seen in Figure 4-23, align the six drilled holes in the frame with the six ¼-20” heat inserts melted into the backplate in the same 2x3 pattern. Use fasteners **AP** and washers **AQ** (Table 4-20) with an Allen key tool to secure the harness and frame to the backplate.



Figure 4-23: Mounting the Frame to the Backplate.

Once secured to the backplate, verify the straps at the top ends of the spine are connected to the straps across the length of the shoulder padding (“vertical adjustment straps”). These straps can be used to help correct slacking or drooping postures and straighten the wearer’s back, which should help mitigate injury and back soreness related to wear of the HS3.

4.2.6 Electronics, Sensors, and Cabling

The electrical system of the HS3 PLSS consists of a central power bank (Anker C200 portable power bank in HS3 2.5, Egrettech 300W portable power bank in HS3 2.0) to provide power to the three different critical subsystems: 1) the liquid cooling subsystem, which includes the DC motor controller, potentiometer, toggle switch for the water pump and the water pump itself; 2) the sensor hardware, which includes a Raspberry Pi assembly with DS18B20 sensors, sensor modules, and associated wiring and boards; 3) a visor ventilation fan and cable with an in-line switch. An equivalent power bank can be used in substitute for the Anker C200 if the power outputs of said power bank are like the Anker C200 or Egrettech 300W. See Table 4-21 for more details on HS3 power consumption of electronics/hardware as well as refer to the manufacturer’s manual for greater details. Note the COSMED K5 metabolic cart has its own internal battery pack, so this is excluded from the usage of the PLSS power bank. Furthermore, the Egrettech 300W is not shown in this table as the table below is for HS3 2.5 hardware, not HS3 2.0 hardware; estimated power consumption for HS3 2.0 hardware was 44-47Wh for a total 282W over 6 hours of usage.

Table 4-21. Power Management Plan of HS3 2.5 Components

BOM ID	Qty.	Short Description	Power Specs	Watt-Hours (Observed)	Power Cons. (for 6 hrs, Observed)	% Battery (for 6 hrs, Observed)
E-3	1	DC Motor Controller	6-30V DC, max 8A output	-	-	N/A
E-17	1	Raspberry Pi 3B+	5V, 3A (15Wh)	~3 Wh	max: 18W	9%
E-26	1	USB Ventilation Fan	5V DC (2.5Wh)	~2 Wh	max: 12W	6%
P-13	1	Water Pump	12V DC, 3A (36Wh)	~28 Wh*	max: 168W*	84%*
E-2	1	Anker SOLIX C200 DC Power Bank Station	(x3) USB Type A, (x1) 15W USB-C, (x1) 100W USB-C, (x1) 140W USB-C ports. 200W max.	Total: 33Wh	Total: 198W	Total: 99%

**Power consumption (observed) and watt-hours of water pump is an estimated max and assumes the pump is switched on for 6 hours straight; in reality, subjects switch ON and OFF the water pump to achieve their desired thermal preference, so the number shown in the table is inflated.*

The PLSS captures the liquid cooling feed water temperature that is directly pulled from the inlet and outlet of the LCG feed water plumbing. The temperature sensors are DS18B20 temperature probes that operate via a 1-wire communication protocol and the probe heads are installed into 50mm thermowells thread into the PVC T-adapters (see Figure 4-24). The sensors subassembly uses a Raspberry Pi to collect the data via a DS18B20 breakout board soldered onto a prototyping customizable Raspberry Pi HAT. Schematic wiring is shown below (Figure 4-24) to show placement of the breakout boards and appropriate power, ground, and data pins. Both breakout kits are tied to the same GPIO pin #4 for data capture (DAT pin on DS18B20 breakout board). The DS18B20 green terminal block is wired to a female 3-pin LEMO connector that is mounted to the Raspberry Pi housing. The DS18B20 temperature probes are then wired to a mating male 3-pin LEMO connector.

Table 4-22. Raspberry Pi - Housing, Sensors, Boards, and Standoffs – Parts List

Item	BOM ID	Qty.	Part #	Description
AS	E-17	1	3775	Raspberry Pi 3 - Model B+ - 1.4GHz Cortex-A53 with 1GB RAM
AT	E-18	4	93655A096	Male-Female Threaded Hex Standoff, M2.5, 10mm long

AU	E-19	4	91292A009	M2.5, 5mm long, 18/8 Stainless Steel Socket Head Screw
AV	E-20	2	B09NVWNLQ	BOJACK DS18B20 Temperature Sensor Module Kit with Waterproof Stainless Steel Probe for Raspberry Pi
AW	E-21	1	1528-1369-ND	Perma-Proto HAT
AX	E-22	2	NOR1416-ND	LEMO CONN RCPT MALE 3P GOLD SLDR CUP
AY	E-23	1	N/A	Raspberry Pi Housing (Top)
AZ	E-24	1	N/A	Raspberry Pi Housing (Bottom)

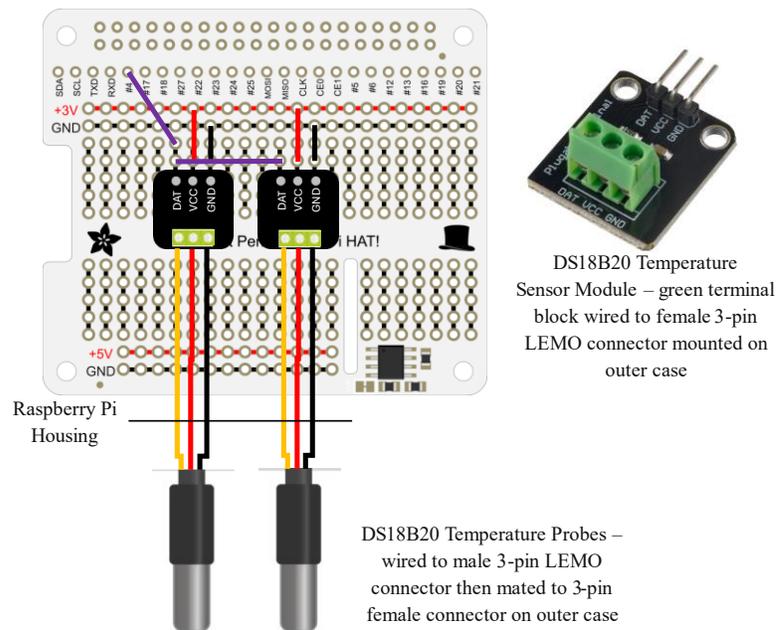


Figure 4-24. Wiring Schematic of Raspberry Pi, Sensors, and Sensor Modules.
Red – Power (VCC), Black – Ground (GND), Yellow – Data (DAT).

Following completion of the schematic wiring diagram, the CAD assembly for the Raspberry Pi data collection subsystem is represented in an assembly step approach (Figure 4-25, parts in Table 4-22). Fasten the Raspberry Pi **AS** to the bottom housing by using hex standoffs **AT**. Fasten the assembled proto-board HAT with DS18B20 sensor modules to the Raspberry Pi using screws **AU** threaded into the hex standoffs. Then, fasten the LEMO connectors **AX** to the Raspberry Pi top housing **AY**. Once fastened and all wiring connected, friction-fit the Raspberry Pi top and bottom housings together to close off the electronics. The Raspberry Pi assembly is now ready to be inserted into the PLSS and the DS18B20 sensors inserted into the 50mm thermowells.

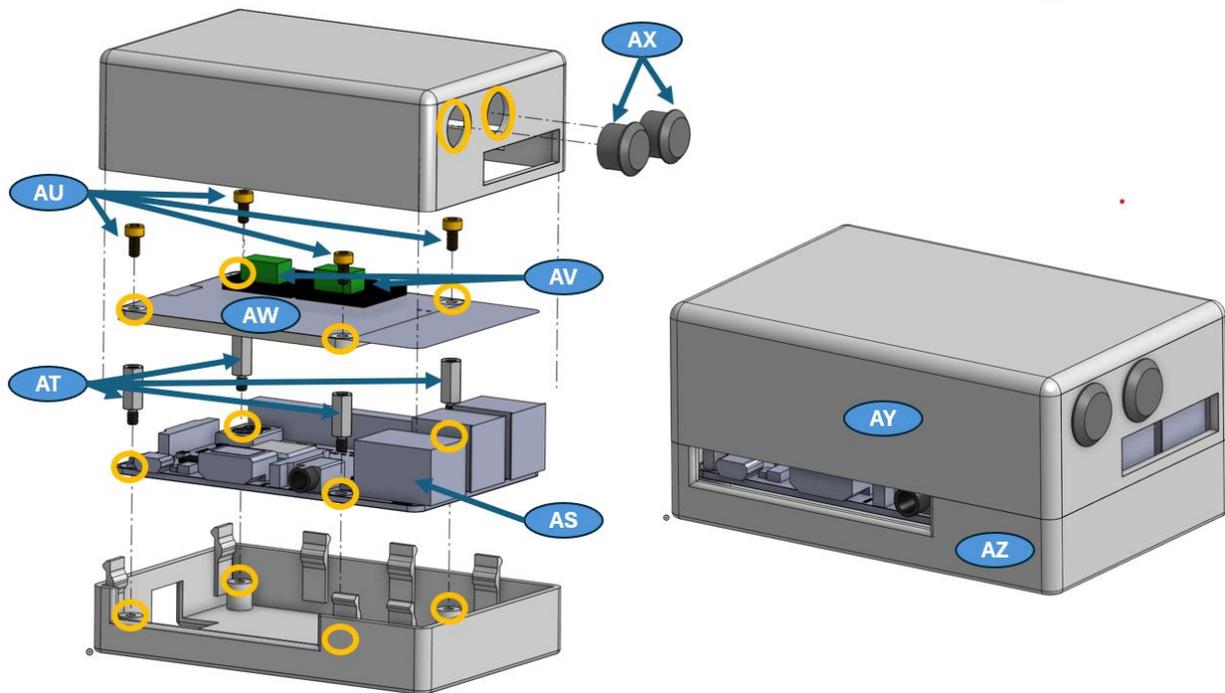


Figure 4-25. Raspberry Pi Sensor Assembly.

Table 4-23. Raspberry Pi and DS18B20 Sensor Wiring/Cables – Parts List

Item	BOM ID	Qty.	Part #	Description
BB	E-2	1	N/A	Anker SOLIX C200 DC Power Bank Station
BC	E-8	1	B0BXX1L8G7	Short Micro USB to USB C Cable 0.65 FT
BD	E-9	1	N/A	CanaKit Raspberry Pi 3 PiSwitch (Micro USB)
AV	E-20	2	B09NVWNLQ	BOJACK DS18B20 Temperature Sensor Module Kit with Waterproof Stainless Steel Probe for Raspberry Pi
AF	P-22	1	B08QV4F8FF	50mm Thermowell
-	E-25	2	N/A	Square 3M Double Sided Adhesive Pads
-	P-29	AR	7565K31	Cable Holders Adhesive-Back, Vinyl, 1/2" Long x 1/2" Wide x 7/16" High
-	P-30	AR	7565K81	Cable Holders Adhesive-Back, Nylon, 1" Long x 5/8" Wide x 9/16" High

To install and plug in the Raspberry Pi and DS18B20 sensors, first mount the Raspberry Pi assembly to the backplate inside the PLSS by using 3M adhesive pads (Table 4-23) attached to the housing. Wire and plug in the microUSB-to-USB-C cable **BC** into the Raspberry Pi and into the

female USB-C end of the CanaKit RPi Switch **BD**. Wire the CanaKit RPi Switch into the 15W USB-C port of the Anker C200 power bank **BB** using the native USB-C cable with the button switch. For the DS18B20 sensors, feed the sensor cables from the lemo connectors of the Raspberry Pi assembly all the way to the bottom of the PLSS. Use cable holders as needed for cable management. Once fed to the bottom of the PLSS, install the DS18B20 sensor probe heads into the 50mm thermowells **AF**; to install, loosen the black caps of the thermowells, insert the probe head into the thermowell until the cable cannot feed any further in, then tighten the black caps to secure the probe heads inside the thermowells. Optionally, use a thermal paste to also secure the sensor probe heads inside the thermowells and to get better sensor contact with the thermowell channel (can help improve sensor accuracy). Once the Raspberry Pi and DS18B20 sensors are installed, power on the Anker C200 battery then verify data readings are being collected by turning on the Pi using the button switch.

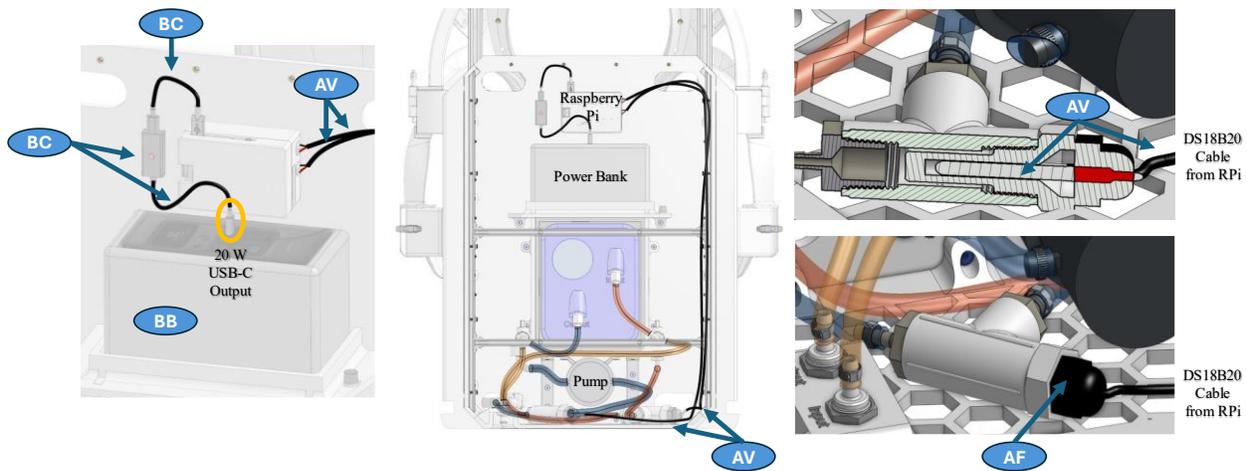


Figure 4-26. Raspberry Pi and DS18B20 Sensor Installation and Cable Routing.

Table 4-24. DC Motor Controller, Pump, and Toggle Switch Wiring/Cables – Parts List

Item	BOM ID	Qty.	Part #	Description
BB	E-2	1	N/A	Anker SOLIX C200 DC Power Bank Station
BE	E-3	1	B098WKHD75	6V-30V 8A DC Motor Speed Controller
BF	E-5	AR	B0CGHF2BSD	16 AWG Stranded PVC Cord, 12V Low Voltage/Tinned Copper/Flexible Cable
BG	E-6	1	B08PYT6HZ2	DC Power Pigtails, 3FT DC 5.5MM x 2.1MM Female Plug to Bare Wire
BH	E-7	1	B0CBNQN7CR	USB C to DC 5.5mm x 2.1mm Power Cable Cord
BI	E-10	1	B07T6XWZKN	Waterproof Toggle Switch 12V DC 30A Heavy Duty 2 Pin
BJ	E-11	1	B07VL7KSZP	Blue Waterproof Safety Cover Switch Guard
BK	E-12	1	N/A	Toggle Switch Box
BL	E-13	1	N/A	Toggle Switch Box Lid

-	E-14	AR	B08BZ972B5	Nylon Spade Quick Disconnect Connectors
BM	E-15	1	B0BQSPD7YL	Universal CPAP Hose - 6 Foot
-	E-16	AR	B08B4GVVQJ	Vinyl Electrical Adhesive Tape
-	E-25	1	N/A	Square 3M Double Sided Adhesive Pads
-	P-29	AR	7565K31	Adhesive Cable Holders Adhesive-Back, Vinyl, 1/2" Long x 1/2" Wide x 7/16" High
-	P-30	AR	7565K81	Cable Holders Adhesive-Back, Nylon, 1" Long x 5/8" Wide x 9/16" High
-	H-24	AR	B00AQ6IS1G	3M Dual Lock Reclosable Fastener Adhesive Tape

First, mount the DC motor controller **BE** (Table 4-24) onto the backplate inside the PLSS by using adhesive pads (see Figure 4-27). For the water pump power cable, connect the USB-C-to-male DC cable **BH** into the female DC-to-bare wire cable **BG**. Then, connect the bare wire ends of the assembled cable to the positive-negative screw terminals of the DC motor controller in the ‘Power’ terminals and tighten down using a Philips screwdriver. The male USB-C end can then be plugged into the 100W output port on the Anker power bank **BB** and the battery can now be powered on. For the water pump itself, the pump has two bare wires (red – power (VCC), green – Ground (GND)) that extend from the back of the pump. With 16 AWG wire **BF** and some male and female quick-disconnect electrical connectors, crimp the cable ends of the pump and the 16 AWG wire together at the necks of the electrical connectors. This minimizes soldering required for the electrical system as well as allows for easy hot swap/disconnection of components if any need to be replaced or troubleshooted. Then, connect the bare wire ends of your assembled cable to the positive-negative screw terminals in the DC motor controller for the ‘Motor’ and tighten down using a Philips screwdriver. The potentiometer for the DC motor controller is already assembled and wired out of the box, so you can easily adhere it to the battery compartment shelf using glue or adhesive pads. Note the potentiometer is always and must be set to ‘100’ [100% power] in our detailed test procedures as indicated by the LED screen, but the potentiometer is otherwise left untouched. Once the motor is wired properly, insert an LCG bladder bag filled with DI water into the LCG compartment and connect the bladder to the inlet and outlet fluid QDs. We will test the liquid cooling system and pump once the toggle switch is installed and wired. Use cable holders for cable management as desired.

To wire the toggle switch, we will need the 16 AWG cable **BF** and some male and female quick-disconnect electrical connectors. First, cut off the rocker switch that comes pre-assembled with the DC motor controller then use a cable stripper tool to expose the bare wire. Then, crimp some male and female electrical connectors to the prepared wire from the DC motor controller and some unsheathed/bare end 16 AWG wire bundle and connect the two wires together. This will be about a 4-5ft cut length bundle of 16 AWG wire. Next, grab the CPAP tubing **BM** and cut off 2.5 feet of one side of the tube while leaving the other rubber connector as is. Feed the rubber connector end of the CPAP tubing around two cutout hexagons of the PLSS right wall to secure it in place snugly; feed the cut end through the bottom right opening of the backplate (see Figure 4-28). Once fed through the backplate, feed the prepared switch wiring through the entire length of the CPAP tubing as to bring the bare ends of the wire bundle through the end of the tube.

Once the wire bundle is through the CPAP tubing, assemble the toggle switch box. To do so, fasten the toggle switch **BI** (Table 4-24) with its hex nut and the switch guard **BJ** to the toggle switch box **BK** at the hole in the box. Note the switch guard is optional (as it will take two flips of the toggle switch to turn on the water pump instead of one). Once the toggle switch is fastened to the box, connect the wire bundle from the CPAP tubing to the screw terminals of the toggle switch and tighten using a Philips screwdriver. Next, slide the toggle switch box lid **BL** onto the box to close off the electrical wires and terminals of the switch. After, use electrical tape to hold the cut end of the CPAP tubing as close to the toggle switch box as possible to cover/shield the wiring underneath. Lastly, add some dual lock strips to the back of the toggle switch box as to allow for easy mounting to the front of the HUT.

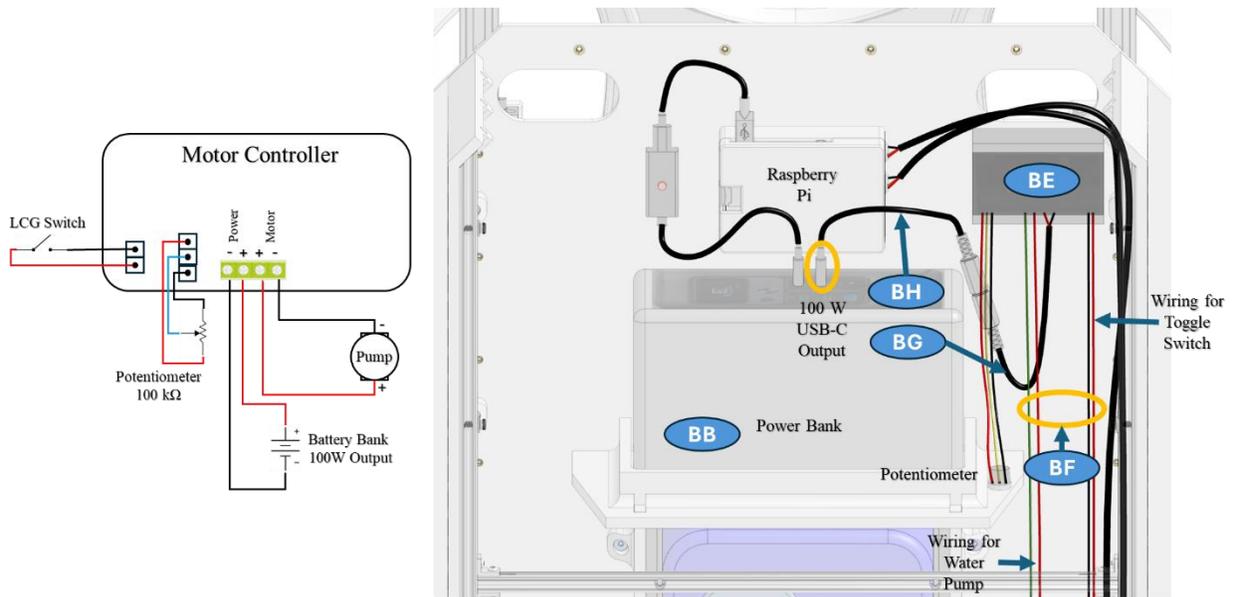


Figure 4-27. DC Motor Controller Wiring Configuration.

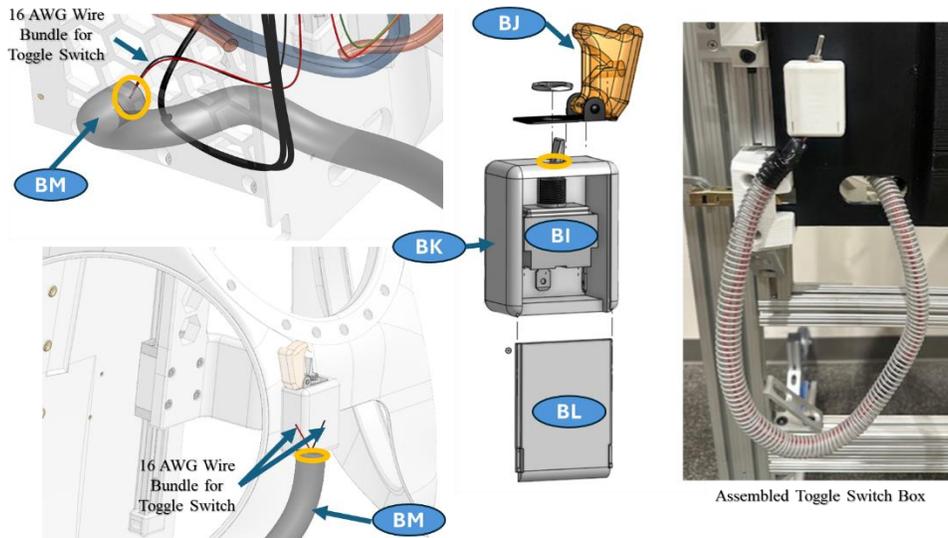


Figure 4-28. Toggle Switch Assembly and Cable Routing

Once the toggle switch is wired and installed, you may now test the liquid cooling system assembled in Section 4.2.4. Connect an LCG garment to the LCG hose extension and turn on the toggle switch by rocking it twice. If any leaks are present/observed while water is running through the system, immediately power off the water pump with the toggle switch and tighten any hose clamps or hose fittings down to repair the leak. If the water pressure seems to be causing the issue: on the top of the water pump, there is a set of three screws with the middle screw being a pressure screw to allow for adjustment of flow pressure. Simply loosen this screw with a Philips screwdriver and power on the water pump again. If leaks are still observed, inspect the tubing itself at all connections for any holes or punctures and replace as necessary.

For the ventilation fan in the visor, this will be assembled and connected to the electrical system in Section 4.1.3.

4.3 Soft Suit and Soft Goods

This section documents the design, construction, and assembly of the HS3 soft suit (Part A, BOM# S-1), HUT Arms Canvas Cover (Part B, BOM#S-13), and Glove System (Part C, BOM#S-12).

4.3.1 Design Details

The soft suit and glove system are designed to provide extravehicular activity (EVA) simulation while offering flexibility and integrability with Human Health and Performance (HH&P) measures. The HUT arms canvas cover is designed to minimize soft suit wear and tear on the underarm sleeve due to repeated contact when the subject's arms brush against the 3D printed HUT.

Key design features of the HS3 soft suit are shown in Figure 4-11. The designs were intentionally kept simple to facilitate good EVA simulation.

- **EVA simulation:** the soft suit creates a space suit-like environment by isolating subject from the surrounding environment.
- **Regulated thermal environment:** The soft suit is made of a breathable water resistant two-layer fabric. It partially retains heat, reduces the effect of skin convective cooling, and allows thermal load simulation similar to a space suit (compared to shirt sleeve where convective cooling makes thermal load simulation less suit-like). It also provides a regulated thermal environment when used with the integrated LCG and reduces external environment impact on in-suit thermal environment.
- **Flexible Anthropometric Range:** the suit is designed with a vertical length adjustment belt and is flexible to accommodate a wide range of subject anthropometry within a single suit size.
- **Flexible health sensor attachment points:** the suit has 8 built-in Velcro sensor attachment points that allow easy attachment of sensors external and internal to the suit.
- **Multiple access ports:** The suit features six 7-in long zipper ports that allow internal access to the suit during EVA simulation without doffing the suit. This feature enables easy adjustment of the underlayer garments and integrated sensors.

- **Built-in PLSS integration:** The suit is designed to integrate directly with the PLSS in providing built-in connection points for the LCG hose and ventilation system (optional in HS3 2.5) via 3D printed (3DPT) ventilation adapter ports on the suit.
- **Knee and Elbow pad pockets:** Integrated pockets on the suit allow insertion of knee and elbow pads. The pocket material was selected to add durability against damage during EVA simulations.
- **Integrated range of motion (ROM) restrictions:** The soft suit itself offers ROM restrictions around the entire body via the baggy fabric layer. The soft suit also keeps ROM restriction devices in place.

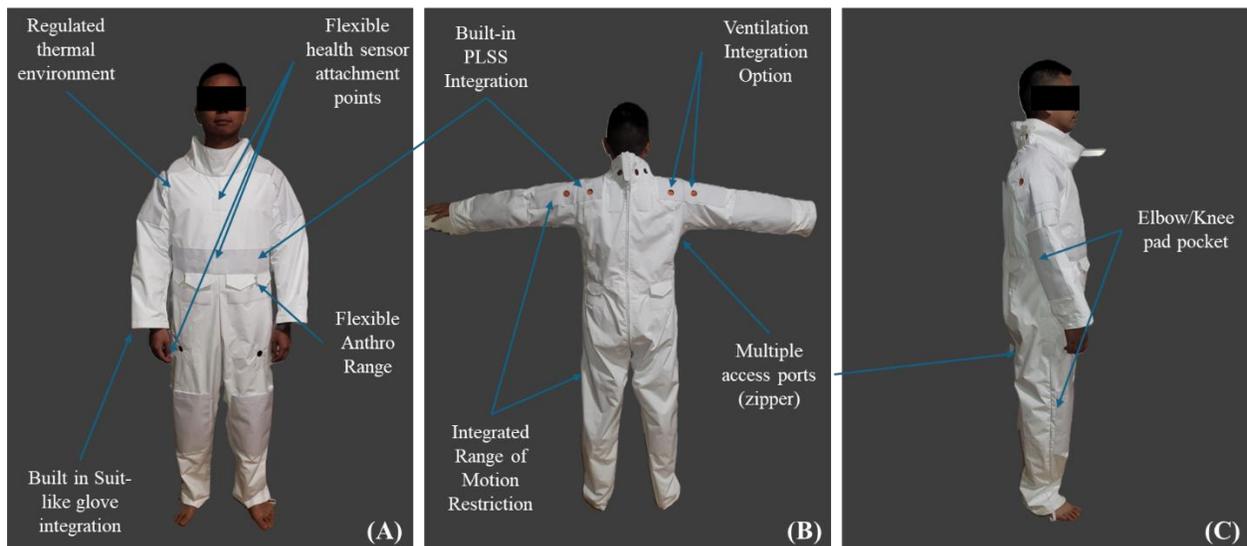


Figure 4-29. HS3 Soft Suit

(A) Front View, (B) Back View, and (C) Side View. Model is wearing a size small.

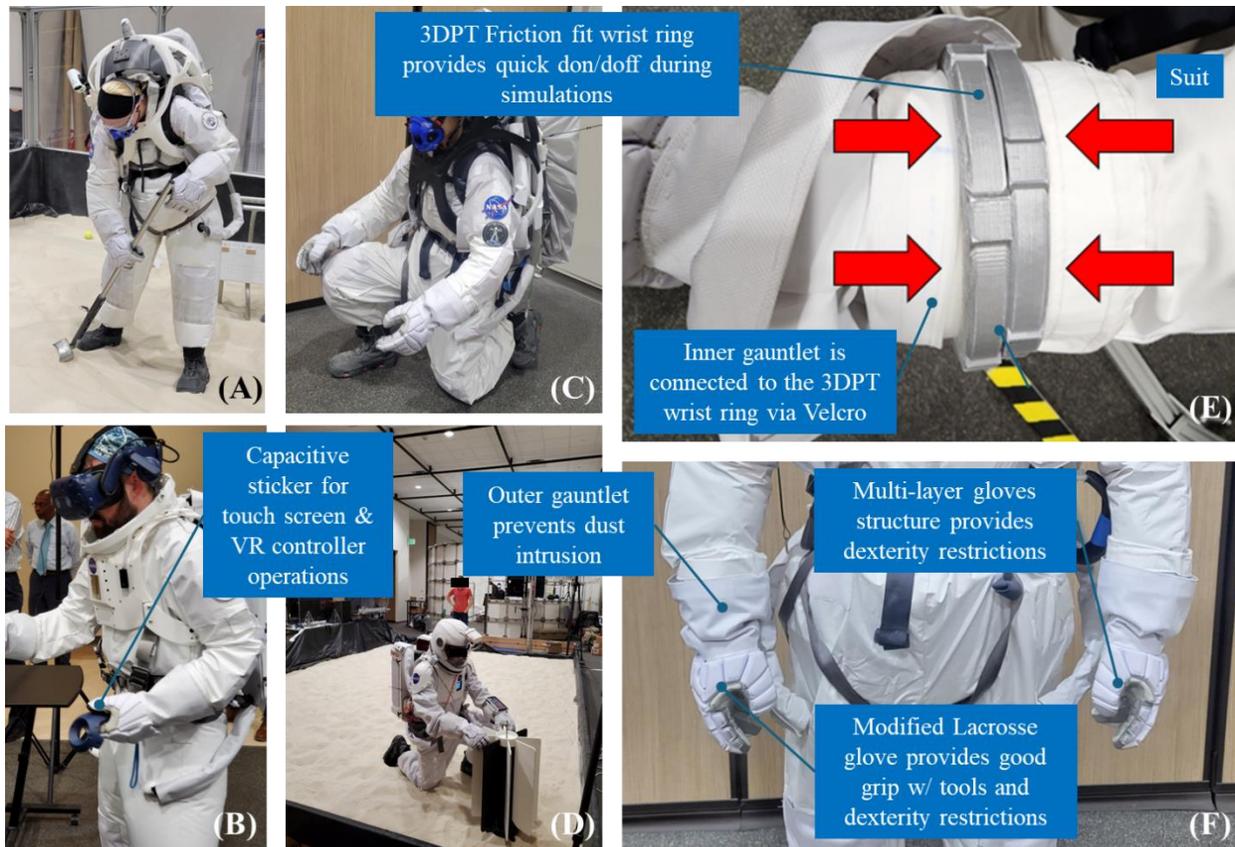


Figure 4-30. HS3 Glove System

(A) Glove System Used During Geology (HS3 2.0), (B) Glove System Used During VR simulation (HS3 1.0), (C) Glove System Keeps Palm Slightly Open During Neutral Position, (D) Glove System Used During Task Board Operation, (E) Glove System Wrist Ring, and (F) Glove System Component View.

The glove system is designed to (1) provide convenient quick-release glove integration, (2) mitigate against dust intrusion, (3) provide EVA-like finger dexterity restriction, and (4) provide Virtual Reality (VR) controller integration via capacitive stickers at fingertips (optional). The glove system is composed of an inner layer of GORE-TEX comfort glove and an outer layer of a modified lacrosse glove. The lacrosse glove is connected to an inner gauntlet with integrated 3DPT wrist ring and an outer gauntlet that protects the wrist ring and inner gauntlet from dust intrusion. The gauntlet can be easily removed from the wrist ring using its Velcro interfaces. In the neutral position, the HS3 glove system keeps the palm semi-open with the thumb separated from the rest of the fingers (Figure 4-12). The multi-layer glove and the bulky lacrosse glove design provides dexterity restriction when subjects close their palms to use tools. Key design features of HS3 glove system are shown in Figure 4-13. The design is intended to mimic that of an Extravehicular Mobility Unit (EMU) glove.



Figure 4-31. HS3 2.5 Glove System Design Features.

(A) Inner Layer Consists of a COTS GORE-TEX Glove (Photo credit: public domain, [LINK](#)) (B) Outer Layer is Made of Modified COTS Lacrosse Glove, and (C) Outer Glove Consists of a Modified COTS Lacrosse Glove Body, an Inner Gauntlet, and Outer Gauntlet, and a 3DPT Wrist Ring that Integrates with a Male 3DPT Wrist Ring on the Suit.

Nomenclature of the Soft Goods Parts

A full glossary of all soft goods construction components is provided in Table 4-8 with information collocated, e.g., pattern ID, material usage, quantity, sub part name and numeration, and where the instructions are located in this report. This table is separated into three segments, i.e. the soft suit (Part A, BOM# S-1) which is constructed using all the [A-#] parts, the HUT Arms Canvas Cover (Part B, BOM#S-13) which is constructed using all [B-#] parts, and the Glove System (Part C, BOM#S-12) which is constructed using all [C-#] parts. An illustration of the location of all the soft suit parts [A-#] is shown in Figure 4-32 (front view) and Figure 4-33 (back view). Figure 4-34 shows the definition and location of the soft suit ventilation/LCG hole, zipper, and seam locations. Table 4-26 provides a soft goods fabric key that matches the master Bill of Materials (BOM) presented in Section 4.6.1. This table shows the required soft good amounts and coding for the soft goods system. The above-mentioned nomenclature overview is critical for

understanding and usage of Section 4.3.2, and users are recommended to reference these nomenclature overview tables and pictures for clarity.

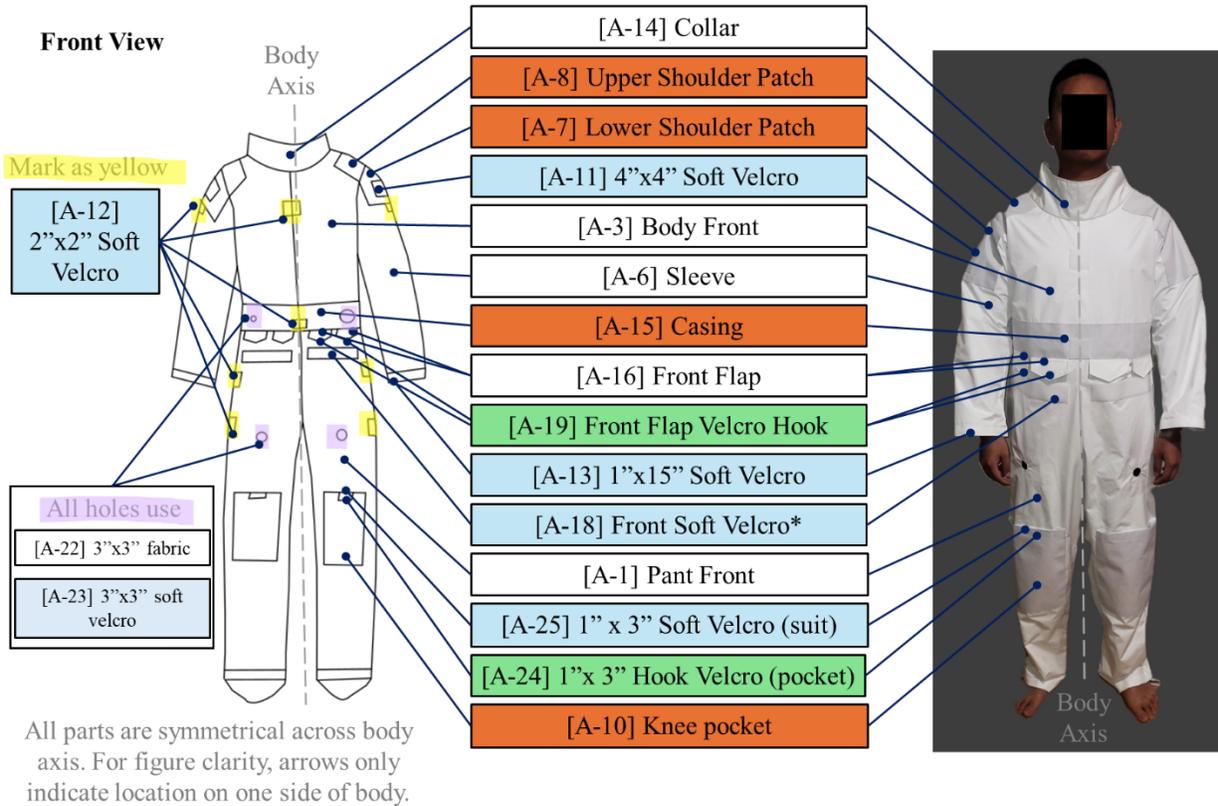


Figure 4-32. HS3 Soft Suit (front view) Schematics (left) and Completed View (right) with Parts Labeled Matching Pattern Index.

Note: * = see Table 4-25 for size details. Color coding follows fabric key in Table 4-26.

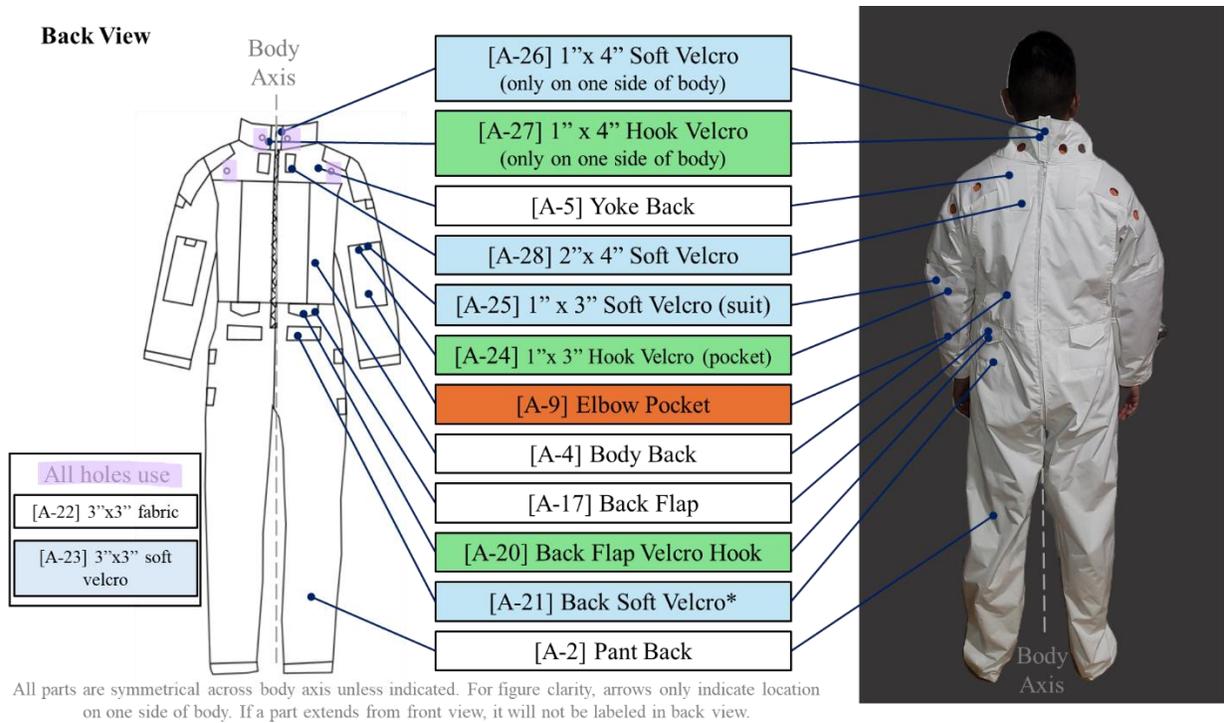


Figure 4-33. HS3 Soft Suit (back view) Schematics (left) and Completed view (right) with parts labeled matching pattern index.

Note: * = see Table 4-25 for size details. Color coding follows fabric key in Table 4-26.

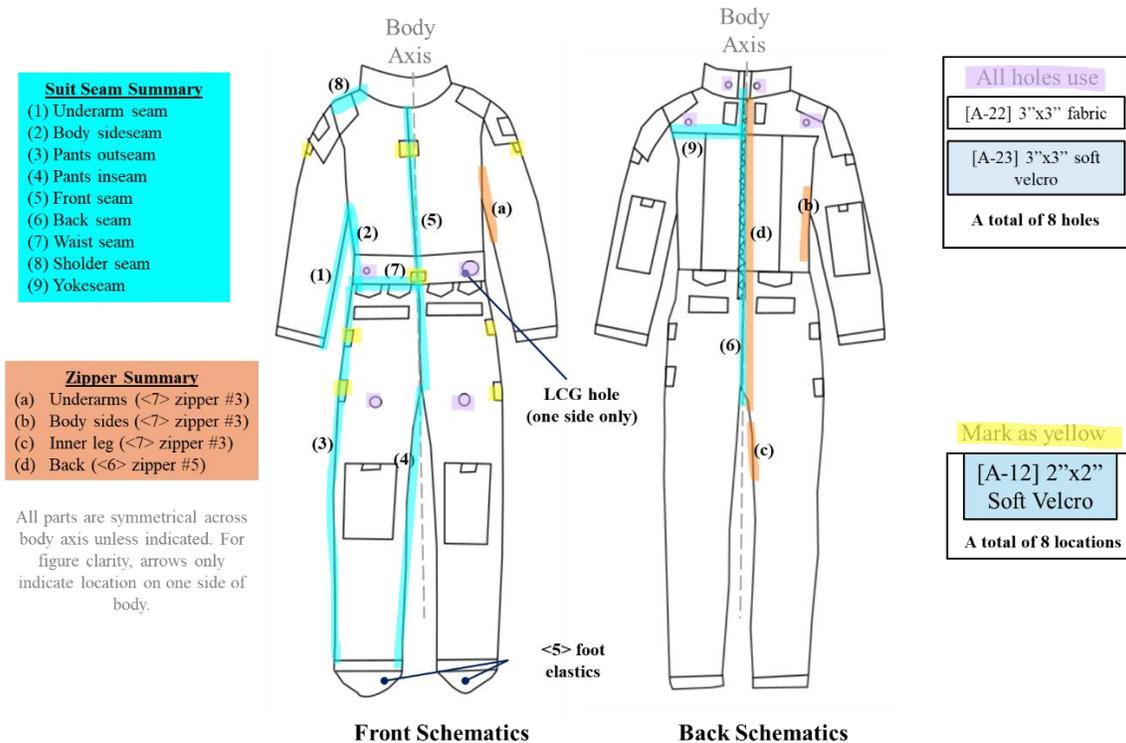


Figure 4-34. HS3 Soft Suit Ventilation/LCG Hole, Zipper, and Seam Locations.

Table 4-25. Pattern Index.

Note: “L” indicates large suit, and “S” indicates small suit. Color coding follows fabric key in Table 4-26.

[#]	Part Name	Qty	Materials	Purpose	Instruction	Pattern
[Part A] Soft Suit (to create one suit: large (L) or small (S))						
[A-1]	Pant Front	2	<2> Nylon	Suit pant (require one per leg)	4.3.2.3.7	(I-1)
[A-2]	Pant Back	2	<2> Nylon	Suit pant (require one per leg)	4.3.2.3.4	(I-2)
[A-3]	Body Front	2	<2> Nylon	Suit body (require one per side)	4.3.2.3.4	(I-3)
[A-4]	Body Back	2	<2> Nylon	Suit body (require one per side)	4.3.2.3.4	(I-4)
[A-5]	Yoke Back	2	<2> Nylon	Suit body (require one per side), Connects [A-3,4,14,6,7,8]	4.3.2.3.4	(I-5)
[A-6]	Sleeve	2	<2> Nylon	Soft suit sleeves	4.3.2.3.3	(I-6)
[A-7]	Lower Shoulder Patch	2	<1> Canvas	Shoulder cover to resist wear/tear with HUT usage, increase ROM restriction	4.3.2.3.3	(I-7)
[A-8]	Upper Shoulder Patch	2	<1> Canvas	Shoulder cover to resist wear/tear with HUT usage, increase ROM restriction	4.3.2.3.5	(I-8)
[A-9]	Elbow Pocket	2	<1> Canvas	Elbow pocket to contain elbow pad	4.3.2.3.2	(I-9)
[A-10]	Knee Pocket	2	<1> Canvas	Knee pocket to contain knee pad	4.3.2.3.2	(I-10)
[A-11]	4”x 4” Soft Velcro	2	<3> Velcro Soft	Allow auxiliary sensor attachment (e.g., IMU) or patch attachment	4.3.2.3.3	NA
[A-12]	2”x 2” Soft Velcro	8	<3> Velcro Soft	Allow auxiliary sensor attachment (e.g., IMU) or patch attachment	4.3.2.3.3	NA
[A-13]	1”x 15” Soft Velcro	2	<3> Velcro Soft	Velcro to attach 3DPT wrist ring	4.3.2.3.7	NA
[A-14]	Collar	2	<2> Nylon	Front and back joint into single collar	4.3.2.3.10	(I-14)
[A-15]	Casing	1	<1> Canvas	Waist casing to support LCG opening	4.3.2.3.12	(I-15)
[A-16]	Front Flap	8	<2> Nylon	Vertical suit length adjustment (front), need two pieces to make one unit. Four units required per suit.	4.3.2.3.11	(I-16)
[A-17]	Back Flap	4	<2> Nylon	Vertical suit length adjustment (back), need two pieces to make one unit. Two units required per suit.	4.3.2.3.11	(I-17)
[A-18]	Front Soft Velcro L: 2” x 9” S: 2” x 8.5”	L: 4 S: 2	<3> Velcro Soft	Vertical suit length adjustment (front)	4.3.2.3.12	NA

#]	Part Name	Qty	Materials	Purpose	Instruction	Pattern
[A-19]	Front Flap Velcro Hook	4	<4> Velcro hook	Hook Velcro on the flap to support vertical suit length adjustment (front)	4.3.2.3.11	(I-19)
[A-20]	Back Flap Velcro Hook	2	<4> Velcro hook	Hook Velcro on the flap to support vertical suit length adjustment (back)	4.3.2.3.11	(I-20)
[A-21]	Back Soft Velcro L: 2" x 5.5" S: 2" x 4"	2	<3> Velcro Soft	Vertical suit length adjustment (back)	4.3.2.3.12	NA
[A-22]	3" x 3" Fabric	8	<2> Nylon	For suit holes, ventilation hose adapter for 3D printed vent coupler (optional for HS3 2.5 if not using ventilation). But x1 hole is required for HS3 2.5 LCG.	4.3.2.3.13	NA
[A-23]	3" x 3" Soft Velcro	8	<3> Velcro Soft		4.3.2.3.13	NA
[A-24]	1" x 3" Hook Velcro	4	<4> Velcro hook	Secure/close knee/elbow pocket (hook side on the pocket)	4.3.2.3.2	NA
[A-25]	1" x 3" Soft Velcro	4	<3> Velcro Soft	Secure/close knee/elbow pocket (soft side on the suit)	4.3.2.3.2	NA
[A-26]	1" x 4" Hook Velcro	1	<4> Velcro hook	Secure/close collar via Velcro	4.3.2.3.10	NA
[A-27]	1" x 4" Soft Velcro	1	<3> Velcro Soft	Secure/close collar via Velcro	4.3.2.3.10	NA
[A-28]	2" x 4" Soft Velcro	2	<3> Velcro Soft	For auxiliary sensor attachment on body back		NA
[A-29]	4"x 4" fabric	2	<2> Nylon	Velcro cover to protect the velcro when not in use. Optional if [A-22] is not made.		NA
[A-30]	4"x 4" hook Velcro	2	<4> Velcro hook	Velcro cover to protect the velcro when not in use		NA
[A-31]	2"x 2" Fabric	8	<2> Nylon	Velcro cover to protect the velcro when not in use		NA
[A-32]	2"x 2" Hook Velcro	8	<4> Velcro hook	Velcro cover to protect the velcro when not in use		NA
[A-33]	3"x 3" Fabric	8	<2> Nylon	Velcro cover to protect the velcro when not in use. (vent holes)		NA
[A-34]	3"x 3" Hook Velcro	8	<4> Velcro hook	Velcro cover to protect the velcro when not in use. (vent holes)		NA
[Part B] HUT Arms Canvas Cover (to create one pair of arms cover)						
[B-1]	10" x 13" Canvas	2	<1> Canvas	Body of the cover (Front Side)	4.3.2.4	(II-1)
[B-2]	10" x 13" Canvas	2	<1> Canvas	Body of the cover (Back Side)	4.3.2.4	(II-2)
[B-3]	1" x 8" Soft Velcro	4	<3> Velcro Soft	Fastening mechanism for the canvas cover	4.3.2.4	NA

#]	Part Name	Qty	Materials	Purpose	Instruction	Pattern
[B-4]	1" x 8" Hook Velcro	4	<4> Velcro hook	Fastening mechanism for the canvas cover	4.3.2.4	NA
[B-5]	4" x 8" Arm Cover Foam	2	<8> EVA Foam	provide padding between arms and 3DPT HUT	4.3.2.4	NA
[Part C] Outer Glove System (to create one pair of gloves)						
[C-1]	18" x 6" Nylon	2	<2> Nylon	Inner gauntlet	4.3.2.5	III-1
[C-2]	20" x 7" Canvas	2	<1> Canvas	Outer gauntlet	4.3.2.5	III-2
[C-3]	6" x 1" Soft Velcro	2	<3> Velcro Soft	Inner Gauntlet Soft Velcro for closing	4.3.2.5	NA
[C-4]	6" x 1" Hook Velcro	2	<4> Velcro hook	Inner Gauntlet Hook Velcro for closing	4.3.2.5	NA
[C-5]	8" x 1" Soft Velcro	2	<3> Velcro Soft	Outer Gauntlet Soft Velcro for closing	4.3.2.5	NA
[C-6]	8" x 1" Hook Velcro	2	<4> Velcro hook	Outer Gauntlet Hook Velcro for closing	4.3.2.5	NA
[C-7]	h3po-pn-xxxx-glv-disc-a (BOM [S-14])	2	IC3D ABS White	3DPT Glove Ring Cuff Connector (male), attached to suit	4.3.2.5	NA
[C-8]	h3po-pn-xxxx-glv-disc-b (BOM [S-15])	2	IC3D ABS White	3DPT Glove Ring Cuff Connector (female), attached to glove	4.3.2.5	NA
[C-9]	13.75" x 1" Soft Velcro	2	<3> Velcro Soft	Inner Gauntlet Soft Velcro (for wrist ring connection)	4.3.2.5	NA
[C-10]	13.75" x 1" Hook Velcro	2	<4> Velcro hook	Velcro on the 3DPT cuff connector (female)	4.3.2.5	NA
[C-11]	Warrior Burn Lacrosse Gloves	2	COTS Lacrosse Gloves	HS3 Outer Glove	4.3.2.5	NA
[C-12]	13.75" x 1" Hook Velcro	4	<4> Velcro hook	Velcro on the 3DPT cuff connector (male)	4.3.2.5	NA

Note: The digital pattern provides only 1 unit of pattern per each line item in Table 4-25. To complete the number of quantities specified in Table 4-8 required for each suit, follow cutting instructions below to “FOLD and DOUBLE LAYER CUT.”

4.3.2 Construction

The HS3 soft suit and soft good items are designed to be easily manufacturable at low cost and can be constructed with basic equipment and skills by following instructions in this section, or at a professional tailor shop by providing the instructions to a tailor.

4.3.2.1 Tools and Materials

For sewing, the study team recommends using a **size 14 needle** for all canvas sewing, **and a size 12 needle** for all other materials. It is expected the user is familiar with sewing machine usage and will use general sewing supplies/tools as needed (i.e., fabric chalk, fabric scissors, seam ripper, measurement tape, hand sewing needles). These items are not listed in the BOM.

For sewing thread, the test team recommends using **T24 Polyester Thread** for soft suit construction and **Gutermann 100% Polyester Thread** ([LINK](#)) for all other constructions. Table 4-26 is the soft goods fabric key for construction of the soft suit, HUT arms canvas cover, and glove system, and it is included in the master BOM in Section 4.6.1.

Table 4-26. Soft Goods Fabric Key for the Soft Suit, HUT Canvas Cover, and Glove Gauntlet.

#	Materials	BOM Item #	Required Dimension per one suit	Diagram Color Code
<1>	Ottertex® Waterproof Canvas (White)	S-2	4 yd	
<2>	1.9 Oz. Ottertex Nylon Ripstop 70 Denier DWR (White)	S-3	8 yd	
<3>	Velcro (soft, white)	S-4	1” (4 yd), 2” (3 yd), 4” (2 yd)	
<4>	Velcro (hook, white)	S-5	1” (4 yd), 2” (3 yd), 4” (2 yd)	
<5>	Elastic (white)	S-6	[1/2” x 14 “] x2	
<6>	Zipper A (white)	S-7	Large Suit: (46” long, zipper #5) x1 Small Suit: (35” long, zipper #5) x1	
<7>	Zipper B (white)	S-8	(7” long, zipper #3) x6	
<8>	High Density EVA Foam (5 mm thick, Ultra High Density 85 kg/m ³ , white)	S-9	(4” x 8” rectangles) x 2	

4.3.2.2 Glossary for the Pattern

Prepare the pattern

The printable sewing patterns in Appendix A (see Section 9.1) can be printed on any paper. Print the patterns at 100% scale and use the 2" x 2" sizing square on each pattern to ensure the pattern was printed to the correct scale. For best results, translucent tracing paper is recommended. The pattern includes only "one side" (e.g., arm = left arm) of the object unless specified. To complete both sides of the suit (right and left), follow **Cutting Instructions** below. This pattern is a multi-size pattern, which includes both small (for subjects below 6 ft) and large (for subject above 6 ft) sized soft suit and gloves. Choose the desired size and follow the cutting lines for that size per Table 4-25 and Table 4-27. To use the pattern, simply pin the pattern with the correct side (per specification) on top of the fabric. It is recommended to reference the **Pattern Legend** and Table 4-27 as some patterning might call for the "wrong side" up. Some portions of the patterning might call for "right side" on one side of body and wrong side of the opposite side of body.

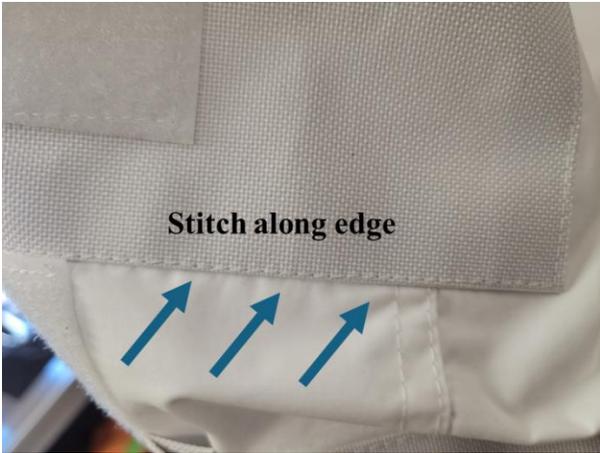
Pattern Legend

The digital pattern list in Table 4-25 provides only 1 unit of pattern per each line item. Table 4-27 provides the symbolic pattern legend for use with the patterns provided in this report. The following cutting and sewing directions are used throughout the following sections in this report.

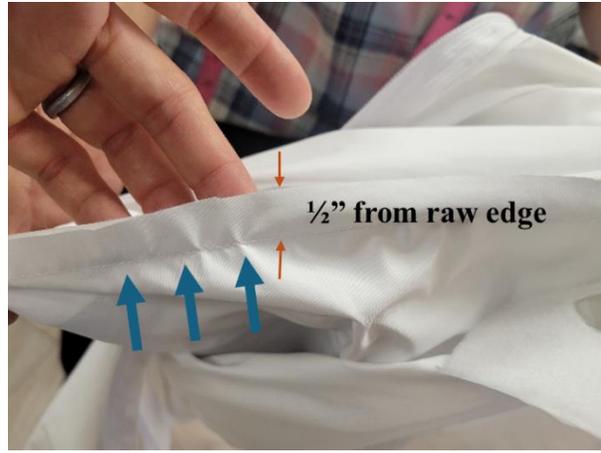
Cutting Directions (unless otherwise specified): To complete the number of quantities specified in Table 4-25 required for each suit, "FOLD and DOUBLE LAYER CUT" to create two units by folding the right side towards each other (so right side is facing inward) and then cut along the pattern.

Sewing Directions: If seam allowance is not specified, default the seam allowance to the following.

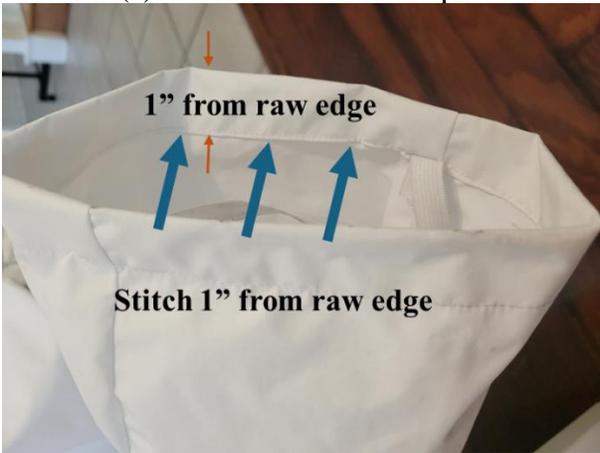
- **Right side of fabric** - The side of the fabric that will be facing outward of the suit.
- **PIN** - Use a pin or machine-baste seam matching notches or per instruction to keep the fabric in place prior to stitching.
- **RAWEDGE** – Sharpie black line (where the fabric is cut). This is also the cut edge.
- **FOLD** – Fold fabric along the fold line.
- **PRESS** - Keep seams in place and iron flat.
- **EDGESTITCH** - Stitch along the edge of the fabric. (see Figure 4-35 (a)).
- **STAYSTITCH** - Stitch 1/2" from the raw edge (joining two pieces of fabric, 1/2" from both sides) (see Figure 4-35 (b)).
- **HEMSTITCH** (assume 1" hem unless otherwise specified) - Stitch 1" (unless otherwise specified) from the raw edge, i.e. fold 1" and stitch along the stitch close to edge of hem (see Figure 4-35 (c)). Single hem unless indicated otherwise.
- **TOPSTITCH** - Stitch 1/4" from the edge of the fabric. (see Figure 4-35(d))



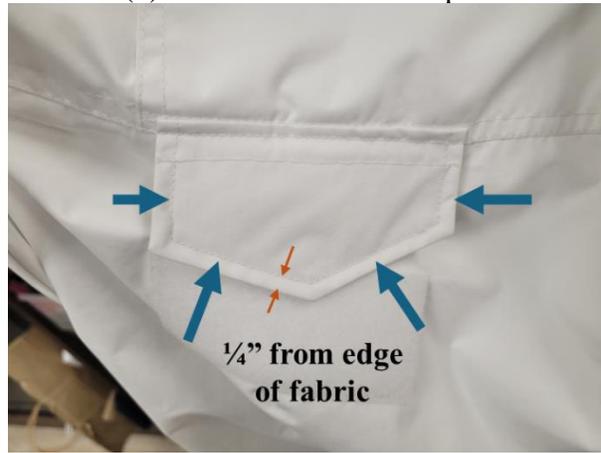
(a) EDGESTITCH Example



(b) STAYSTITCH Example



(c) HEMSTITCH Example



(d) TOPSTITCH Example

Figure 4-35. Stitch Pattern Examples

(Large blue arrows show the stitch location, and orange small arrows show the distance to stitch line).

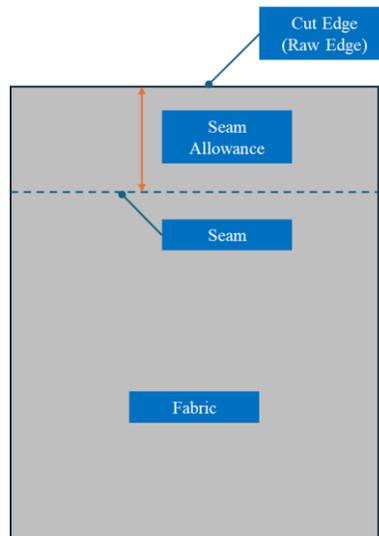
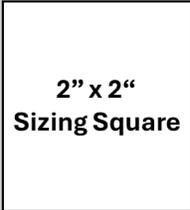


Figure 4-36. Stitch Pattern Examples

Table 4-27. Soft Suit Pattern Legend

Pattern Terms	Description	Symbol
Notches	Match notches	<
Fold Line	Place on fold of fabric	-----
Hem Line	Fold along this line, and apply HEMSTITCH
Cut Lines	Multi size pattern. Cut along this line for large suit. Multi size pattern. Cut along this line for small suit. (the scissor icon is optional)	
STITCH LINE	Where the needles/stitch goes	— — —
Position	Position a part here	-----
Grainline	The direction of the threads in a fabric	←————→
Zipper	Location of the zipper	
Pattern Number	Indicating the pattern number (see Table 4-27)	[XX]
Fabric: Right Side	The side that is visible in the completed product, e.g., on the outside of the suit. For <1> this is the rough side of the fabric. For <2> this is the non-slippery side of the fabric. (Right sides together means “right sides are touching each other”)	RIGHT SIDE (RIGHTSIDE)
Fabric: Wrong side	The side that is NOT visible in the completed product, e.g., on the inside of the suit. For <1> this is the smooth side of the fabric (PVC backing side). For <2> this is the slippery side. (Wrong sides together means “wrong sides are touching each other”)	WRONG SIDE (WRONGSIDE)
Sizing Square	Sizing square helps user to scale the provided pattern to the correct scale for printing. Each sizing square represents a 2-inch by 2-inch block when it is at 1-to-1 scale.	

4.3.2.3 Manufacturing Instructions: Part A – Sewing Instruction

The soft suit pattern described in this section is a multi-size pattern.

4.3.2.3.1 Part A – Cutting Instruction

Cutting instruction for construction of Part A – soft suit is summarized in Table 4-28. Leverage the FOLD and DOUBLE LAYER CUT technique where applicable as shown below.

Table 4-28. Cut Instruction for Part A - Soft Suit Construction

#]	Part Name	Qty	Cut Instruction	Pattern
[A-1]	Pant Front	2	(1) Fold the fabric with right sides together, pin the pattern on fabric wrong side and cut along the pattern cutline to create two units. (2) Use “cutline (small size)” for small suit construction), and “cutline (large size)” for large suit construction. If size is not mentioned, it is for a large suit. (3) Follow grain line direction per pattern when cutting.	(I-1)
[A-2]	Pant Back	2	Same as [A-1]	(I-2)
[A-3]	Body Front	2	Same as [A-1]	(I-3)
[A-4]	Body Back	2	Same as [A-1]	(I-4)
[A-5]	Yoke Back	2	Same as [A-1] but without grainline consideration	(I-5)
[A-6]	Sleeve	2	Same as [A-1]	(I-6)
[A-7]	Lower Shoulder Patch	2	(1) Pin the pattern on the right side of the fabric and cut along the pattern cutline to create 1 unit. Repeat for second unit (2) Use “cutline (small size)” for small suit construction), and “cutline (large size)” for large suit construction. If size is not mentioned, it is for a large suit.	(I-7)
[A-8]	Upper Shoulder Patch	2	Same as [A-7]	(I-8)
[A-9]	Elbow Pocket	2	Same as [A-7]	(I-9)
[A-10]	Knee Pocket	2	Same as [A-7]	(I-10)
[A-11]	4”x 4” Soft Velcro	2	On <3> Velcro soft (4” wide), cut 4” x 4” squares per required quantity.	NA

[A-12]	2"x 2" Soft Velcro	8	On <3> Velcro soft (2" wide), cut 2" x 2" squares per required quantity.	NA
[A-13]	1"x 15" Soft Velcro	2	On <3> Velcro soft (1" wide), cut 1" x 15" strips per required quantity.	NA
[A-14]	Collar	2	Same as [A-1]	(I-14)
[A-15]	Casing	1	(1) Pin the pattern on the right side of the fabric and cut along the pattern outline to create 1 unit. (2) Use "cutline (small size)" for small suit construction, and cutline (large size) for large suit. (3) Follow grain line direction per pattern when cutting.	(I-15)
[A-16]	Front Flap	8	Same as [A-7]	(I-16)
[A-17]	Back Flap	4	Same as [A-7]	(I-17)
[A-18]	Front Soft Velcro L: 2" x 9" S: 2" x 8.5"	L: 4 S: 2	On <3> Velcro soft (2" wide), cut required length strips per required quantity.	NA
[A-19]	Front Flap Velcro Hook	4	Same as [A-7]	(I-19)
[A-20]	Back Flap Velcro Hook	2	Same as [A-7]	(I-20)
[A-21]	Back Soft Velcro L: 2" x 5.5" S: 2" x 4"	2	On <3> Velcro soft (2" wide), cut required length strips per required quantity.	NA
[A-22]	3" x 3" Fabric	8	Cut a square per size and quantity	NA
[A-23]	3" x 3" Soft Velcro	8	On <3> Velcro soft (3" wide), cut 3" squares per required quantity.	NA
[A-24]	1" x 3" Hook Velcro	4	On <4> Velcro hook (1" wide), cut required length strips per required quantity.	NA
[A-25]	1" x 3" Soft Velcro	4	On <3> Velcro soft (1" wide), cut required length strips per required quantity.	NA
[A-26]	1" x 4" Hook Velcro	1	On <4> Velcro hook (1" wide), cut required length strips per required quantity.	NA
[A-27]	1" x 4" Soft Velcro	1	On <3> Velcro soft (1" wide), cut required length strips per required quantity.	NA

[A-28]	2" x 4" Soft Velcro	2	On <3> Velcro soft (2" wide), cut required length strips per required quantity.	NA
[A-29]	4"x 4" fabric	2	Cut a square per size and quantity	NA
[A-30]	4"x 4" hook Velcro	2	On <4> Velcro hook (4" wide), cut required length strips per required quantity.	NA
[A-31]	2"x 2" Fabric	8	Cut a square per size and quantity	NA
[A-32]	2"x 2" Hook Velcro	8	On <4> Velcro hook (2" wide), cut required length strips per required quantity.	NA
[A-33]	3"x 3" Fabric	8	Cut a square per size and quantity	NA
[A-34]	3"x 3" Hook Velcro	8	On <4> Velcro hook (3" wide), cut required length strips per required quantity.	NA

4.3.2.3.2 Knee Pockets [A-10] and Elbow Pockets [A-9]

Patterns I-9 (Elbow) and I-10 (Knee) are used in this section. See Appendix section (Appendix A: Soft Suit Pattern) for printable detail version.

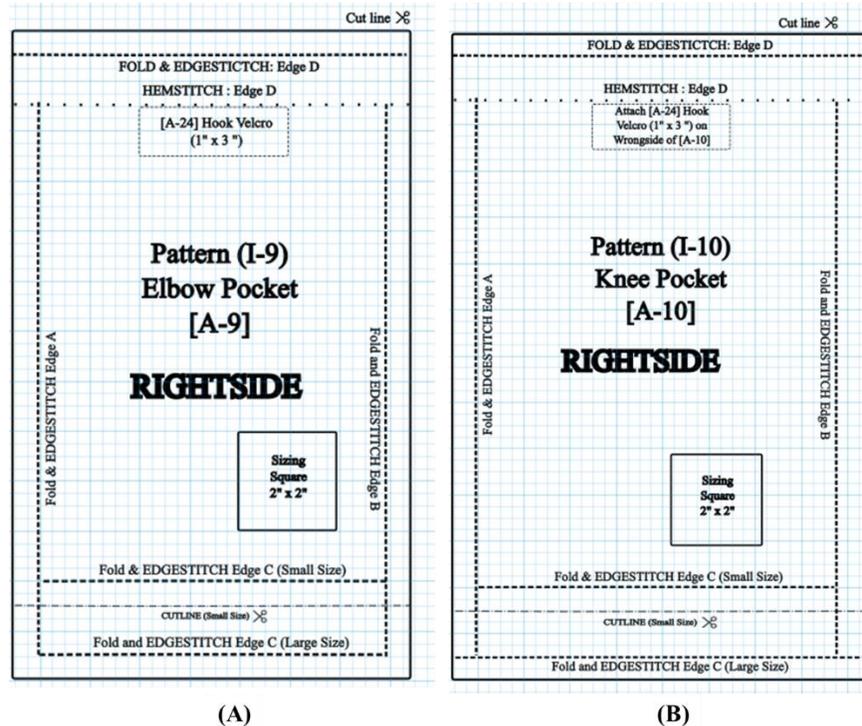


Figure 4-37. Pocket Patterns.
(A) A-9 Elbow Pocket, (B) A-10 Knee Pocket. (See Appendix Pattern (I-9) and (I-10) for printable version)

1. Fold and press the upper edge (Edge D) of Elbow Pocket [A-9] ½” from the raw edge. EDGESTITCH along the fold, and then 1” HEMSTITCH from the edge by folding along the hemline and apply hemstitch.
2. Fold and press the Edge A, B, and C of Elbow Pocket [A-9] along the fold line at ½” from the raw edge. EDGESTITCH along these three edges.



Figure 4-38. Pocket Construction: (A) Top Edge, (B) Completed View, (C) Velcro Locations.

3. On the back of Elbow Pocket [A-9], pin 1” x 3” Hook Velcro [A-24] on the fold as show in Figure 4-38(A). EDGESTITCH the perimeter of 1” x 3” Hook Velcro [A-24] in place.
4. Pin Elbow Pocket [A-9] to Sleeve [A-6] per Pattern I-6 (see Figure 4-39). EDGESTITCH the 3 sides of the pocket (Edge A, B, and C) to attach the pocket onto the Sleeve [A-6].
5. Align and pin 1” x 3” Soft Velcro [A-25] on the suit (Sleeve [A-6]) beneath the 1” x 3” Hook Velcro [A-24]. EDGESTITCH the 1” x 3” Soft Velcro [A-25] on Sleeve [A-6]. See Figure 4-38(C).
Note: [A-25] is stitched directly onto the Sleeve [A-6], and [A-24] is on the pocket (inner side).
6. Repeat steps 1-5 for the other Sleeve [A-6] (the other arm). See Figure 4-38 (B).
7. Repeat steps 1-6 to attach Knee Pockets [A-10] onto both legs - Pant Front [A-1].

4.3.2.3.3 Lower Shoulder Patch [A-7], Sleeve [A-6], Soft Velcro [A11, A12]

Patterns I-6 (Sleeve) and I-7 (Lower Shoulder) are used in this section. See Appendix section for printable detail version.

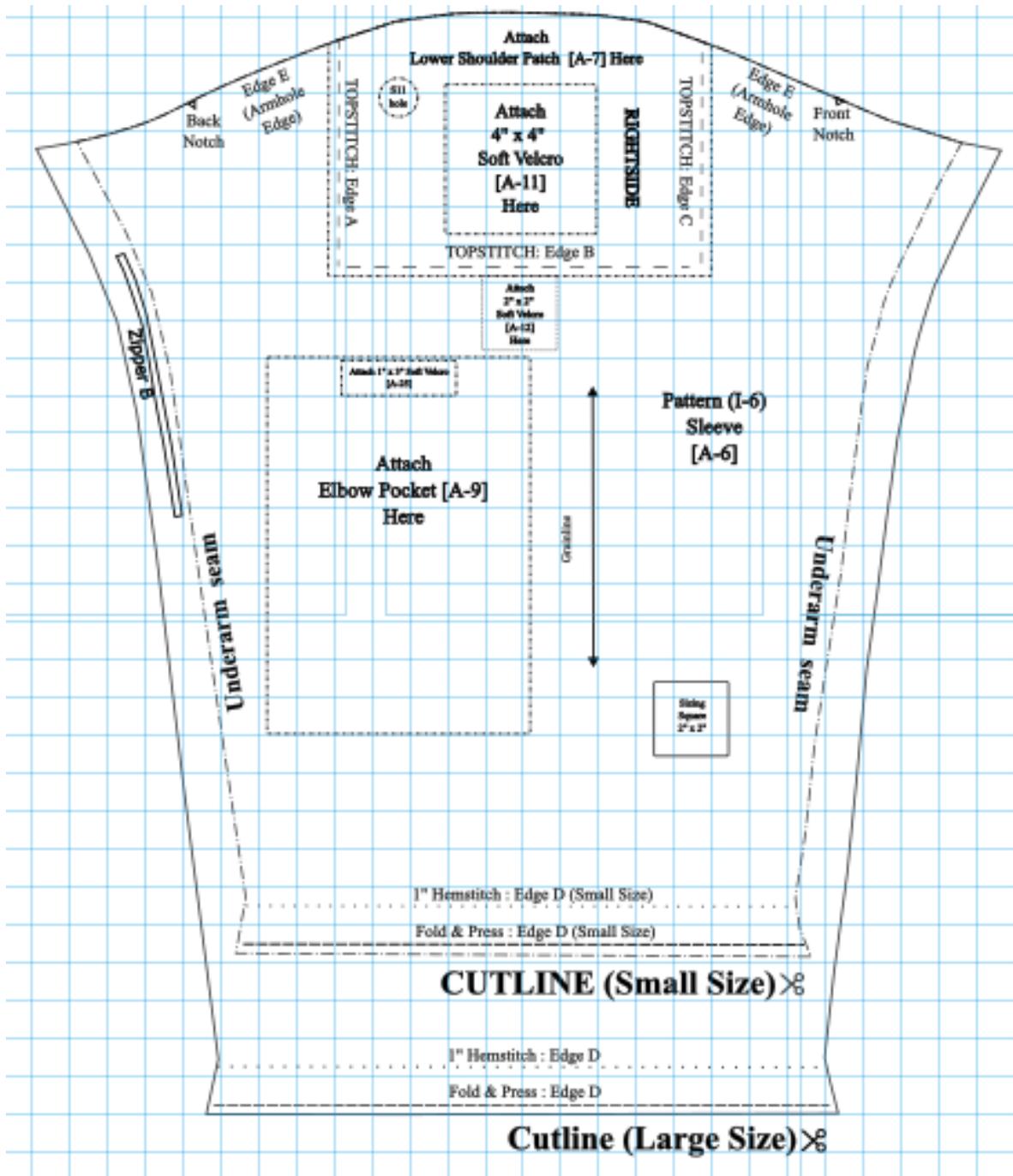


Figure 4-39. Sleeve [A-6].

(See Appendix Pattern (I-6) for printable version). Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

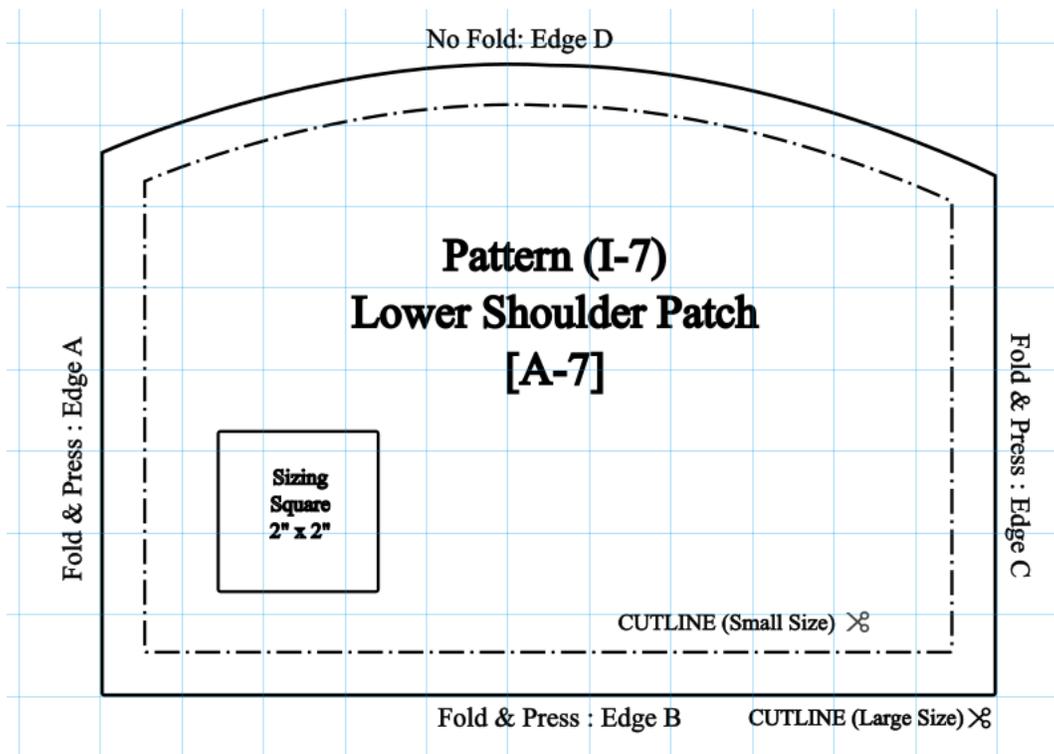


Figure 4-40. Lower Shoulder Patch [A-7].
 (See Appendix Pattern (I-7) for printable version). Major grid line is spaced 1 inch part,
 minor grid line is 1/8".

1. Excluding the upper edge (Edge D) of Lower Shoulder Patch [A-7], fold and press Lower Shoulder Patch [A-7] 1/2" along perimeter from raw edge (for Edge A, B, and C).
2. Pin Lower Shoulder Patch [A-7] onto Sleeve [A-6] on top of each other with RIGHTSIDE facing the same direction. EDGESTITCH Edge A, B, C of Lower Shoulder Patch [A-7] in place per pattern I-6 (See Figure 4-39 and Figure 4-41). Then, apply TOPSTITCH along these Edge A, B, and C.

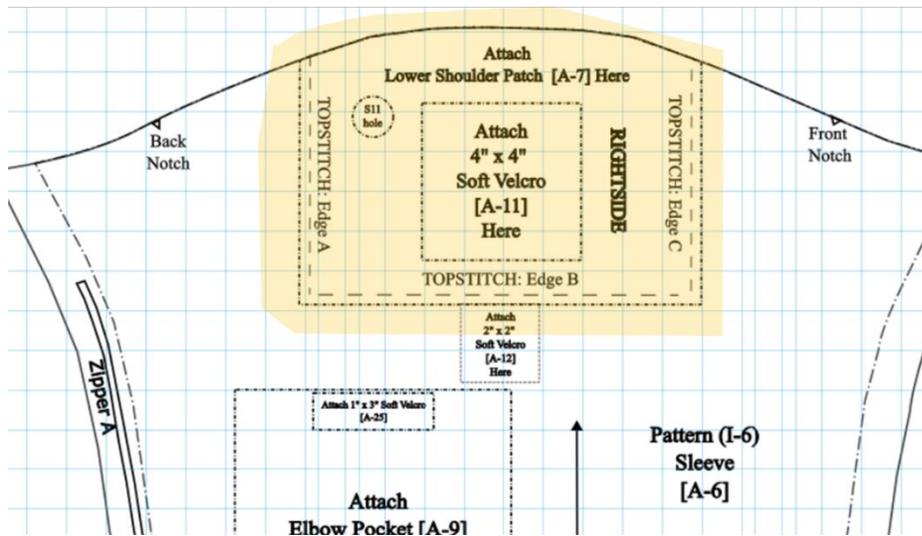


Figure 4-41. Integrate Lower Shoulder Patch [A-7] onto Sleeve [A-6].

3. Place 4" x 4" Soft Velcro [A11] at the center of Lower Shoulder Patch [A-7] per Pattern I-6 (See Figure 4-41 highlighted area). EDGESTITCH 4" x 4" Soft Velcro [A-11] in place.
4. Place 2" x 2" Soft Velcro [A-12] below Lower Shoulder Patch [A-7] per Pattern I-6 (See Figure 4-39). EDGESTITCH 2" x 2" Soft Velcro [A-12] in place.
5. Repeat Steps 1-4 for the other Sleeve [A-6] and Lower Shoulder Patch [A-7].

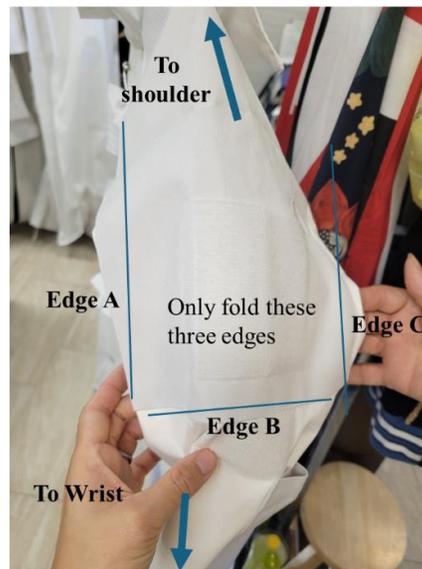


Figure 4-42. Lower Shoulder Patch Construction Complete View.

4.3.2.3.4 Body [A-1 through A-5]

Patterns I-1 (Pant Front), I-2 (Pant Back) I-3 (Body Front), I-4 (Body Back), and I-5 (Yoke Back) are used in this section. See Appendix section for printable detail version.

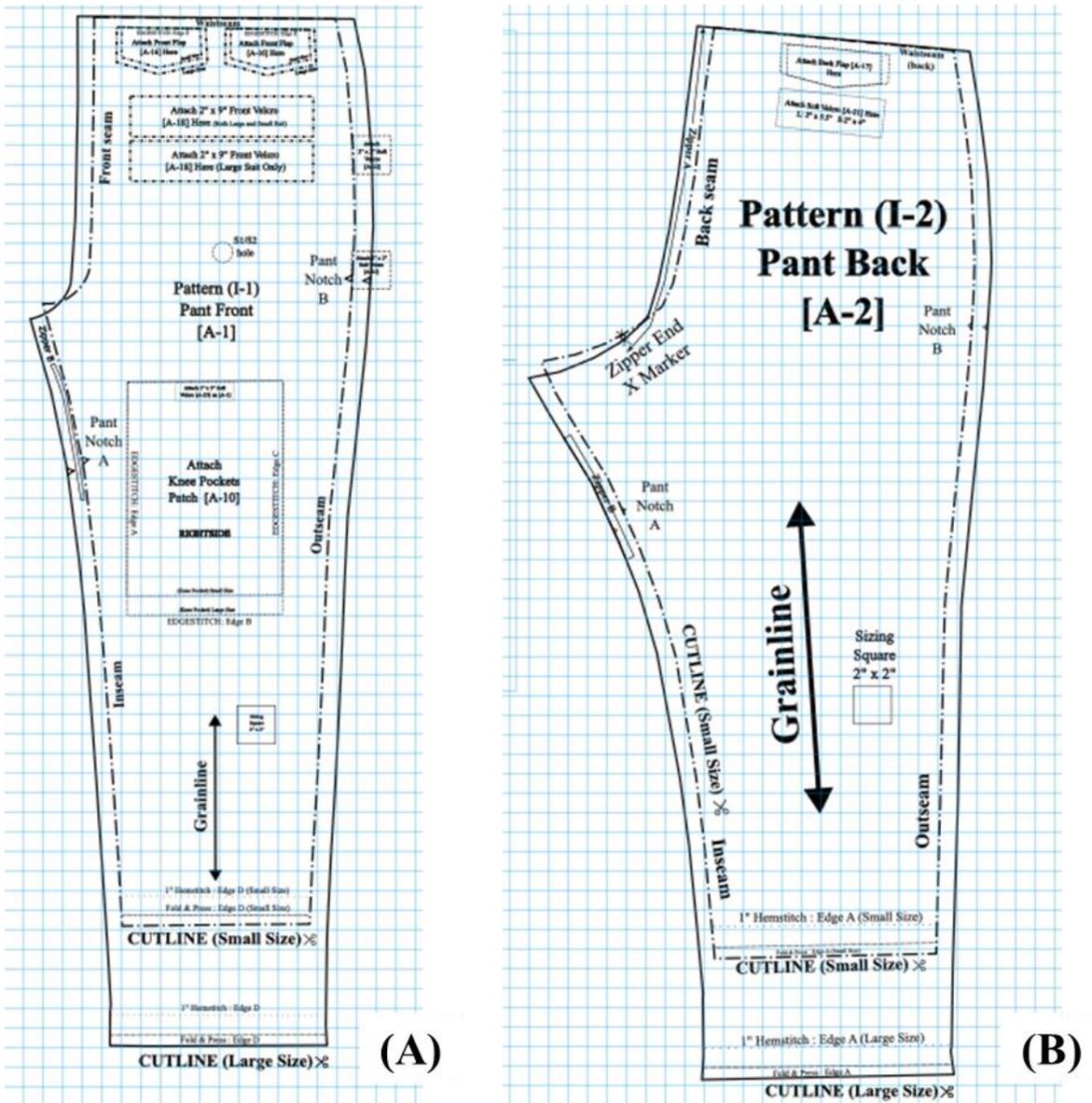


Figure 4-43. Pants Pattern.

(A) Pant Front [A-1] (See Appendix Pattern (I-1) for printable version). (B) Pant Back [A-2] (See Appendix Pattern (I-2) for printable version). Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

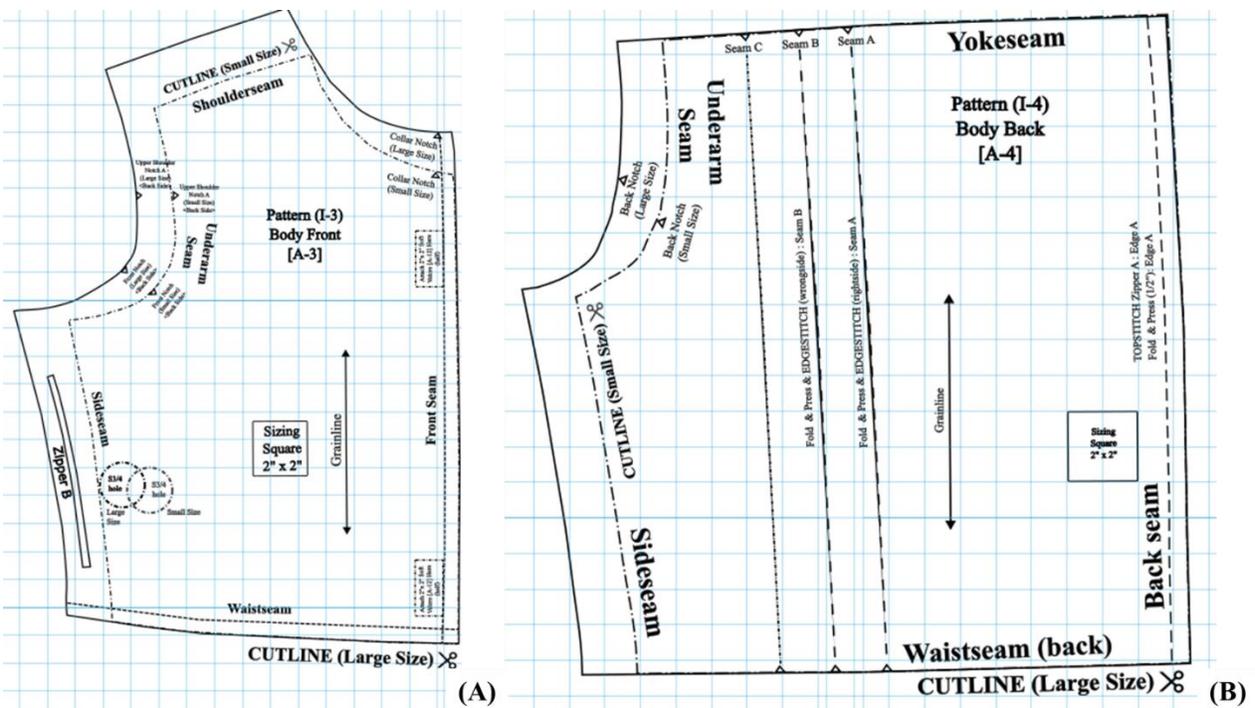


Figure 4-44. Body Patterns.

(A) Body Front [A-3] (See Appendix Pattern (I-3) for printable version). (B) Body Back [A-4] (See Appendix Pattern (I-4) for printable version). Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

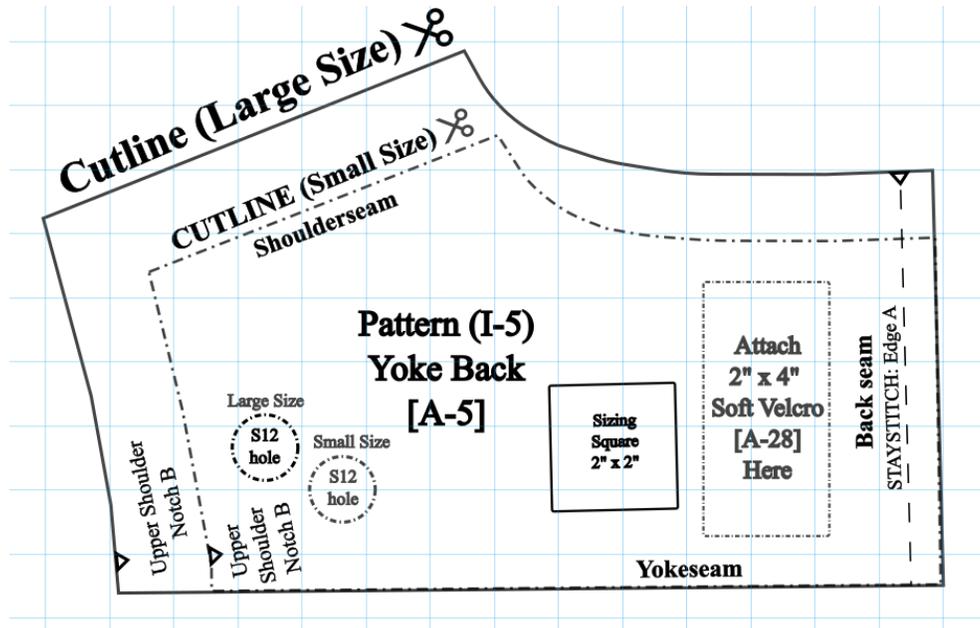


Figure 4-45. Yoke Back [A-5].

See Appendix Pattern (I-5) for printable version). Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

1. With right sides together, pin Pant Front [A-1] to Body Front [A-3], ensuring sideseam of Body Front [A-3] aligns with outseam of Pant Front [A-1]. STAYSTITCH Pant Front [A-1] to Body Front [A-3]. Press waistseam toward Body Front [A-3]. EDGESTITCH and TOPSTITCH the waistseam from the right side. See Figure 4-46.

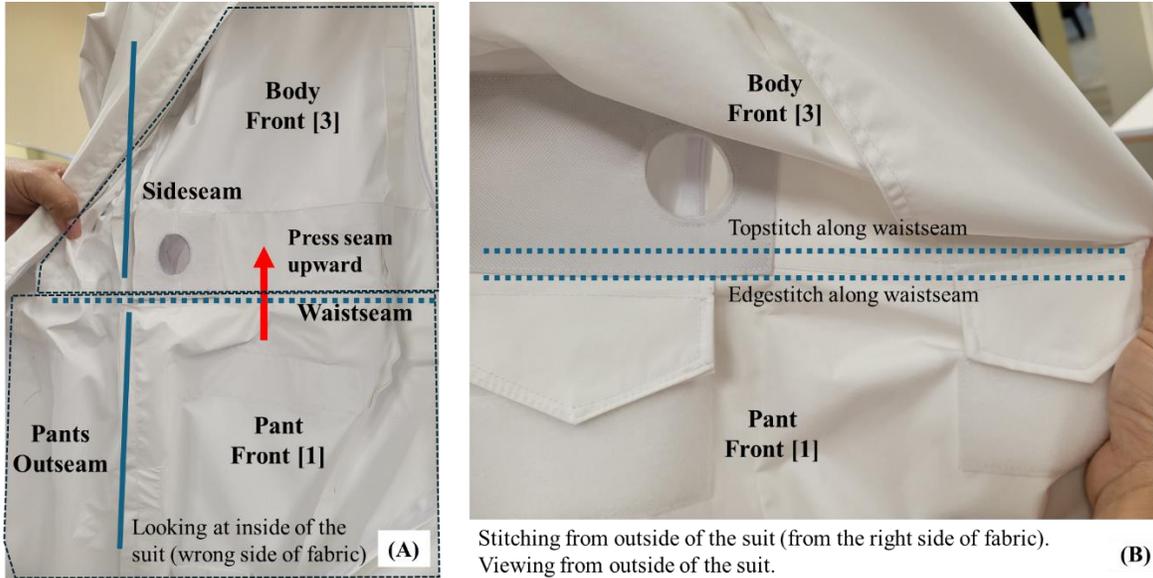


Figure 4-46. Align the Sideseam of Body Front [A-3] with Outseam of Pant Front [A-1]. (A) Looking at inside of the suit (wrong side of fabric), (B) Looking from outside of the suit.

2. With right sides together, fold (towards right side of fabric), press, and EDGESTITCH Seam B on the wrong side of fabric on Body Back [A-4] as shown in Figure 4-47.

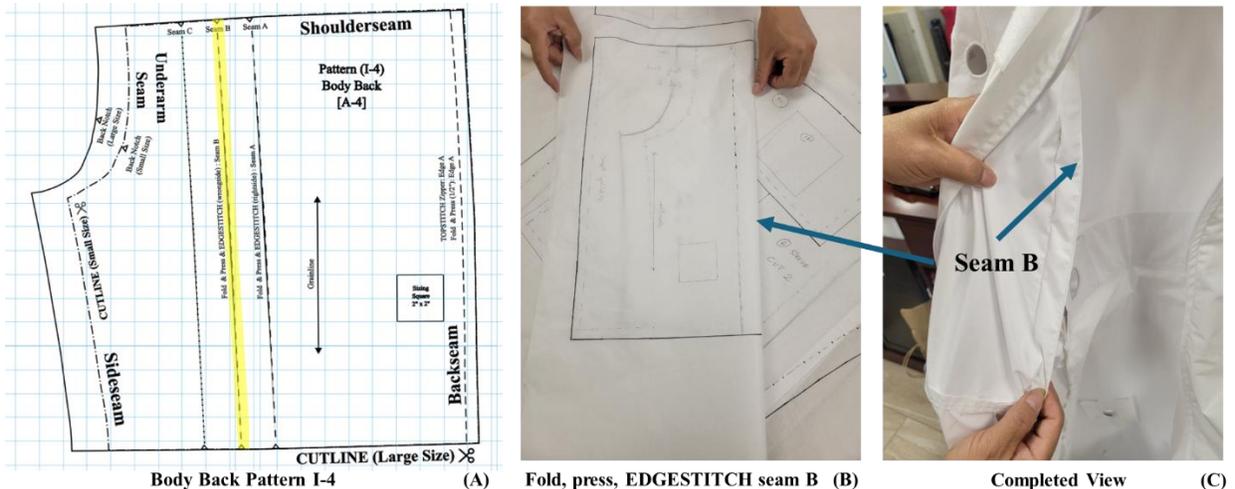


Figure 4-47. Body Back Seam Instructions (Part 1). (A) Body Back Pattern [A-4], (B) Fold, press, and edgestitch along seam B, and (C) completed view.

3. Fold, press, and EDGESTITCH Seam A on the right side of fabric on Body Back [A-4]. Then, pin Seam A onto Seam C on Body Back [A-4]. TOPSTITCH the top and bottom edge of Body Back [A-4] to secure the pleats. See Figure 4-48

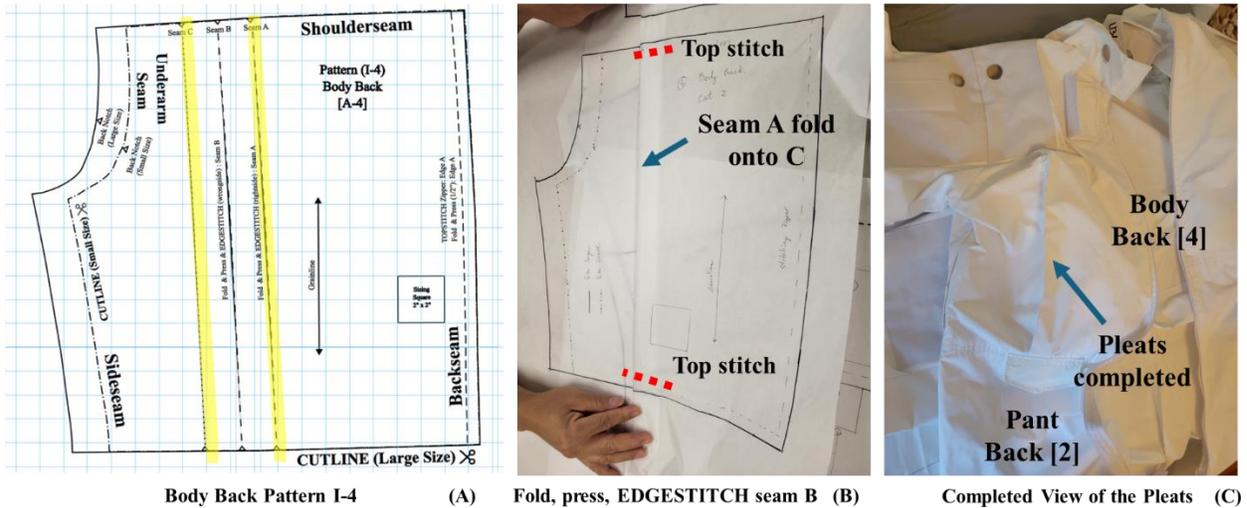


Figure 4-48. Body Back Seam Instructions (Part 2).

(A) Body Back Pattern [A-4], (B) Fold, press, and edgestitch along seam B, and (C) completed view.

4. With right sides together, STAYSTITCH Yoke Back [A-5] to Body Back [A-4]. Press Yokeseam towards Yoke Back [A-5]. EDGESTITCH and TOPSTITCH the Yokeseam (stitch this double seam on right side of fabric).
5. With right sides together, pin Body Back [A-4] to Pant Back [A-2], ensuring sideseam of Body Back [A-4] aligns with outseam of Pant Back [A-2]. STAYSTITCH Body Back [A-4] to Pant Back [A-2]. Press waistseam(back) toward Body Back [A-4]. EDGESTITCH and TOPSTITCH the waistseam(back) from the right side of fabric.
6. Repeat steps 1-5 in this section for the other side of the suit.

4.3.2.3.5 Shoulder [A-3, A-5, and A-8]

Continue from last section, patterns I-3 (Body Front), I-5 (Yoke Back), I-8 (Upper Shoulder Patch) are used in this section. See Appendix section for printable detail version.

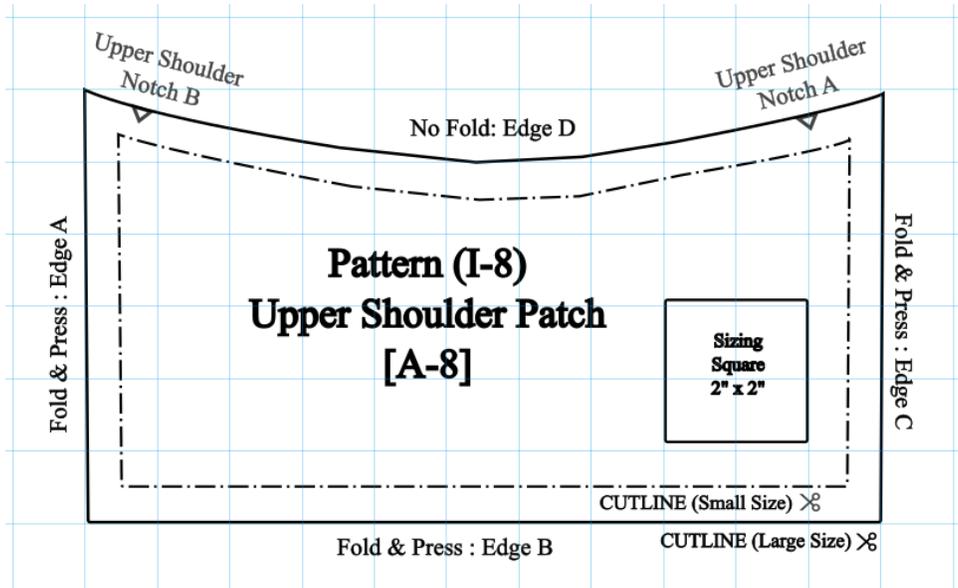
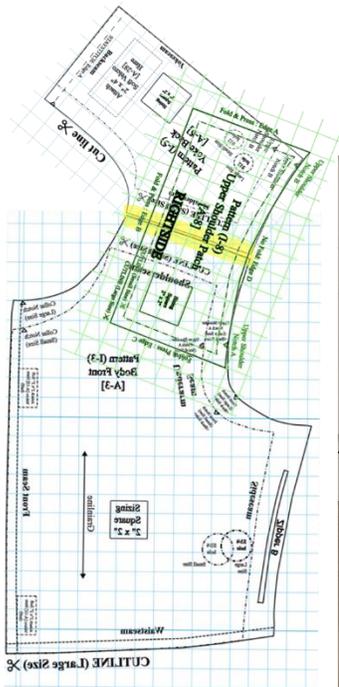


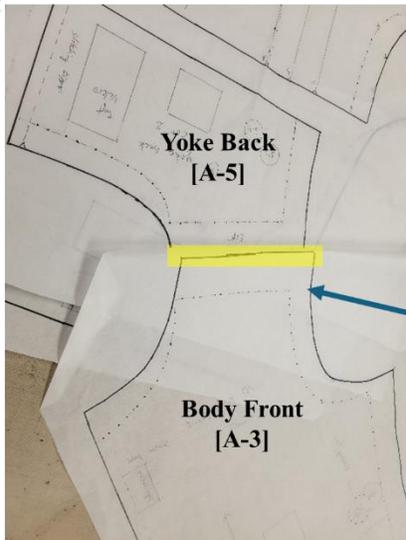
Figure 4-49. Upper Shoulder Patch [A-8].

See Appendix Pattern (I-8) for printable version. Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

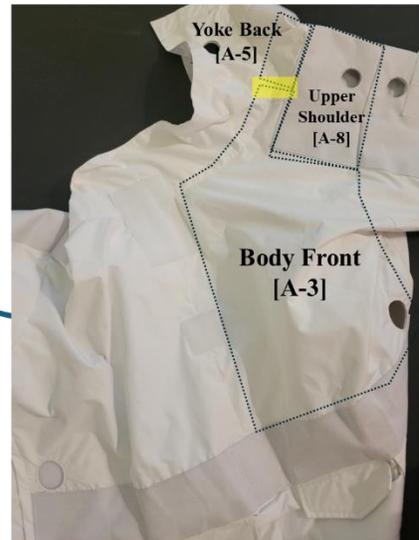
1. With right sides together, STAYSTITCH along the shoulderseam of Yoke Back [A-5] to the shoulder of Body Front [A-3] as shown in Figure 4-50(A & B). Press this seam toward the shoulder of Yoke Back [A-5]. EDGESTITCH and TOPSTITCH the shoulderseam from the right side of fabric.



Line up the shoulderseam (yellow), Yoke Back [A-5], Body Front [A-3], and [A-8] (green) (A)



Line up the shoulderseam (yellow) (B)



Completed View (C)

Figure 4-50. Upper Shoulder Patch [A-8] Integration

2. Fold and press Upper Shoulder Patch [A-8] ½” along perimeter from raw edge (for Edge A, B, and C) excluding top (Edge D).
3. EDGESTITCH Upper Shoulder Patch [A-8] to the Yoke Back [A-5] and Front Body [A-3] by lining up the Upper Shoulder Notch A and B on [A-8] with the Upper Shoulder Notch A on [A-3] and the Upper Shoulder Notch B on [A-5]. Figure 4-50(A & C).
4. Repeat steps 1-3 in this section for the other side of the suit.

4.3.2.3.6 Body Sideseam [A-1 through A-8]

Patterns I-1 (Pant Front), I-2 (Pant Back), I-3 (Body Front), I-4 (Body Back), I-5 (Yoke Back), I-6 (Sleeve), I-7 (Lower Shoulder Patch), I-8 (Upper Shoulder Patch) are used in this section. See Appendix section for printable detail version.

1. With right sides together, STAYSTITCH Sleeve [A-6], Lower Shoulder Patch [A-7] and Upper Shoulder Patch [A-8] along Edge E (Armhole edge), allowing [A-7] and [A-8] to match along Edge A, B, and C. Press seam toward Sleeve [A-6].

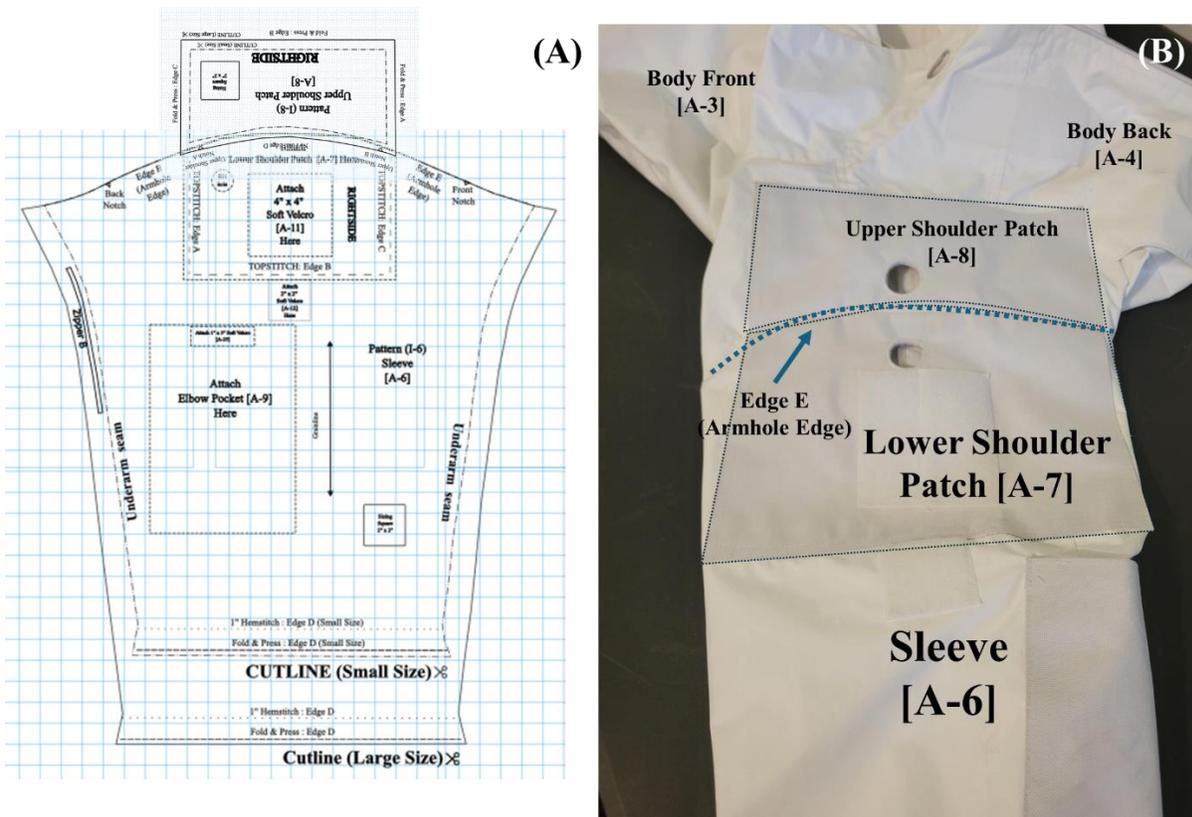


Figure 4-51. Sewing Sleeve [A-6], Lower Shoulder Patch [A-7], and Upper Shoulder Patch [A-8] Along Edge E.

(A) Lining up in pattern view (note this is flipped horizontally 180-degree from (B)), (B) Completed view.

2. With right sides together, pin outseam of Pant Front [A-1] to outseam of Pant Back [A-2]. Pin sideseam of Body Front [A-3] to sideseam of Body Back [A-4]. Pin underarm seams of Sleeve [A-6] together. Matching each part together, STAYSTITCH the entire underarm seams, body sideseams, and pant outseams. Verify the following notches are lined up:
 - a. Underarm seam
 - i. Back Notch: Body Back [A-4], Sleeve [A-6]
 - ii. Front Notch: Body Front [A-3], Sleeve [A-6]
 - iii. Upper Shoulder Notch A: [A-3], Upper Shoulder Patch [A-8]
 - iv. Upper Shoulder Notch B: Yoke Back [A-5], Upper Shoulder Patch [A-8]
 - b. Pants outseam - Pant Notch B: Pant Back [A-2], Pant Front [A-1]
 - c. Pants inseam - Pant Notch A: Pant Bank [A-2], Pant Front [A-1]
3. With right sides together, STAYSTITCH inseam of Pant Front [A-1] to inseam of Pant Back [A-2].

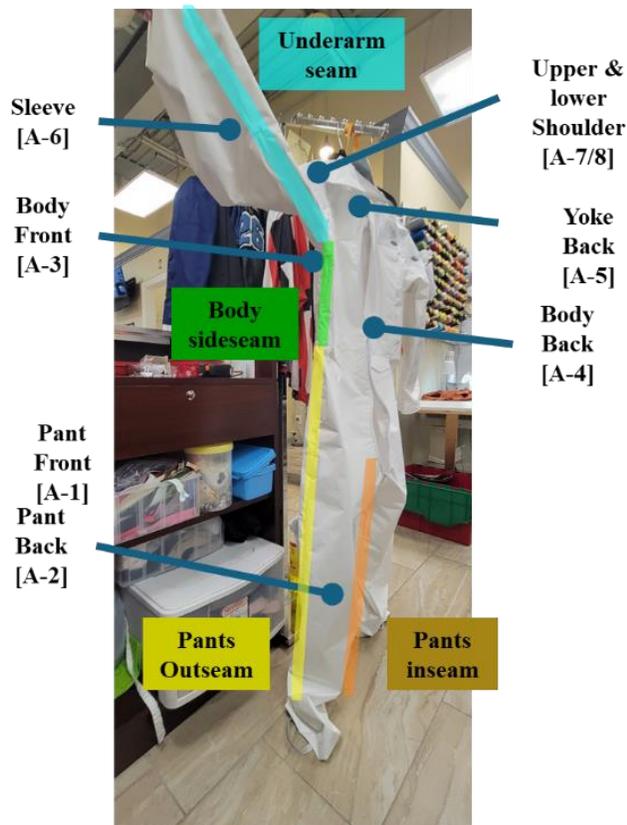


Figure 4-52. Completed View Body Side Seam Integration.

4. Repeat steps 1-3 in this section for the other side of the suit.

4.3.2.3.7 Pants and Sleeve Hem [A-1, A-2, A-6]

Patterns I-1 (Pant Front), I-2 (Pant Back), and I-6 (Sleeve) are used in this section. See Appendix section for printable detail version.

1. Fold and press Pant Front [A-1] and Pant back [A-2] ½” from raw edge along the fold line (Edge D for [A-1], Edge A for [A-2]). Fold and press again along the hemline (Edge D for [A-1], Edge A for [A-2]). HEMSTITCH along the hemline to create a 1” hem from the edge.
2. Cut 11” of a ½” elastic band from material <5>. Sew each end of the elastic band to the outseam and inseam of the inside of the pant leg.
3. Repeat steps 1-2 for the other pant leg.
4. Fold and press wrist ½” from raw edge on Sleeve [A-6]. Fold and press again along the hemline. HEMSTITCH along the hemline to create a 1” hem from the edge.
5. Pin 1”x 15” Soft Velcro [A-13] into the inside of the wrist hem. EDGESTITCH [A-13] in place.



Figure 4-53. Complete Hem. (A) Pants Hem with Elastic, (B) Wrist Hem with Soft Velcro.

6. Repeat steps 1-5 in this section for the other side of the suit.

4.3.2.3.8 Front and Back Seam [A-1, A-2, A-3]

Patterns I-1 (Pant Front), I-2 (Pant Back), and I-3 (Body Front) are used in this section. See Appendix section for printable detail version.

7. 1. With right sides together, align the left and right half of the body, STAYSTITCH (Body Front [A-3], Pant Front [A-1], Pant Back [A-2]) the entire front seam body through the back crotch, stopping at the X-mark on Pant Back [A-2]. See Figure 4-54

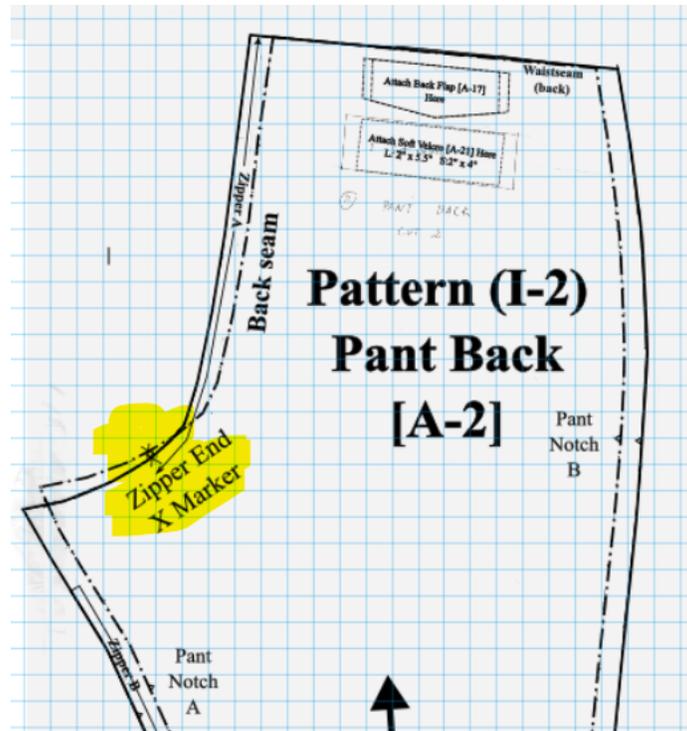


Figure 4-54. Staystitch Entire Front Seam Until the X Marker Shown in [A-2].

8. Press and fold $\frac{1}{2}$ " from raw edge of the body back seam through the back crotch stopping at the X-mark [2] through Body Back [A-4] (Edge A/back seam), Pant Back [A-2] (back seam).
9. Repeat step 2 for the other side.
10. Pin a zipper A <6> (Large suit: 46" long size #5 zipper; Small suit: 35" long size #5 zipper) under both sides of the previously folded back seam edges. TOPSTITCH the zipper in place.

4.3.2.3.9 Zipper B Integration

1. Open 7" long inseam on pant leg 2 $\frac{1}{2}$ " inseam below the crotch. See Pant Back [A-2] Pattern (I-2) at zipper B location. See Figure 4-43.
2. Press and fold $\frac{1}{2}$ " from raw edge of the inseam previously opened. Pin a 7" long size #3 zipper <7> under both sides of the previously folded back seam edges. Ensure that the zipper opens downward and closes upward. TOPSTITCH the zipper in place.
3. Repeat steps 1-2 for the following locations, there is a total of 7 zipper B. See Figure 4-55.
 - a. Both legs: Pant Leg [A-2] at zipper B location on inseam
 - b. Both arms: Sleeve [A-6] at zipper B location on underarm seam
 - c. Both sides of suit: Body Front [A-3] at zipper B location on side seam

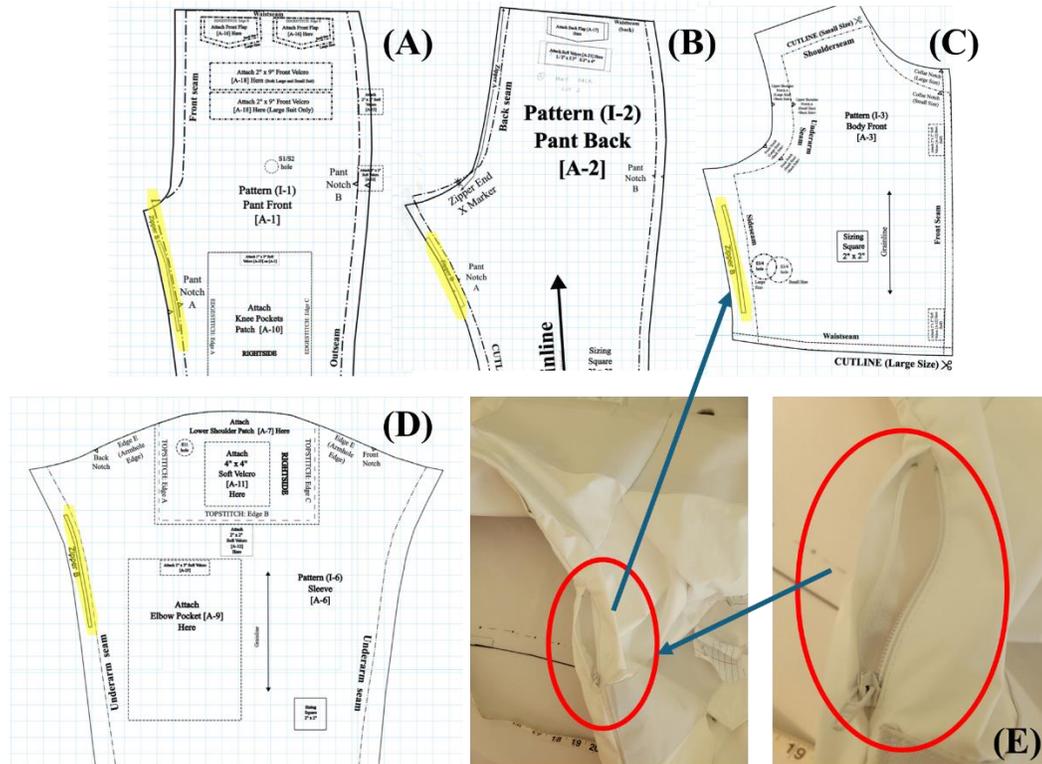


Figure 4-55. Zipper B Integration.

(A)-(D) shows the 6 locations of zipper B (note, (A) and (B) is one location, i.e., pant inseam), (E) completed view for zipper B at (C) location.

4.3.2.3.10 Collar [A-14]

Patterns I-14 (Collar) is used in this section. See Appendix section for printable detail version.

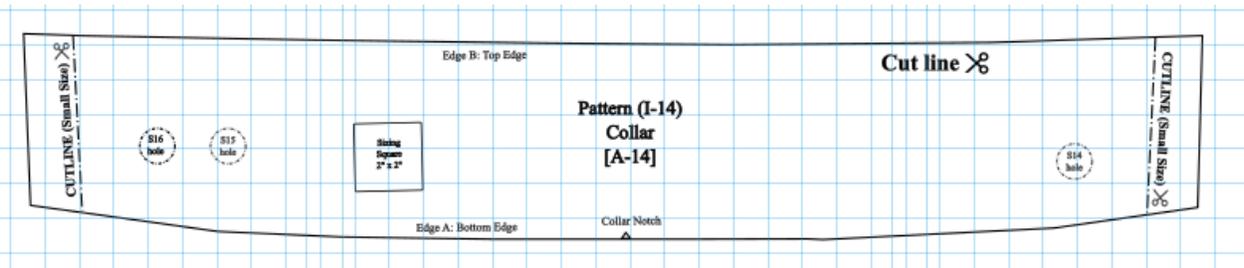


Figure 4-56. Collar [A-14]

(See Appendix Pattern (I-14) for printable version). Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

1. Press and fold 1/2" from the bottom raw edge (Edge A) of Collar [A-14]. TOPSTITCH Collar [A-14] in place. Do this for both pieces of Collar [A-14], i.e., front and back of collar.

2. With right sides together for the two Collars [A-14], STAYSTITCH the perimeter of Collars [A-14] (Edge B, C, D), excluding the bottom edge (Edge A) of Collar [A-14]. Flip Collar [A-14] inside out and press the collar perimeters.
3. TOPSTITCH the perimeter of Collar [A-14] (Edge B, C, D), excluding the bottom edge (Edge A) of the Collar [A-14].
4. Pin Collar [A-14] onto the neck, leaving $\frac{3}{4}$ " excess on both ends of Collar [A-14] (Edge C and D). Adjust the placement of Collar [A-14] as needed to match the **Collar Notches** in the center of Collar [A-14] to the center of the neck on Body Front [A-3]. EDGESTITCH Collar [A-14] in place. See Figure 4-56.
5. To secure the back ends of Collar [A-14] together, align and pin a 1" x 4" Hook Velcro [A-26] and a 1" x 4" Soft Velcro [A-27]. EDGESTITCH the perimeter of [A-26 and [A-27] in place. See Figure 4-57.

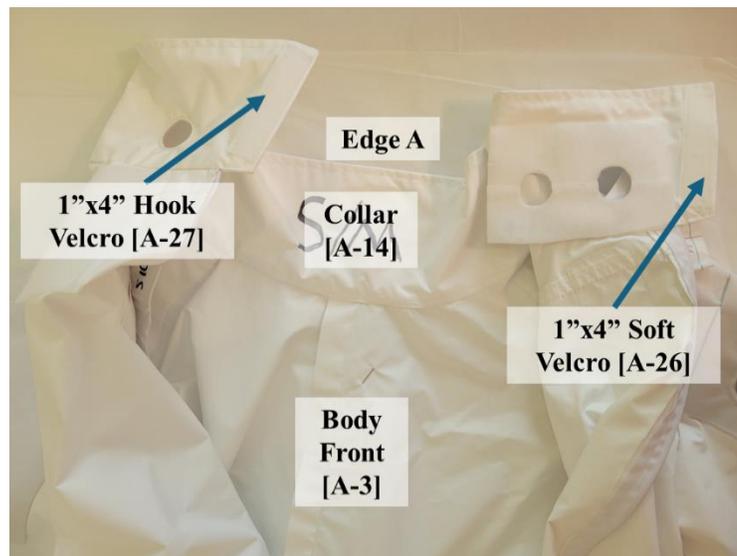


Figure 4-57. Completed View of the Collar.

4.3.2.3.11 Front Flaps [A-16, A-19] and Back Flaps [A-17, A-20]

Patterns I-16 (Front Flap) and I-17 (Back Flap) are used in this section. See Appendix section for printable detail version.

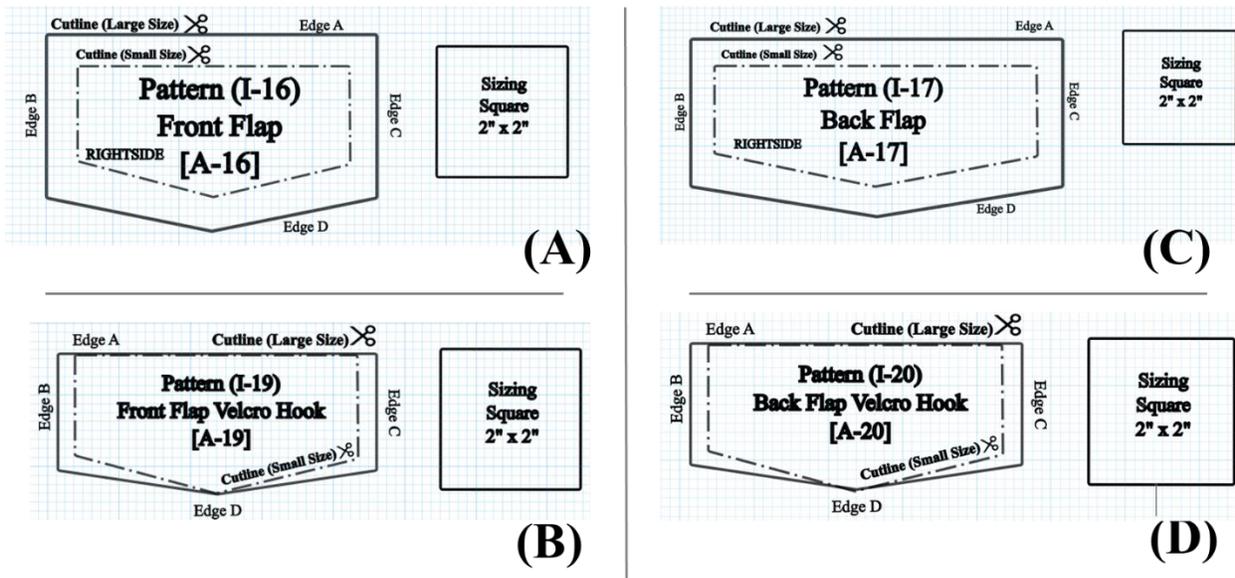


Figure 4-58. Flap Patterns.

See Appendix Pattern (I-16, I-17, I-19, and I-20) for printable version. (A) Front Flap [A-16], (B) Back Flap [A-17], (C) Front Flap Velcro Hook, (D) Back Flap Velcro Hook. Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

1. With right sides together of two units of Front Flaps [A-16], STAYSTITCH the perimeter of Front Flap [A-16] to create one unit of Front Flap.
2. Flip Front Flap [A-16] inside out. Press Front Flap [A-16] flat.
3. Pin Front Flap Velcro Hook [A-19] under Front Flap [A-16]. TOPSTITCH the perimeter of Front Flap [A-16] with Front Flap Velcro Hook [A-19]. See Figure 4-60 for completed view.
4. Repeat steps 1-3 in this section to create **three** units Front Flaps (each unit uses two units of [A-16]).
5. Repeat steps 1-3 in this section for the **two** units Back Flaps [A-17] using the Back Flap Velcro Hook [A-20]. See Figure 4-61.

4.3.2.3.12 Casing [A-15]

Patterns I-1 (Pant Front), I-3 (Body Front), I-15 (Casing), I-16 (Front Flap), and I-17 (Back Flaps) are used in this section. See Appendix section for printable detail version.

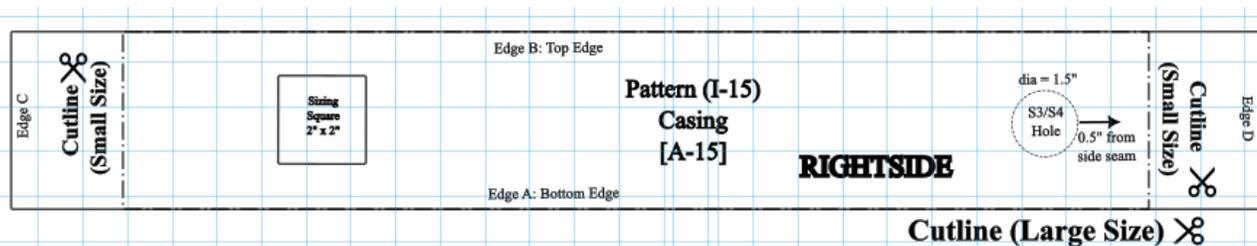


Figure 4-59. Casing [A-15]

See Appendix Pattern (I-15) for printable version. Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

Note: Each Pant Front [A-1] has 2 units of Front Flap [A-16], and thus a total of 4 units Front Flaps [A-16] for both legs. Each Pant Back [A-2] has 1 unit of Back Flap [A-17], and thus a total of 2 units Back Flaps [A-17] per suit for both legs.

Note: A large HS3 suit uses 2 units of 2"x 9" Front Soft Velcro [A-18] per Pant Front [A-1], and thus a total of 4 units of [A-18] per large HS3 suit. A small HS3 suit uses 1 unit of 2"x 9" Front Soft Velcro [A-18] per Pant Front [A-1], and thus a total of 2 units of [A-18] per small HS3 suit.

1. Pin Front Flaps [A-16] below the waistline, with 2 Front Flaps [A-16] on each front panel as shown in Figure 4-43 on Pant Front [A-1] per Pattern (I-1). EDGESTITCH Front Flaps [A-16] in place. See Figure 4-60(A and B). Complete this step for both legs.
2. Press and fold ½" from the top (Edge B) and bottom (Edge A) raw edges of Casing [A-15]. Press and fold both ends (Edge C and D) of Casing [A-15] to fit the width of Body Front [A-3].
3. Pin Casing [A-15] to Body Front [A-3] above the waistline. EDGESTITCH [A-15] in place, see Figure 4-60(A).
4. Pin 2" x 9" Front Soft Velcro [A-18] 3 ¼" below the waistline as pictured in Figure 4-60 (A). EDGESTITCH [A-18] in place. For the large suit, place two units of [A-19] vertically next to each other below each pair of Front Flaps [A-16] as shown in Figure 4-60(A). For small suit, place one unit of [A-19]. Repeat for the other leg.

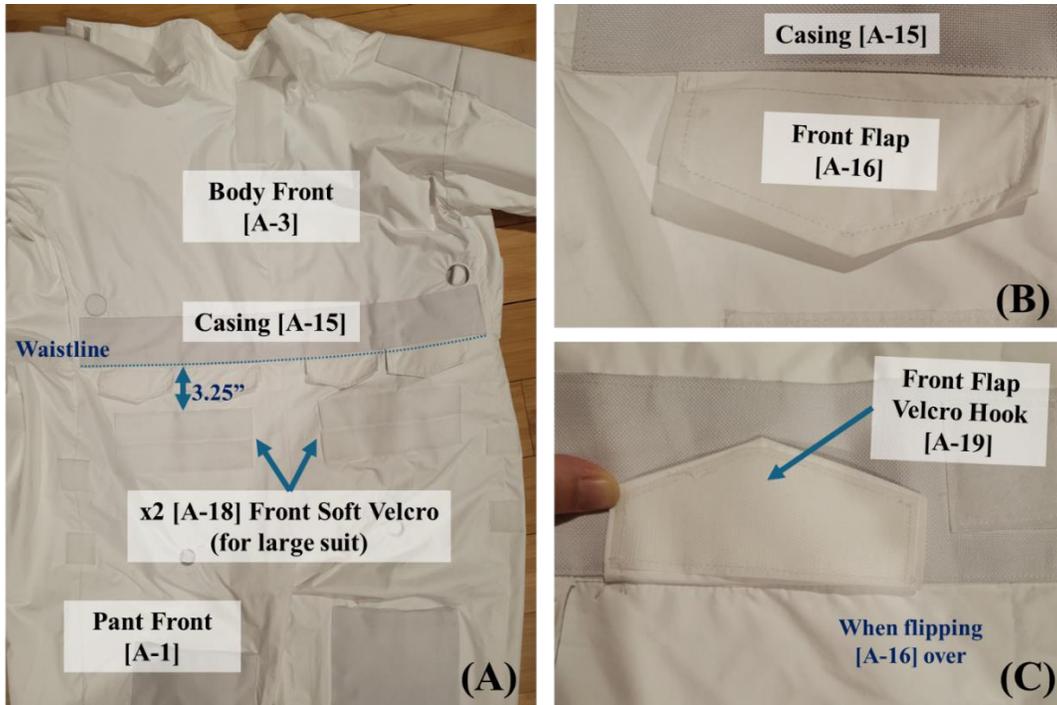


Figure 4-60. Integrate Front Flaps [A-16] onto the suit with the following completed views. (A) A Large HS3 Suit, (B) Front Flap [A-16], (C) Front Flap Velcro Hook [A-19].

5. Press and fold $\frac{1}{2}$ " from the top edge of Back Flaps [A-17]. Pin 1 unit of Back Flap [A-17] to each Pant Back [A-2] panel as shown in Figure 4-43. TOPSTITCH the Back Flaps [A-17] in place. Complete this step for both legs.
6. Pin 2" x 5 $\frac{1}{2}$ " Back Soft Velcro [A-21] 3 $\frac{1}{4}$ " below the waistline as shown in Figure 4-61. EDGESTITCH [A-21] in place. Repeat for the other leg.

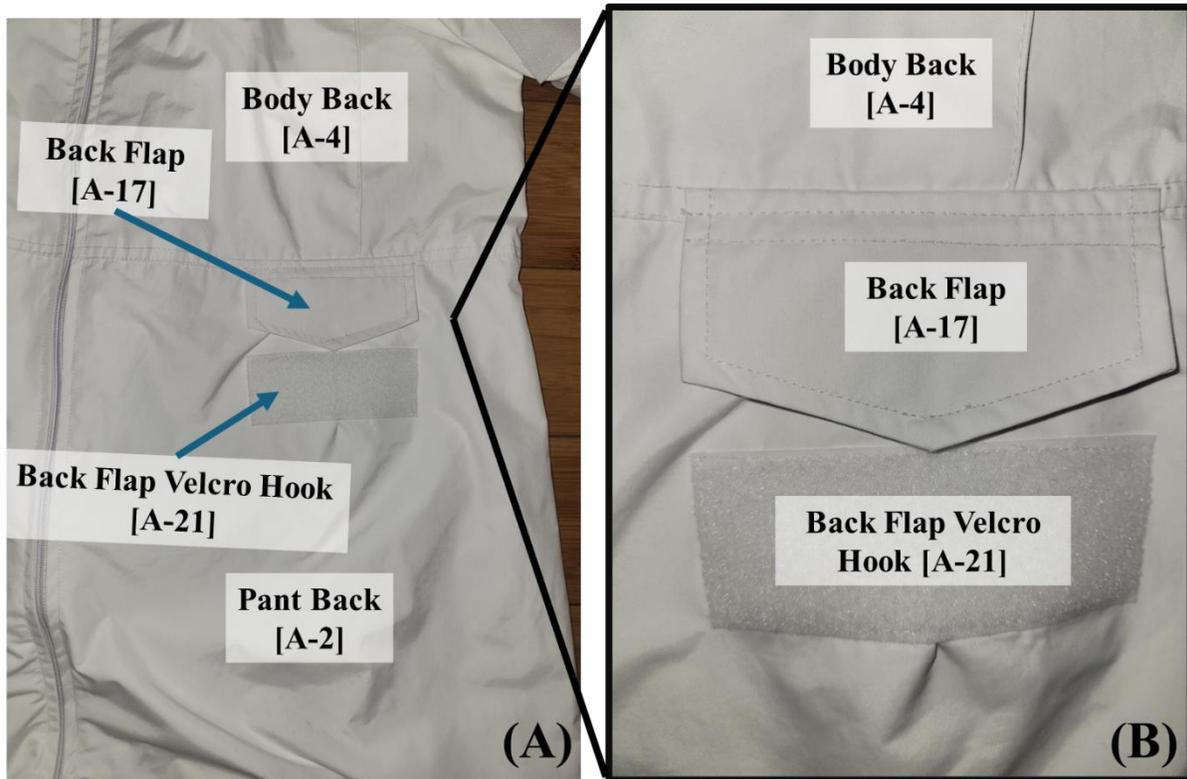


Figure 4-61. Integrate Back Flaps [A-17] onto the suit with the following completed views. (A) A Large HS3 Suit, (B) Back Flap [A-17].

4.3.2.3.13 Holes [A-22, A-23]

Holes are labeled with S1, S2, S3, etc, on the inside of the suit. **The only hole (hole S3/S4) required for HS3 2.5 is the LCG hole (diameter = 1.5") located on Casing [A-15] since HS3 2.5 does not use body ventilation.** All other holes (diameter 1 inch) are for body ventilation purposes for HS3 2.0 version (3D printed ventilation adapters). If body ventilation is not used, user can opt to not make those holes listed in this section.

1. Draw a 1" diameter circle in the center of 3" x 3" Fabric [A-22]. With right sides together, pin 3" x 3" Fabric [A-22] on the suit where the hole is needed. Stitch the along the previously drawn circle onto the fabric [A-22]. See Figure 4-62(A).
2. Cut out an inner circle $\frac{1}{4}$ " smaller from the previous stitch and cut small flaps (See Figure 4-62(D)) along the circle without cutting through the previously sewn circle in previous step. See Figure 4-62(B, C, D).
3. Flip 3" x 3" Fabric [A-22] into the inside of the suit. See Figure 4-62(E).
4. Press the circle flat. See Figure 4-62(F).

5. Cut a 1" diameter circle in the center of 3" x 3" Soft Velcro [A-23]. Line up 3" x 3" Soft Velcro [A-23] under the 3" x 3" Fabric [A-22] on the suit. Ensure that the 3" x 3" Soft Velcro [A-23] faces inside the suit and the circles align together. Figure 4-62 (G) shows the completed view from inside of the suit.
6. EDGESTITCH around the perimeter of the circle, ensuring that the stitch goes through the 3" x 3" Soft Velcro [A-23], 3" x 3" Fabric [A-22], and suit. Figure 4-62 (H) shows the completed view.
7. EDGESTITCH around the perimeter of the 3" x 3" Soft Velcro [A-23] and 3" x 3" Fabric [A-22]. Figure 4-62(G and I) shows the completed view.
8. Repeat steps 1-6 for additional holes and sizes as needed.

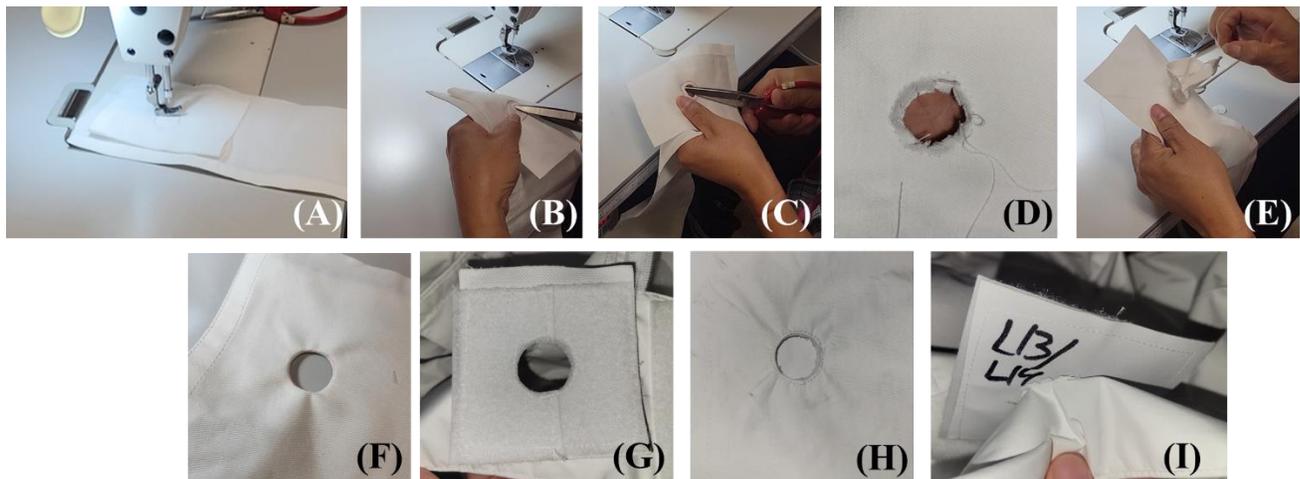


Figure 4-62. Hole Making Process for the HS3 Suit.

(A) Step 1: Overlay [A-22] onto desired hole location and stitch along the desired circle, (B, C) Step 2: Cut an inner circle that is ¼" smaller, (D) Step 2: Cut small flaps along the circle, (E) Step 3: Flip the circle over, (F) Step 4: Press the circle, (G) Step 5: Completed view (from inside of the suit), (H) Step 6: Completed view (from outside of the suit), (I) Step 7: Stitch together [A-22] and [A-23].

4.3.2.4 Manufacturing Instructions: Part B – HUT Arm Canvas Covers

Patterns II-1 and II-2 are used in this section. See Appendix section for printable versions.

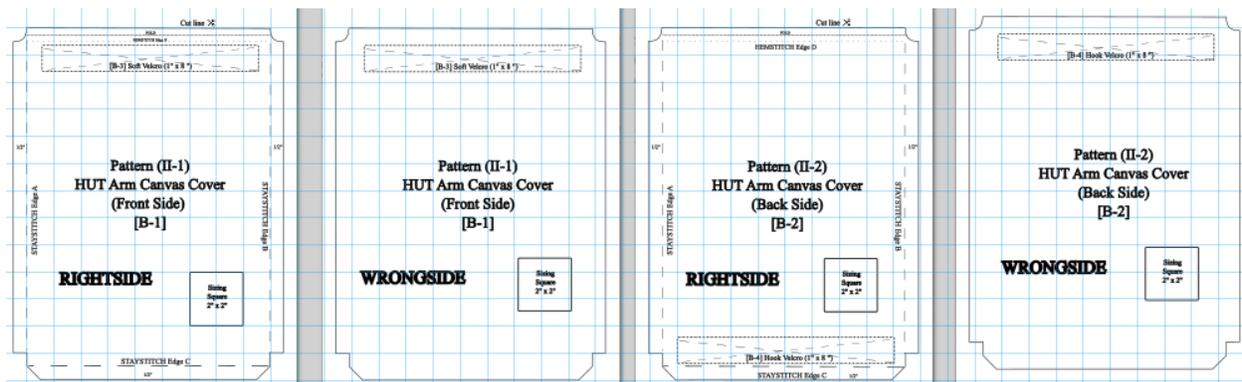


Figure 4-63. HUT Arm Canvas Cover Soft Good Pattern.

(See Appendix Pattern (II-1 and II-2) for printable version). Major grid line is spaced 1 inch part, minor grid line is 1/8". Note: this pattern needs to be split printed on multiple papers.

4.3.2.4.1 Part B - Cutting Instruction

1. On the **RIGHTSIDE**, cut out **2 units** of pattern (II-1) on <1> canvas material along the cut line (_____) to create **2 units** of [B-1].
2. Note: 1 unit of [B-1] and 1 unit of [B-2] make 1 unit of Canvas Cover. Thus 2 units of [B-1] and [B-2] create 2 units of Canvas Cover (one for each arm per suit).
3. On the **RIGHTSIDE** up, cut out **2 units** of pattern (II-2) on <1> canvas material along the cut line (_____) to create 2 units of [B-2].
Note: At this point [B-1] and [B-2] should look identical.
4. Cut 4 units of [B-3] soft velcro (1" x 8") on <3> velcro soft material.
5. Cut 4 units of [B-4] hook velcro (1" x 8") on <4> velcro hook material.
6. Cut 2 units of [B-5] 4" x 8" (rectangle shape) Arm Cover Foam on <8> EVA Foam material.

4.3.2.4.2 Part B - Sewing/Assembly Instruction

1. To make the **front side** [B-1] of the canvas cover:
 - a. **EDGESTITCH** 1 unit of [B-3] on the **RIGHTSIDE** of fabric per pattern (II-1) instruction on [B-1]
 - b. **EDGESTITCH** 1 unit of [B-3] on the **WRONGSIDE** of fabric per pattern (II-1) instruction on [B-1]
 - c. Add in some reinforcement stitches by stitching along the stitch lines across the Velcro to make it more secure under repeated use.
2. With **RIGHTSIDES** together, **STAYSTITCH** front [B-1] x1 and back [B-2] x1 pieces together.
 - a. Only **STAYSTITCH** with ½" seam allowance along Edge A, B, and C stitch line (_____) as labeled on Pattern (II-1).
 - b. The top edge of the cover should remain opened.
 - c. Repeat this step for the 2 unit of canvas cover
3. With **RIGHTSIDES** together, **HEMSTITCH** ½" along top edge (Edge D). See completed view in Figure 4-64.



Figure 4-64. Completed View of the Hem Edge on the Top Edge of the HUT Arm Canvas Cover.



Figure 4-65. Insert the EVA Foam [B-5] all the way into the Canvas Cover Pocket.

4. Flip the fabric over, with **WRONGSIDES** together, **EDGESTITCH** 1 unit of [B-4] hook velcro on the **RIGHTSIDE** of [B-2] (**back sides** of the canvas cover) per pattern (II-2) instruction. The stitches should go across all layers of fabric, i.e., [B-1] and [B-2].
5. To complete the **back sides** [B-2] of the canvas cover:
 - a. **EDGESTITCH** 1 unit of [B-4] on the **WRONGSIDE** of fabric per pattern (II-2) instruction. Verify positioning of this hook velcro so that it will properly align with the [B-3] soft velcro on the opposite side of [B-1] (wrong side).
 - b. Add in some reinforcement stitches by stitching along the stitch lines across the Velcro to make it more secure under repeated use.
6. Insert 1 unit of [B-5] EVA foam and push it all the way down into each arm canvas cover as shown in Figure 4-65.
7. Repeat steps 8-15, to make a second unit of HUT Arm Canvas Cover. See Figure 4-66 for the completed assembly of one unit of HUT Arm Canvas Cover.

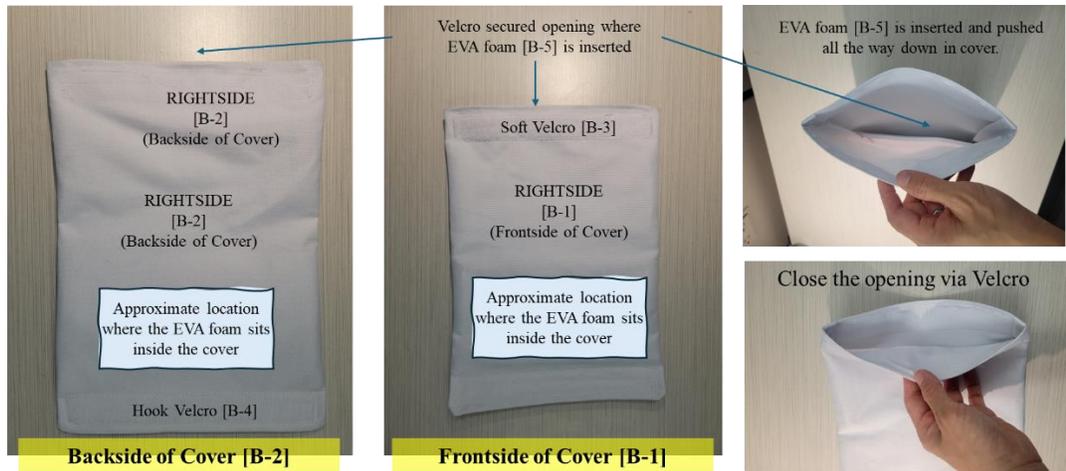


Figure 4-66. Completed Assembly of 1 Unit of HUT Arm Canvas Cover.

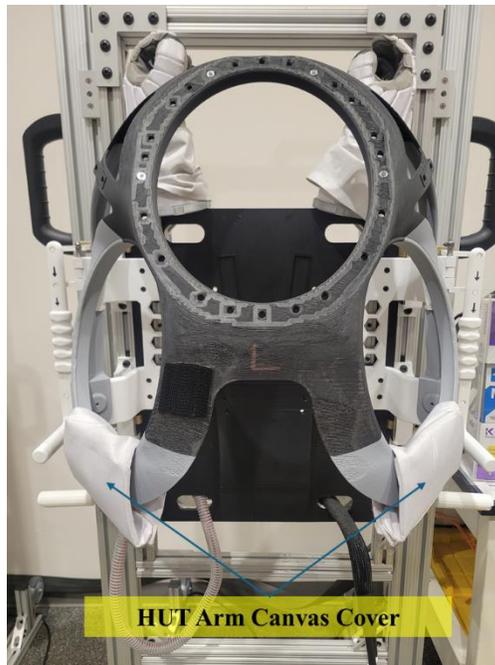


Figure 4-67. HUT Arm Canvas Cover Installed on the HUT.
Notice the Velcro are on the lower edge of the HUT openings to prevent subjects accidentally pulling the Velcro or rubbing it open with arms.

4.3.2.5 Manufacturing Instructions: Part C – Glove and Glove Gauntlet

Patterns III-1 and III-2 are used in this section. See Appendix section for printable versions.

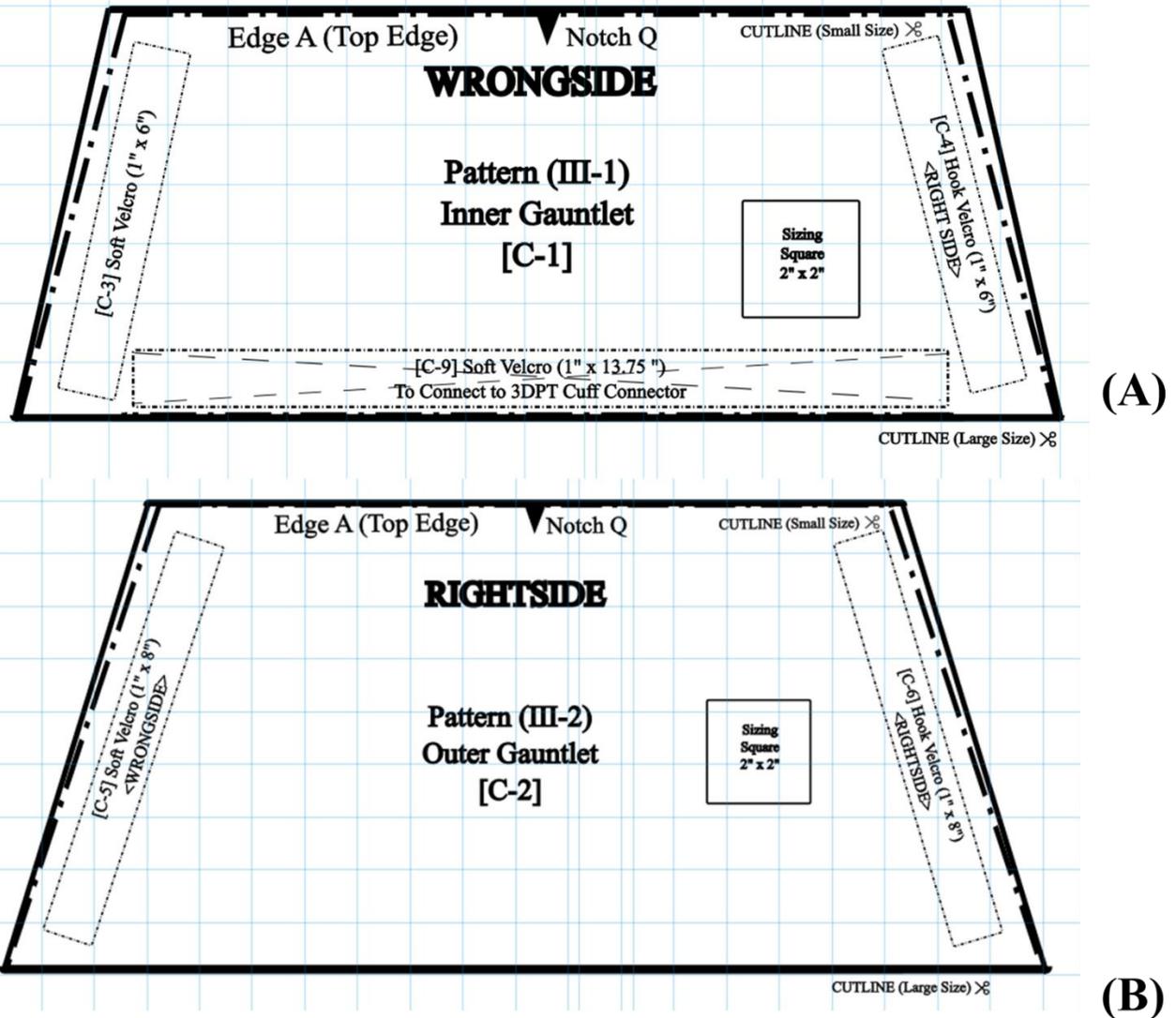


Figure 4-68. Glove Gauntlets Soft Good Pattern.

See Appendix Pattern (III-1 and III-2) for printable version. (A) Pattern (III-1) inner gauntlet, (B) Pattern (III-2) outer gauntlet.

4.3.2.5.1 Part C - Cutting Instruction

1. On the RIGHTSIDE, cut out **2 units** of pattern (III-1) on <2> nylon and **2 units** of pattern (III-2) on <1> canvas material along the cut line (————) to create **2 units** of [C-1] and [C-2]. Follow the appropriate size line for large glove vs. small glove per patterns shown in Figure 4-68.
2. Cut 2 unit for each component ([C-3] through [C-6], [C-9], and [C-10]) for various size of Velcros per Part C section of Table 4-25.

4.3.2.5.2 Part C - Sewing/Assembly Instruction

Prepare COTS lacrosse glove

1. Use seam ripper to remove the lower part of the lacrosse glove and dispose of those materials, see Figure 4-69.

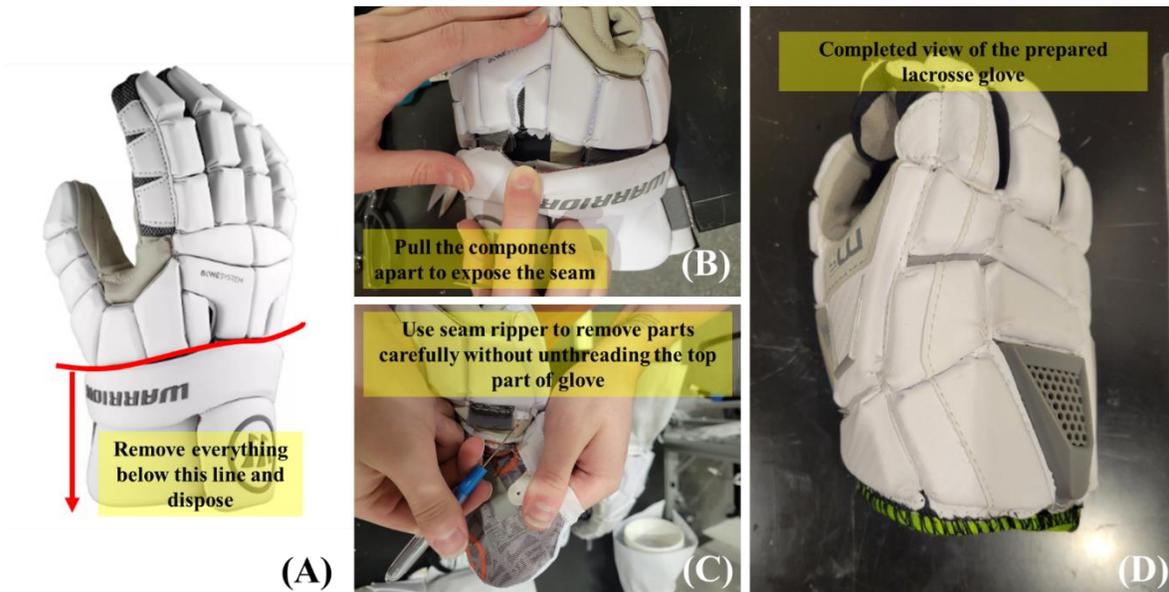


Figure 4-69. Prepare the COTS Lacrosse Glove.

- (A) Remove all contents below the red line, (B) Expose seam, (C) Remove seam stitching, and (D) Complete view.**

Sewing the Gauntlets

2. Fold 0.5" and press along all raw edges of [C-1] and [C-2], remove excess fabric as needed at the corners for a flat surface. See Figure 4-70(A).
3. EDGESTITCH all edges along [C-1] and [C-2]
4. On [C-1], pin [C-3] Soft Velcro (1" x 6") on the WRONGSIDE of fabric, [C-4] Hook Velcro (1" x 6") on the RIGHTSIDE of fabric, and [C-9] Soft Velcro (1" x 13.75") on the WRONGSIDE of fabric. EDGESTITCH the perimeter of all Velcros in place. Perform cross stitch (making reinforcement X) on the Velcro as necessary to improve strength since this is a frequently removed area.
5. On [C-2], pin [C-5] Soft Velcro (1" x 8") on the WRONGSIDE of fabric, and [C-6] Hook Velcro (1" x 8") on the RIGHTSIDE of fabric. EDGESTITCH the perimeter of all Velcros in place. Perform cross stitch (making reinforcement X) on the Velcro as necessary to improve strength since this is a frequently removed area.

Assemble the Gauntlets and the Gloves

6. Align the Notch Q on [C-1] and [C-2] and pin the Outer Gauntlet [C-2] on top of Inner Gauntlet [C-1] with RIGHTSIDE face up. Figure 4-70(B).
7. EDGESTITCH along the top edge (Edge A), and then TOPSTICHTH along the same edge.
8. Pin the gauntlet from step 2 around the perimeter of the prepared lacrosse glove as shown in Figure 4-71. Verify the opening is located along the extension of index finger or along extension of the little finger.

9. Hand stitch the gauntlet Edge A along the perimeter of the bottom of lacrosse glove. Perform at least two complete rounds (around the perimeter) of stitches to secure the gauntlet and the glove.
10. Wear appropriate Personal Protective Equipment (PPE) per vendor recommendations. Apply adhesive spray [S-19] per BOM or industrial grade double side tape on the outer side of the wrist ring [C-8]. Attach the hook Velcro [C-10] onto the wrist ring [C-8]. See Figure 4-70(C).
11. Repeat step 3 to attach x1 [C-12] the side that is connected to the suit on [C-7] wrist ring. See Figure 4-70(C).
12. Repeat steps 1-6 on the other hand to complete the second glove. See Figure 4-71 for completed view.

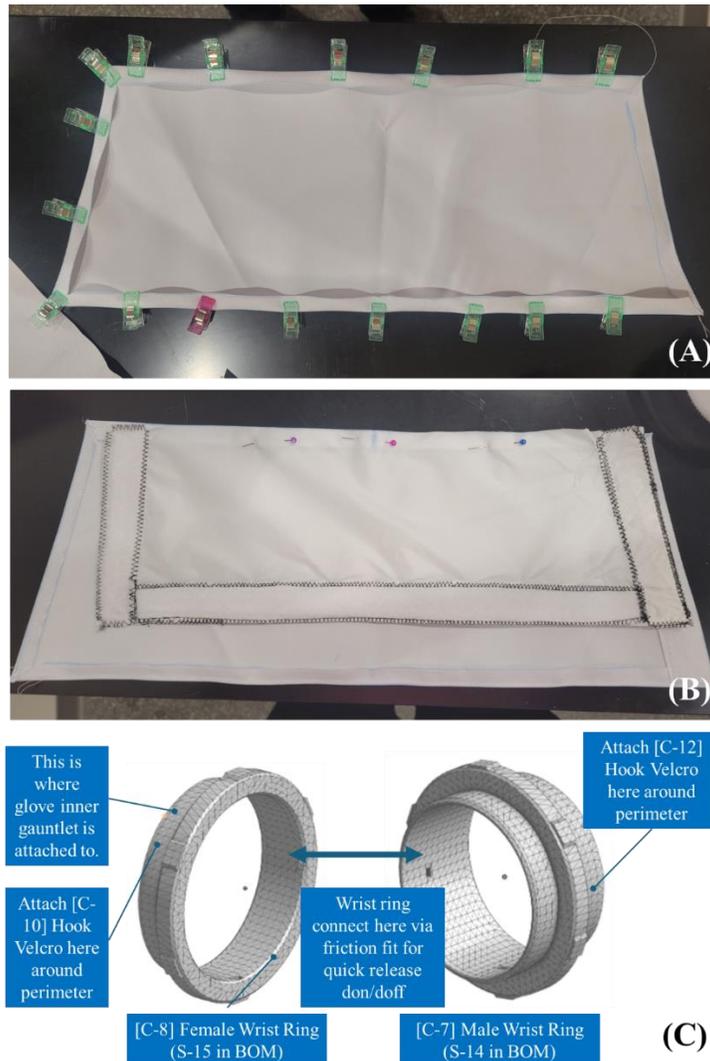


Figure 4-70. Construction and Assembly of the Glove System:
(A) Fold and press along the raw edge per step 1 for the gauntlets, (B) Align the inner and outer gauntlet and pin, (C) Velcro integration on the wrist rings.

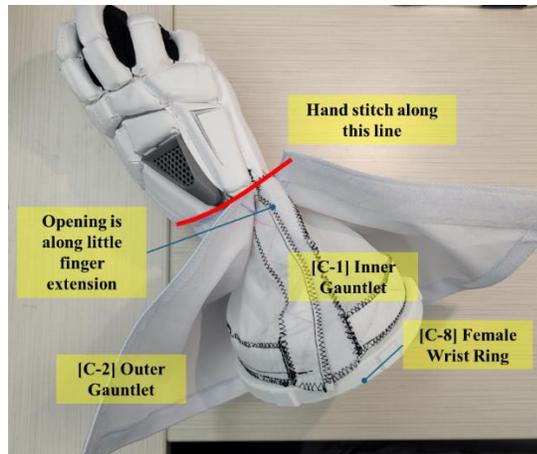


Figure 4-71. Completion View of the Glove System.

4.4 Peripheral Systems

This section documents the design, construction, and assembly of the HS3 peripheral systems (BOM #R1-17).

4.4.1 Design Details

The HS3 peripheral system provides an enhanced experience to simulate systems used during EVA. When designing the peripheral system, the test team consulted with the flight operations directorate and analog-experienced test subjects on ancillary equipment. With the feedback provided, the test team identified the following design features to achieve good suit simulation quality:

- Integrated communication system with wireless connectivity.
- Integrated camera assembly for first-person view.
- Integrated full body cooling system with uniform water cooling.
- Overall lightweight system (clothing and ancillary equipment).
- Enhance suit-like restricted range of motion (ROM).
- Enhance simulation quality with integrated assets (VR and treadmill).
- Integrated lighting system for performing in dark testing environment (EVA simulation).

4.4.1.1 Communication System

The HS3 communication system provides wireless two-way voice interface while considering the testing environment. Testing environments typically involve physical activity resulting in sweat thus requires the system to be water resistant and withstand movement. The test team selected bone conduction headphones (BOM #R-14). The selected SHOKZ OpenRun headphones provide an 8-hour battery life with 33 feet Bluetooth range which is sufficient for EVA simulation. This can be a limitation for outdoor field testing. However, it can be easily solved with connecting to a mobile device (add in PLSS) to remove range limitation. This system is lightweight (26 g) with open ear comfort and fit to allow for integration with HS3 HUT and helmet/visor. For two-

way communication between the test team and subject, any computer system with Bluetooth capability and meeting application (e.g. MS Teams, Discord) can be used.



Figure 4-72. HS3 Bone Conduction Headphones.

4.4.1.2 Camera Assembly

The HS3 camera assembly mounted to the HS3 HUT provides a live streaming first-person view during EVA simulation. The test team selected Logitech Mevo wireless camera (BOM #R-15) and camera mount adapter (BOM# R-16). The view can be modified by physically manipulating the mount adapter. The wireless camera provides HD (1080p) resolution with the ability to stream using Wi-Fi, ethernet, or LTE hotspot network. Mevo can easily integrate into any system setup that is compatible with webcam capability. The camera mount adapter can easily adapt other cameras such as GoPro, and/or subject facing view camera extension if required via standard ¼”-20 screw interface. Camera assembly is mounted by a bolt on the HUT multipurpose attachment joint.

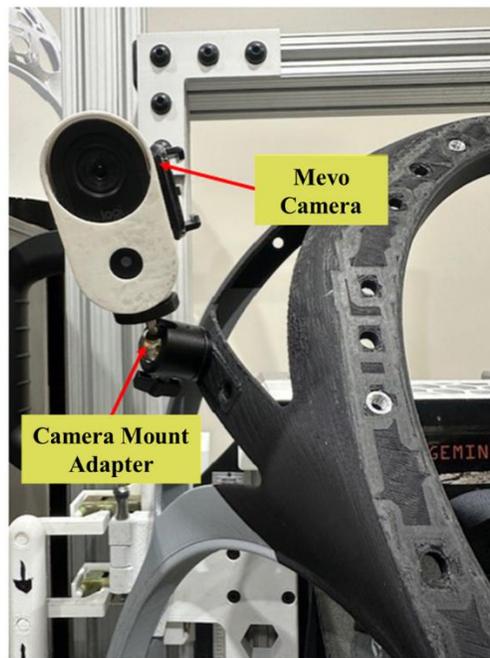


Figure 4-73. HS3 Camera Assembly

4.4.1.3 Liquid Cooling Garment (LCG)

The HS3 LCG provides full body, uniform water cooling to the subject during EVA simulation. The test team selected COMPCOOLER Full Body Cooling Garment (BOM# R-7) due to its similarity to the EMU Liquid Cooling and Ventilation Garment (LCVG). This is a breathable stretchable garment with tubing lined throughout the full body. Though stretchable material, the LCG provides a snug fit for maximum thermal transfer around the torso, arms, and legs. With four

sizes available, there is the ability to fit a wide range of subject anthropometries. The LCG water inlet and outlet ports consist of quick disconnect (QD) fittings allowing for integration with the PLSS liquid cooling system.

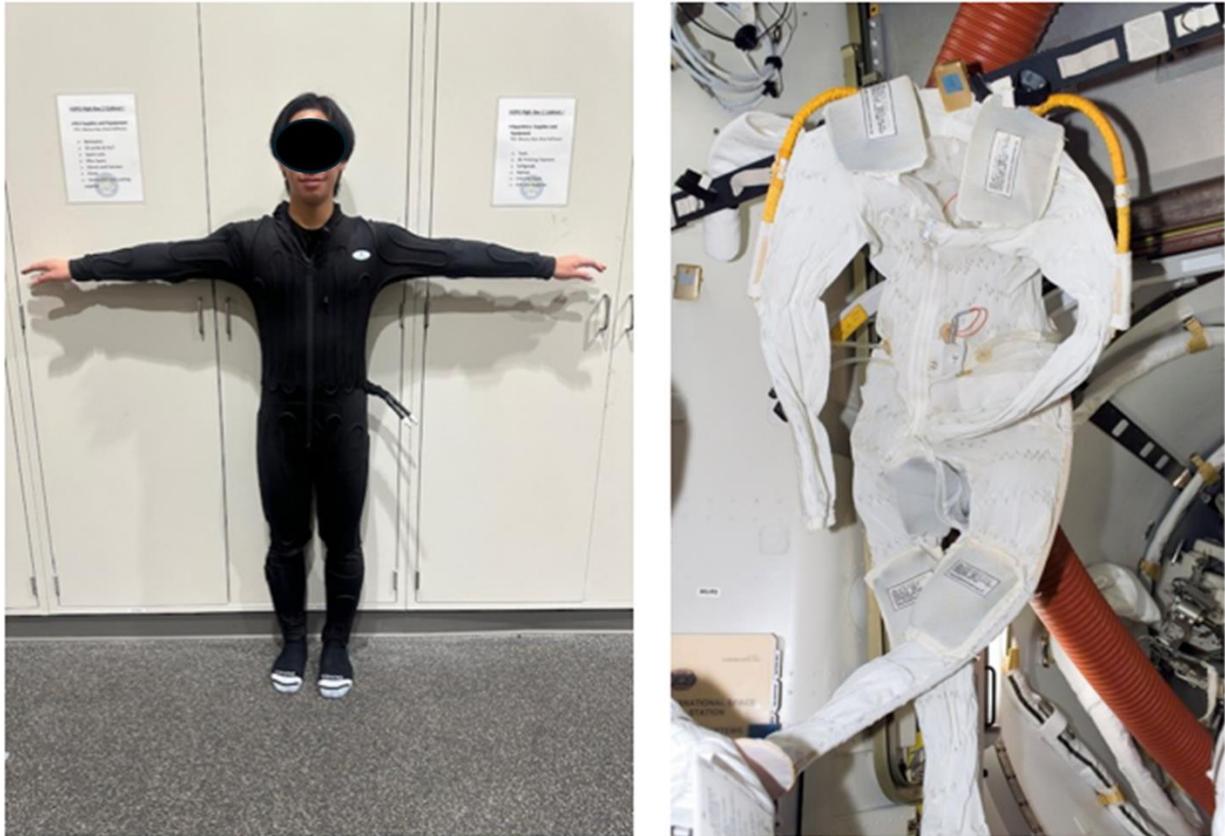


Figure 4-74. Comparison between HS3 LCG (Left) and EMU LCVG (Right Source: NASA).

4.4.1.4 Thermal Comfort Undergarment (TCU)

To avoid direct skin contact with the HS3 LCG, subjects wear a thermal base layer similar to the EMU thermal comfort undergarments (TCUs) for comfort and ease of cleaning posttest. The HS3 TCU (BOM# R5 – R6) were selected by the test team due to the fabric selection and fit. These lightweight COTS athletic thermal base layers are made with 40% Polyester, 34% Acrylic, 22% Rayon, and 4% Spandex which allow for moisture wicking and quick drying. The fit accommodates wearing under the LCG without disrupting thermal cooling capability.



Figure 4-75. HS3 Thermal Comfort Undergarment uses COTS Base Layers.

4.4.1.5 Boot Assembly

The test team selected hiking boots (BOM# R1 – R3) due to its volumetric size and mobility restriction being similar to the xEMU boot in ankle support [13]. The boot system features a quick release twist design which makes donning and doffing process easy. Additionally, padded insoles (BOM# R-4) can be installed in the boot prior to donning to allow for sizing adaptation to fit different individual's feet.



Figure 4-76. HS3 Boot (Left) xEMU Boot (Right).

4.4.1.6 Range of Motion (ROM) Ancillary Equipment

To provide restricted ROM similar to the xEMU, the subject must experience restriction in the extremities (arms and legs) and at the waist. Due to the xEMU being a pressurized system, crewmember have difficulty performing certain movements such as bending and flexing. To mimic this mobility restriction, HS3 included ROM ancillary equipment subsystem consisting of an elbow brace (BOM# R-8), knee brace (BOM# R-9) and waist inhibitor with crotch pad assembly (BOM# R10 – R13).

The elbow brace provides resistance with the adjustable Velcro straps along with compression to restrict the elbow from bending fully. The knee brace provides support and resistance to the knee without fully restricting knee movement, allowing the subject to still walk and kneel. Both the elbow and knee braces are to be worn outside the LCG but must not be strapped down too tight to prevent any tubing blockage or subject discomfort.

The waist inhibitor provides restriction at the waist and crotch. With the intention to be similar to the xEMU design, the subject must be unable to bend at the waist but maintain rotational pivoting of the legs. The waist inhibitor was designed by the test team using a swim floating belt, foam pool

noodle, belt loops, and webbing buckles. Manufacturing instruction can be found in Section 4.4.2. The design features flexible size adjustment to keep the foam noodle at the desired location to provide the “separating leg” function akin to a space suit’s hard waist/brief/hip assembly.

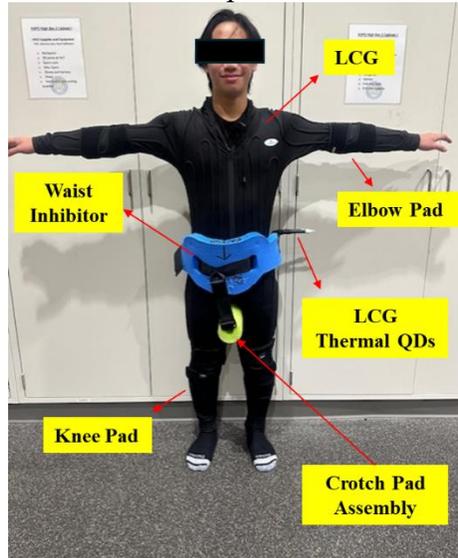


Figure 4-77. HS3 Range of Motion Ancillary Equipment.

4.4.1.7 Treadmill Adaptation

An optional HS3 enhancement when using treadmill for simulation EVA traverse task is the addition of a safety harness. The safety harness is used with a fireman knot to create a low-profile harness for positioning a subject on a treadmill and providing fall restraint, especially when used in unique ambulation scenarios (i.e. coupled with VR). The test team selected tubular webbing made from high tenacity Nylon (BOM# R-17) due to being UIAA certified. It is recommended to have two sizes (30ft and 50ft) for varying subject anthropometries.



Figure 4-78. HS3 Treadmill Adaptation

4.4.1.8 Lighting System

An optional HS3 enhancement is the addition of a lighting system to provide a light source during low light or dark testing conditions. This lighting system needed to be lightweight (≤ 1 lb) and mountable to the HS3 helmet/visor. Additionally, the lighting system was required to be powered via rechargeable battery or PLSS battery power. Although no xEMU lighting requirement is available for reference when designing HS3 lighting system, NASA lighting experts recommend using similar design guidelines for headlamps that are used for hiking at night. When selecting a helmet light, it is recommended for lights with a brightness of 400-600 lumens and a 30 degree beam holographic diffuser for viewing coverage. Helmet lights are mounted by a bolt on the HUT multipurpose attachment joint.

4.4.2 Manufacturing Instructions – Waist Inhibitor

Construction of the waist inhibitor consists of two main parts: swim floating belt (waist inhibitor) and foam pool noodle (crotch pad assembly). The crotch pad assembly is attached to the waist inhibitor using belt loops in front and webbing with buckles in front and back.

For the crotch pad assembly to accommodate various subject anthropometrics, the foam pool noodle can be cut in three sizes: 10-inch, 15-inch, and 18-inch. Once cut, follow instructions below for each size (3 total):

1. Using cut foam pool noodle, insert 2” webbing (BOM# R-13) through middle hole.
2. With excess webbing at end of foam pool noodle, install side release buckle by sliding webbing through the inside slot and thread down through the outside slot.



Figure 4-79. Side Release Buckle Installation

3. Repeat step 2 for other side of foam pool noodle, resulting in two side release buckles being installed (one on each end). Take swim floating belt and install belt loop horizontally to the front middle of belt.

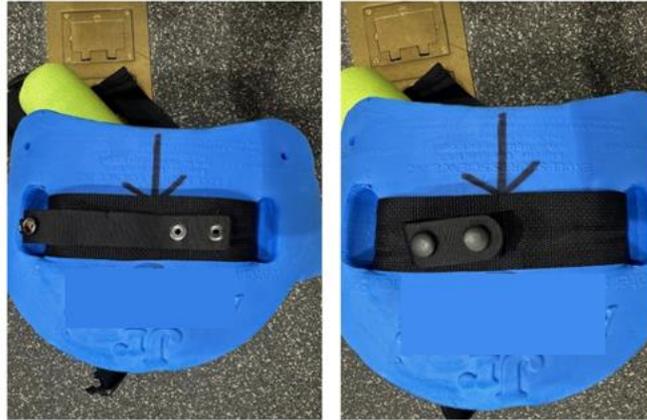


Figure 4-80. Belt Loop Installation

4. Leaving 5-6 inches of excess webbing after the side release buckles, install foam pool noodle to the belt loop on the swim floating belt by securing with a loop and then sewing closed.



Figure 4-81. Crotch Pad Assembly Securing Loop

5. With the other end of excess webbing, install foam pool noodle to a tri-glide slide on back of swim floating belt by securing with a loop and sewing closed.



Figure 4-82. Tri-Glide Slide Installation-

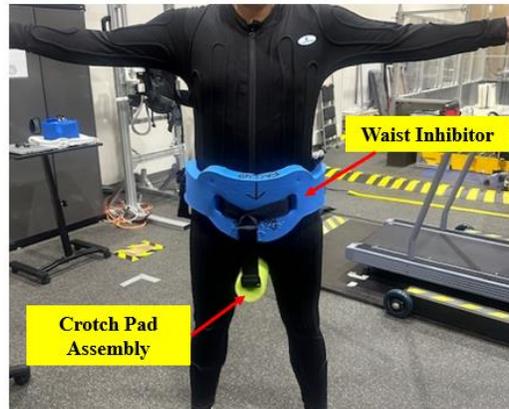


Figure 4-83. Complete Waist Inhibitor with Crotch Pad Assembly

4.5 Donning Stand System:

This section documents the design, construction, and assembly of the HS3 donning stand system (BOM #D1-27).

4.5.1 Design Details

The purpose of the donning stand is to provide a robust and safe method for donning and doffing the HS3 while being as EVA-like as possible. When designing the donning stand, the test team consulted with NASA's flight operations and engineering directorates and evaluated the donning stands that are currently used for EVA simulations and operations. Taking those design ideas into consideration, a list of requirements was set to ensure the donning stand accomplished the test team's needs. The following list highlights key design features for the donning stand:

- Tolerant of the environment (i.e. usable indoor and outdoor)
- Transportable
- Self-supporting and sturdy
- Safe ingress and egress
- Self-donning/doffing capability as well as assisted donning/doffing by two operators
- Inclusion of a soft-capture mechanism to provide more subject feedback during doffing process
- Hard-capture mechanism to secure the HS3 in the donning stand
- Ability to adjust height for each subject

The test team incorporated these key features to provide the ability to safely don, doff, and stow the HS3 effectively. The donning stand is primarily built out of aluminum t-slotted framing, providing a sturdy and durable structure as shown in Figure 4-84.

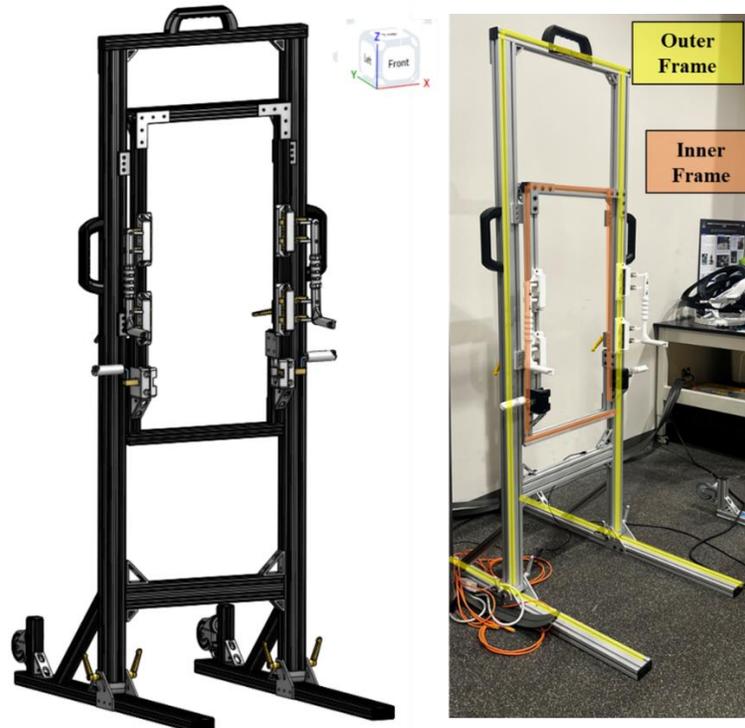


Figure 4-84. HS3 Donning Stand- CAD Model (left) and Full Build (right).

The donning stand is constructed with two main parts: the ‘inner frame’ that interfaces with the HS3, and the ‘outer frame’ that gives the stand its stability and free-standing structure. The inner frame is connected to the outer frame via four sliding carriages (two on each side). The bottom sliding carriages have a height adjustment handle that secures the inner frame at the desired location.

The design utilizes a standing donning procedure and offloads the weight of the HS3 from the subject during donning stand operations. During the egress and ingress procedures, soft capture mechanisms lock the PLSS freedom of movement in the X-Y directions (fore-aft and lateral movements). During soft capture, the PLSS is still allowed free vertical movement in the Z direction. The hard capture then will fully secure the subject in the donning stand and offload the HS3. The mechanism for both the hard capture and soft capture relies on COTS door latches, allowing for one-way actuation as shown in Figure 4-85. The PLSS backplate has a lip extended beyond each side wall that will slide through the door latch for soft capture. At the bottom of the PLSS backplate are two notches that then slide into the hard capture mechanism for final locking position.

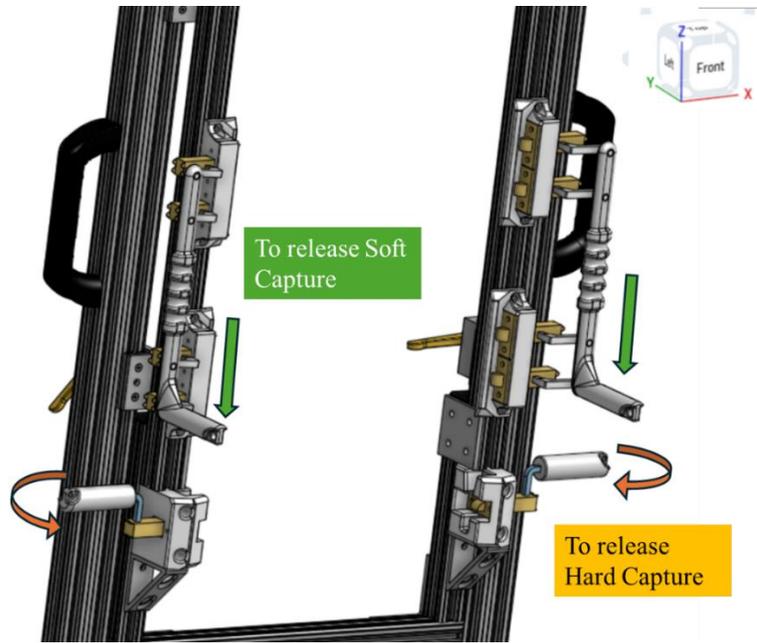


Figure 4-85. Capture Actuation for Donning Stand.

Handles are mounted to the hard capture mechanisms to enable self-ingress and egress. The hard capture handles have holes at each end for optional tethers to be attached and enable easier subject reach during self-don/doff scenarios and can be seen in use in Figure 4-86. The donning stand design components are shown in Figure 4-87.



Figure 4-86: Doffing Donning Stand.

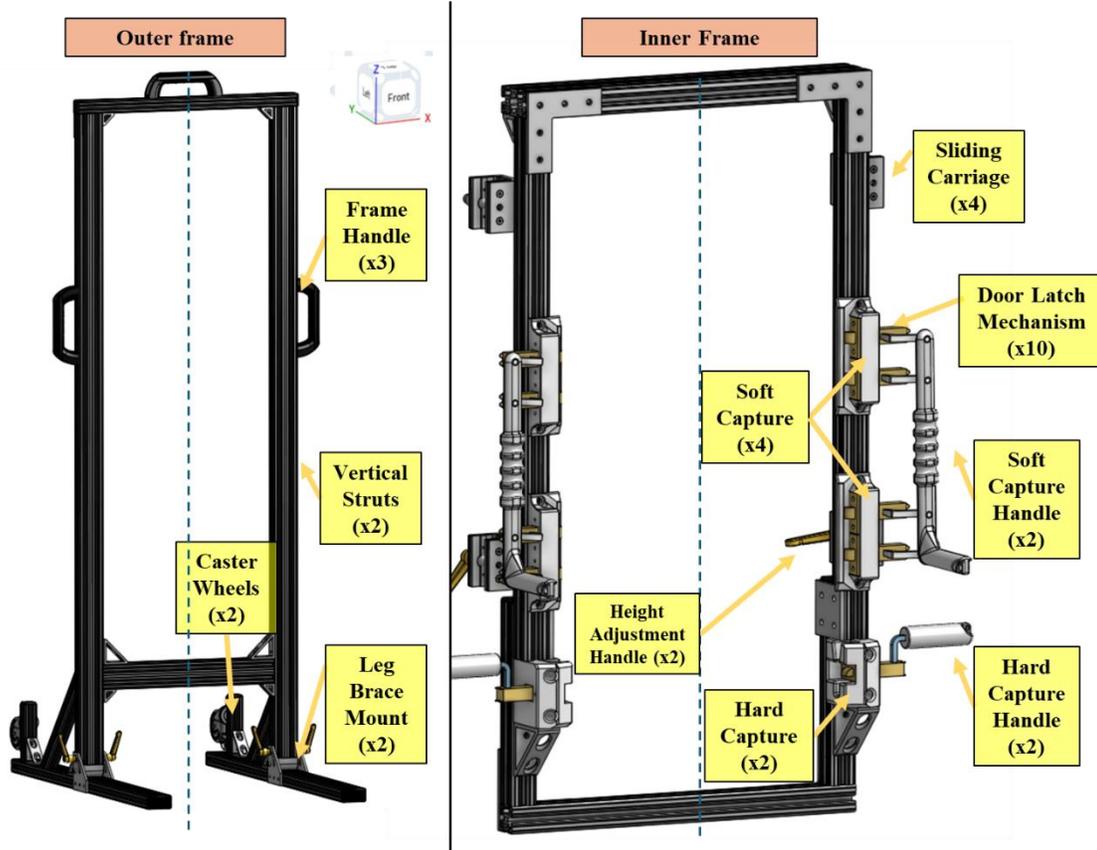


Figure 4-87. HS3 Donning Stand Components of Outer Frame (left) and Inner Frame (right)

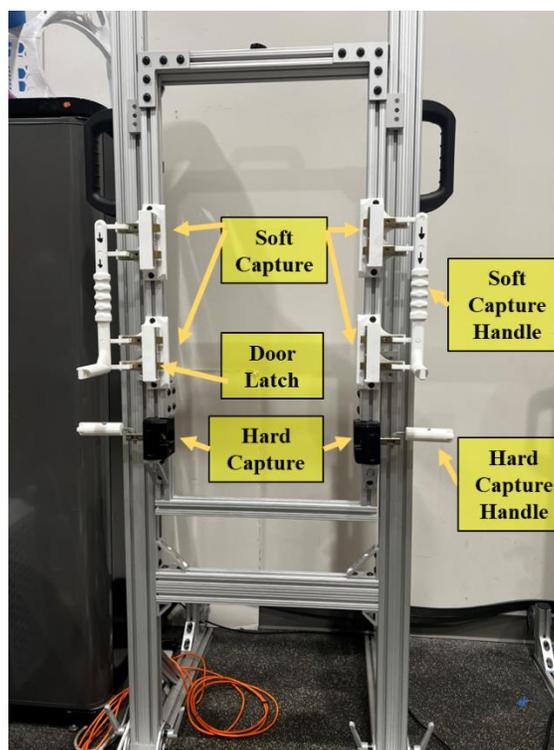


Figure 4-88. Design Components Labeled on Actual Build of Donning Stand

Transportation

For transportation, the donning stand has handles on both sides of the vertical struts and the top crossbar of the outer frame for easy maneuvering. Additionally, the stand has caster wheels that allow for the test team to easily tip the stand back and transport. The leg brace mount can be unlocked and allow for the front legs to fold up 90 degrees, making it more consolidated for transportation. While the donning stand has primarily been used indoors, the design was considerate of conducting operations outdoors and is robust and durable to where there should not be any issues if exposed to elements. The donning stand (weighing ~90 lb) can be easily transported by two operators.

4.5.2 Manufacturing Instructions

Construction of the donning stand can be broken into two parts, (1) the inner frame and (2) outer frame. The BOM can be found in Section 4.6.2, and is referenced throughout this section. Some of the aluminum t-slot framing in the BOM will be cut into multiple different pieces. To begin construction, cut the following parts from the donning stand BOM per Table 4-29 instruction. In each figure is a positioning vertex box that designates the parts orientation (e.g., back, front, right, left)

Table 4-29. Donning Stand Frame Cutting Instructions

BOM Item Number (qty)	BOM Piece	To make (qty)	Dimensions	Item Name
D-1 (x1)	8' single width	D-1.1 (x2)	30"	Inner Main Vertical
		D-1.2 (x1)	27 5/8"	Outer Upper Horizontal
D-2 (x1)	6' single width	D-2.1 (x1)	21 1/16"	Inner Lower Horizontal
		D-2.2 (x2)	11 1/4 "	Interior Lower Vertical
		D-2.3 (x2)	7"	Base Wheel Feet
D-4 (x3)	4' double width	D-4.1 (x4)	24"	Base Legs
		D-4.2 (x1)	21 9/16"	Outer Lower Horizontal
		D-4.3 (x1)	21 1/16"	Inner Upper Horizontal

4.5.2.1 Assembly Instructions - Inner Frame

Once the frame cuts are completed per Table 4-29, the full list of materials needed for the 'Inner Frame' are shown in Table 4-30. Assemble per instructions below and/or per donning stand CAD assembly file. This assembly uses t-slotted framing, which uses a standard nut and screw (15 series) to secure parts together in the slots. If at any time "0820 nut and screw" is referred to, it is utilizing the 15 series common nut and screw. All corner supports, brackets, and braces will come with the 0820 nuts/screws in the standard order package.

Table 4-30. Materials List for 'Inner Frame' of Donning Stand

BOM Item Number	Quantity	Use
D-1.1	2	Inner Main Vertical
D-2.1	1	Inner Lower Horizontal
D-2.2	2	Inner Lower Vertical
D-4.3	1	Inner Upper Horizontal
D-5	2	Connect two Inner Vertical Frames
D-6	4	Corner brackets for Inner frame
D-7	2	Corner support for Inner frame
D-8	2	Support for Hard Capture
D-18	18	Screws to secure door latches
D-19	4	Screw for Hard Capture
D-20	10	Capture Mechanism
D-21	2	Handle for Soft Capture
D-22	8	Adapter for Soft Capture
D-23	4	Housing for Soft Capture
D-24	2	Housing for Hard Capture
D-25	2	Handle for Hard Capture
D-26	12	Additional 0820 Fasteners
D-27	2	Actuate the Hard Capture

1. Attach (x2) D-6 brackets to the FRONT of D-4.3 and fasten.
2. Attach (x2) D-7 supports to the BACK of D-4.3 and fasten.
3. Slide (x2) D-1.1 into the D-6 brackets and D-7 supports, connecting D-1.1 to D-4.3 as shown in Figure 4-89.

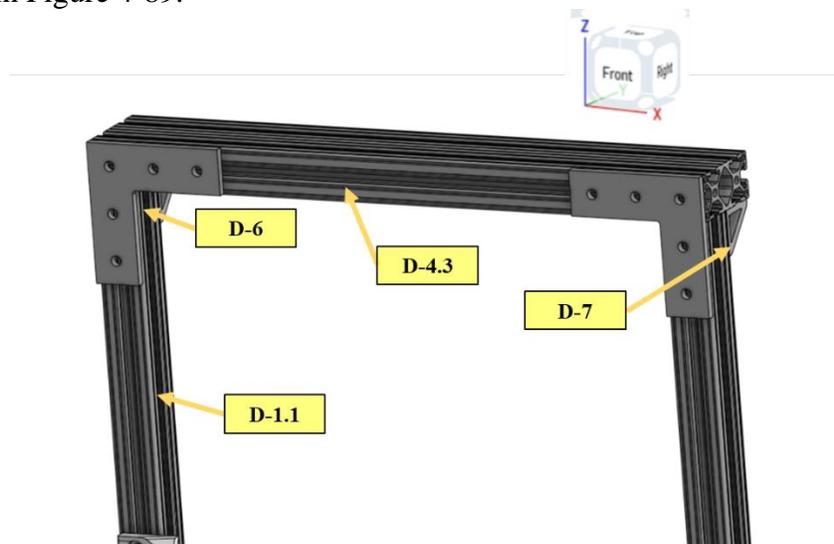


Figure 4-89. Attach Inner Vertical Frame to Upper Horizontal Frame of Donning Stand.

- Attach 4 sliding carriages (D-11, x2 per side) to the BACK slot of the inner frame vertical struts (D-1.1) as seen in Figure 4-90, with the D-15 attachment point facing laterally outward from inner frame.

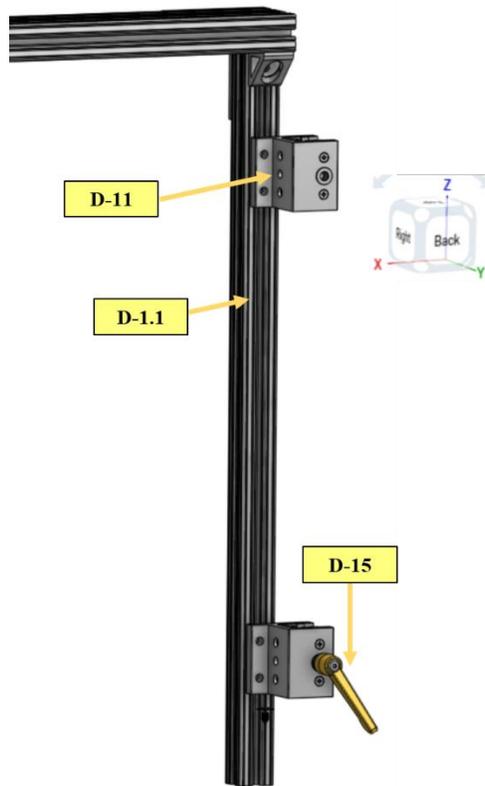


Figure 4-90. Attach Slide Carriage to Inner Vertical Upper Frame of Donning Stand.

- Space the top carriage 3” from the top of D-1.1 and space the bottom carriage 0.5” above the bottom of D-1.1.
- Attach (x2) slide carriage brakes (D-15) to the bottom two slide carriages (D-11).
- Connect the D-2.2 (x2) pieces to the BACK side of D-1.1 (x2) with (x2) D-5 brackets as shown in Figure 4-91 so that the lower vertical piece is in line with the extra width of the inner upper horizontal structure. Make sure the ends of D-1.1 and D-2.2 are flush with the ends of the square bracket.

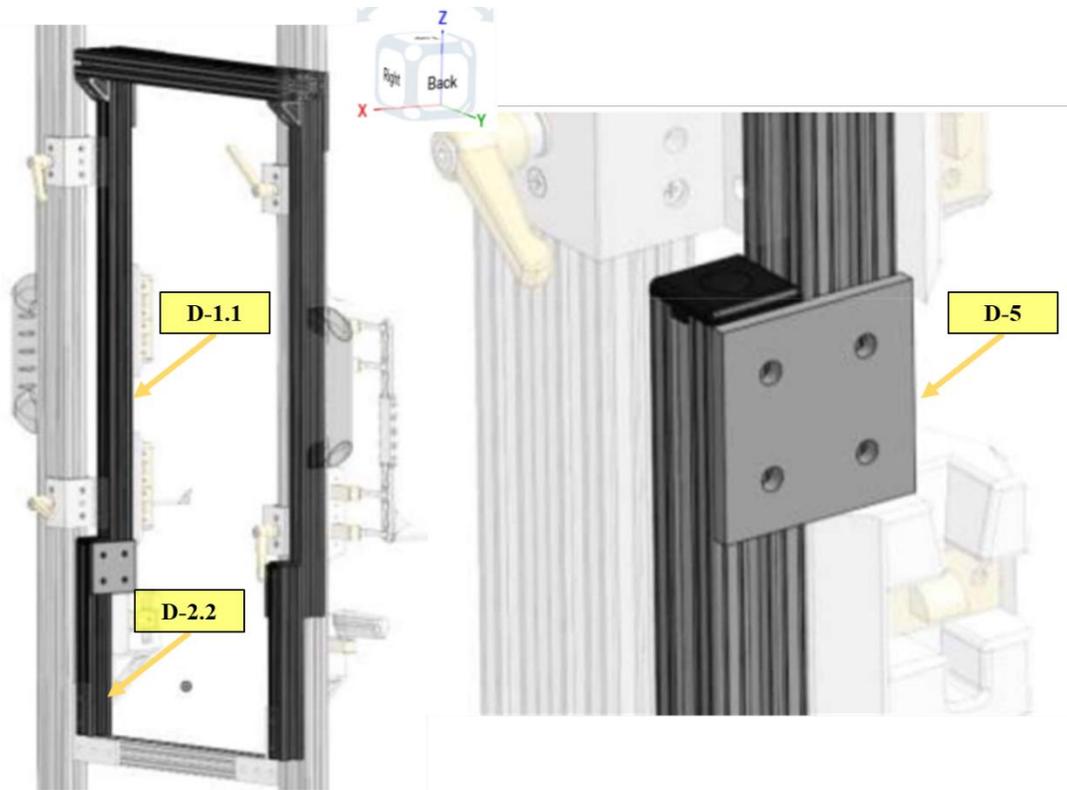


Figure 4-91. Attach Main Inner Vertical Strut to Lower Strut of Donning Stand.

7. Add plastic caps (x2) to the top of D-2.2.
8. Prepare 4 Soft capture housing (D-23 x4) with 0820 fasteners (D-26, both screw and nut), facing inward as shown in Figure 4-92.

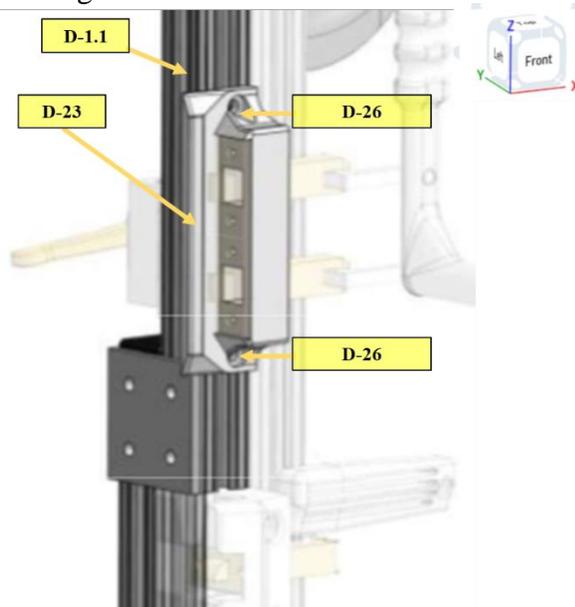


Figure 4-92. Attach Soft Capture Housing to Inner Frame of Donning Stand.

- Measuring up from the base of the inner main vertical (D-1.1) to the bottom face of each soft capture housing, tighten the first mount at 12.5" and the second at 2.75" as shown in Figure 4-93. Complete for other side as well.

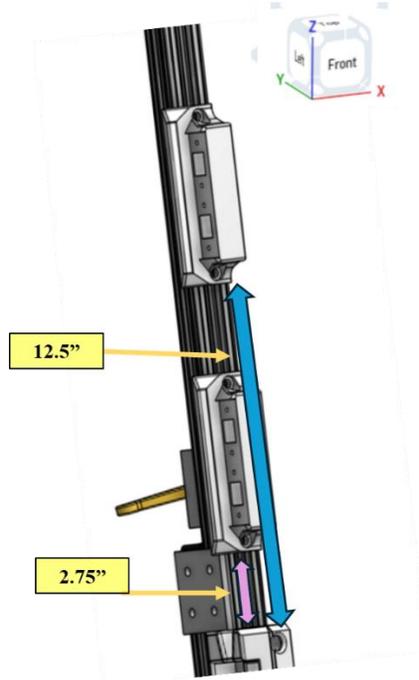


Figure 4-93. Distances for Spacing of Soft Capture Housing in Donning Stand.

- Slide x2 standard 0820 nuts (D-26, nut only) in the FRONT slot of D-2.2 and attach the hard capture mount with the (x2) 2.25" hex screws (D-19) to the FRONT slot of D-2.2. Align it so that it is flush with D-1.1 as shown in Figure 4-94. Repeat on the other side.

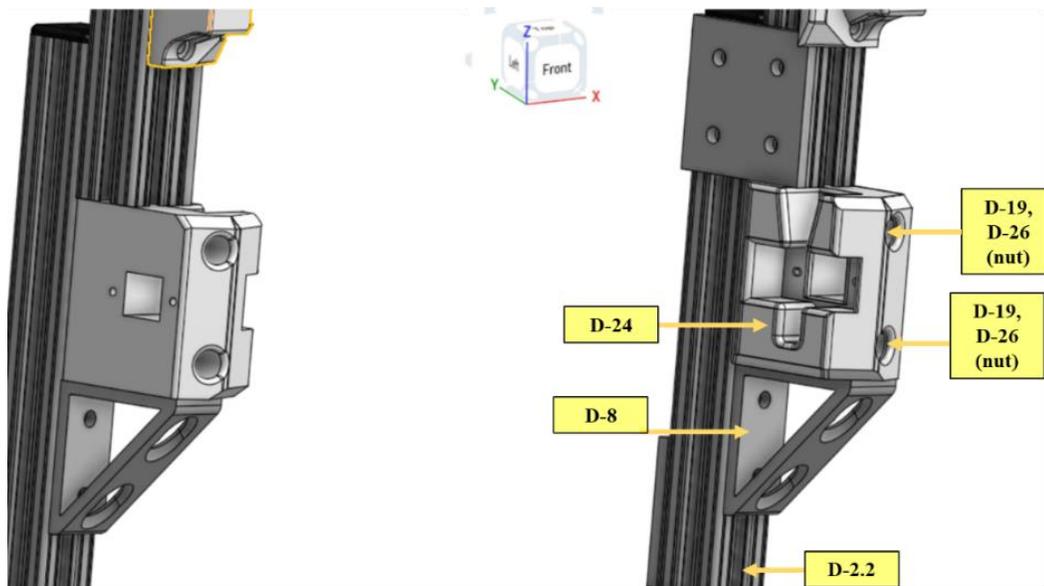


Figure 4-94. Attach Hard Capture to Inner Frame of Donning Stand.

11. Attach the 2"x2" corner brace (D-8) below the hard capture housing (D-24) on the FRONT slot of D-2.2. Repeat for the other side Figure 4-76.
12. Attach the inner lower horizontal frame (D-2.1) to the bottom of D-2.2 via the BACK slot with D-6 Brackets (x2) as shown in Figure 4-95.

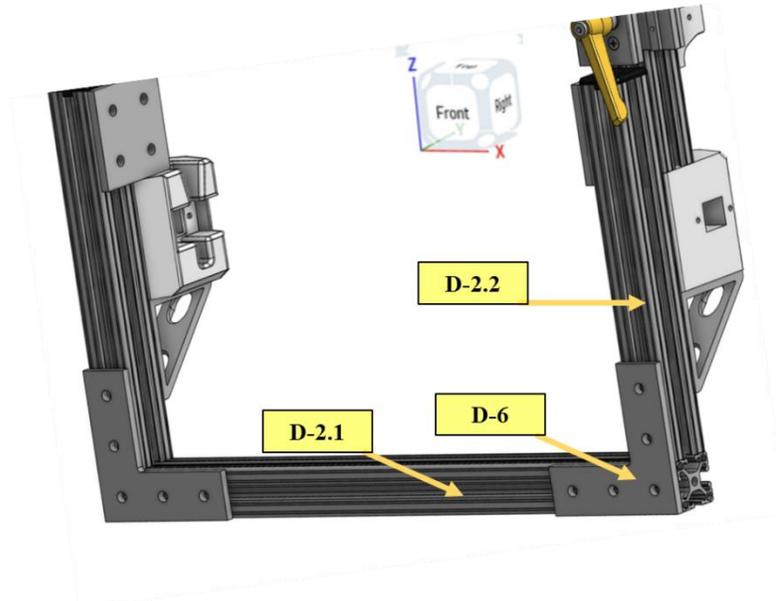


Figure 4-95. Attach Inner Lower Horizontal Strut to Inner Donning Stand.

ATTENTION: AT THIS POINT, WAIT UNTIL THE INNER FRAME IS ATTACHED TO OUTER FRAME TO INSTALL CAPTURE MECHANISMS AND 3DP LEVERS.

13. Insert capture mechanisms (D-20, x10) into slot for the soft captures with the rounded side facing FORWARD, and orient the rounded side facing UPWARD for the hard capture as shown in Figure 4-96.

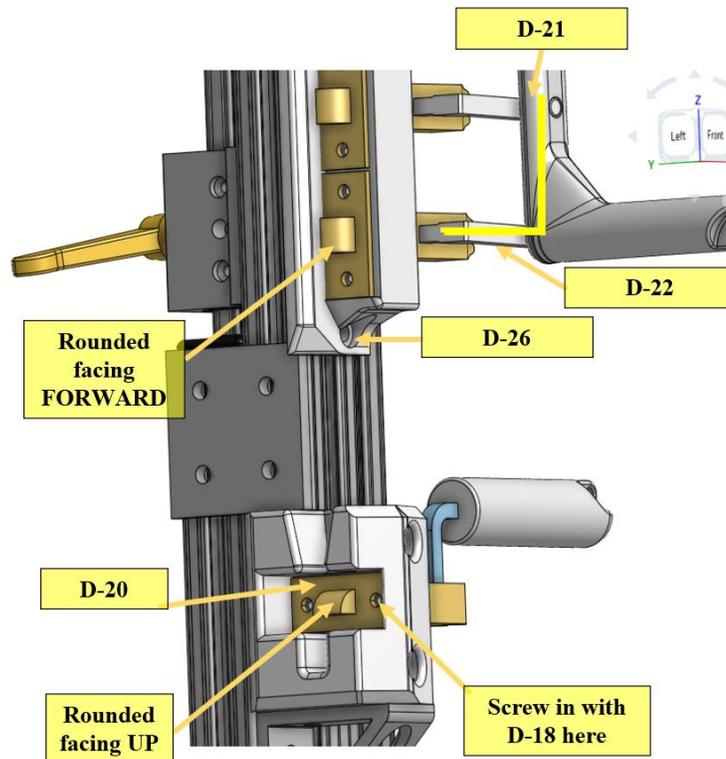


Figure 4-96. Insert Slide Capture Mechanisms into Housings in Donning Stand.

14. Secure the D-20 latches with Phillips head screws (D-18, x18) into the holes in the respective housings.
15. Attach the soft capture adapters (D-22 x8, x4 per handle) to the soft capture handle (D-21 x2). This is a rotational lock. The adapters should be perpendicular to the handle.
16. Install soft capture adapters into the rotational mechanisms in the D-20 latches, this is a friction fit.
17. Install the hard capture handle (D-25 x2) on the hard capture levers (D-27 x2) with the lateral hole facing UP Figure 4-97.
18. Install the hard capture levers into the door latch, dropping it through the latch as shown in Figure 4-97.

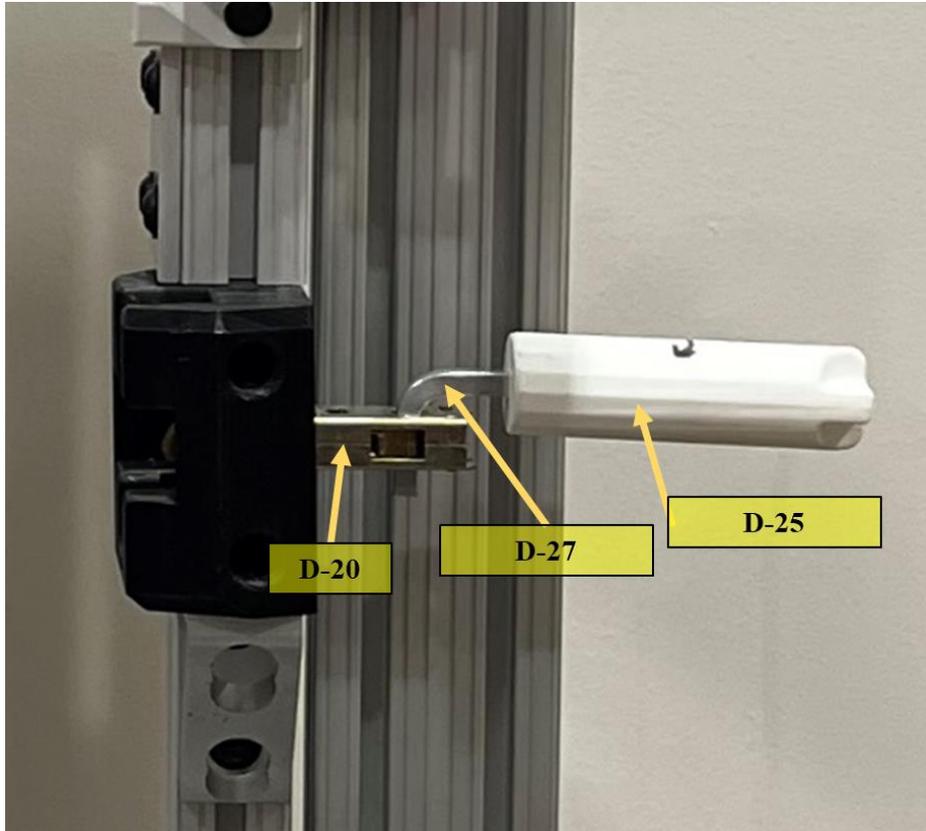


Figure 4-97. Hard Capture Lever Sitting in Position.

4.5.2.2 Assembly Instructions - Outer Frame

For the outer frame of the donning stand, the following list of items from the BOM are used in the assembly as shown in Table 4-31.

Table 4-31. Materials Needed for Outer Frame

BOM Item Number	Quantity	Use
D-1.2	1	Outer Upper Horizontal
D-2.2	2	Base Wheel Foot
D-3	2	Outer Vertical Strut
D-4.1	4	Base Leg
D-4.2	1	Outer Lower Horizontal
D-6	2	Bracket Support (3"x3")
D-7	2	Corner Support (1"x1")
D-8	4	Base Corner Support (2"x1")
D-9	2	Base Corner Support (2"x2")
D-10	2	Base Angled Support
D-11	4	Slide Carriage
D-12	2	Base Brace

D-13	2	Caster Wheels
D-14	3	Outer Frame Handle
D-15	2	Slide Carriage Brake
D-16	4	Double Width Cap
D-17	4	Single Width Cap

1. Attach (x2) the 2x1 supports (D-8) to the TOP of D-4.2 and (x2) of the 1"x1" supports (D-7) to the BOTTOM of D-4.2.
2. Identify the tapped side of D-3 struts, this will be the base of the frame.
3. Slide the D-4.2 between the (x2) D-3 pieces starting at the tapped end and tighten it 1' above the bottom as shown in Figure 4-98.

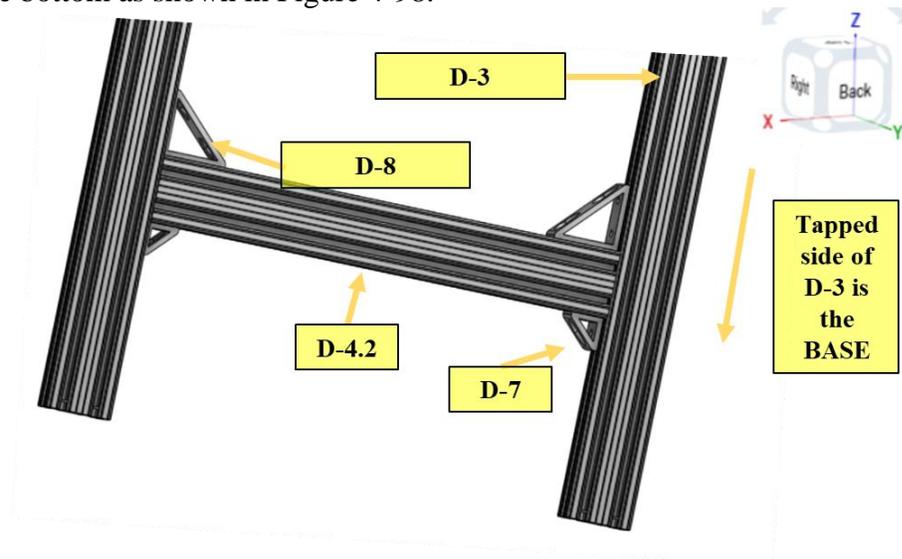


Figure 4-98. Attach Outer Bottom Frame to Outer Vertical Struts for Donning Stand.

4. At this point, lay the outer frame struts flat on the ground, with the BACK slot facing up.
5. Grab the inner frame and align the slide carriages to the two outer vertical struts (D-3)
6. Slide the inner frame onto the vertical struts till all 4 carriages are on the frame.
7. Use the two yellow slide carriage brakes (D-15) to keep the position of the inner frame fixed.
8. Insert the black frame handles (D-14) on the LATERAL slot of the vertical struts of the outer frame (D-3), one on each side. Secure them at halfway down the frame.

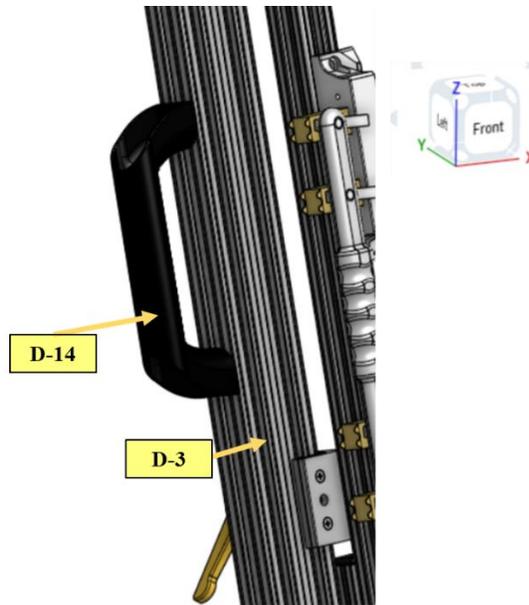


Figure 4-99. Attach D-14 Handles to Side of D-3 on Donning Stand.

9. Attach (x2) D-6 Brackets to the BACK slot of the outer upper horizontal strut (D-1.2)
10. Attach (x2) D-7 braces to the BOTTOM slot of the outer upper horizontal strut (D-1.2)
11. Attach the outer upper horizontal strut to the vertical struts(D-3) using the D-6 and D-7 supports as shown in Figure 4-100.

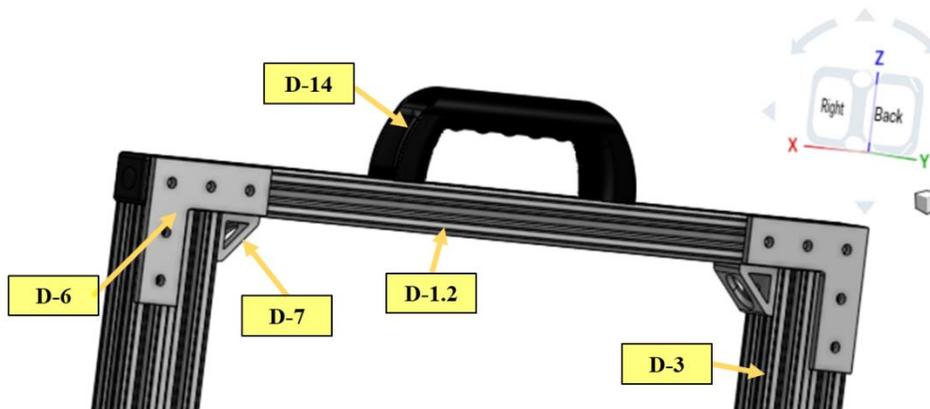


Figure 4-100. Attach Outer Upper Horizontal Strut to Outer Vertical Struts of Donning Stand.

12. Attach a frame handle (D-14) to the TOP of D-1.2.

Attention: At this point, it will be easiest if you can rest the BACK of the frame on a table and have the bottom hanging off the edge to mount the base to the stand

Assembling the front legs of the base

13. Attach the rounded top of the base brace (D-12) to the tapped holes at the bottom of the outer vertical struts (D-3).

14. Once the brace is attached to the D-3 pieces, ensure it is at the 90-degree locked position with the brake handles, and then attach the locking nuts to the front base legs (D-4.1) as shown in Figure 4-101.

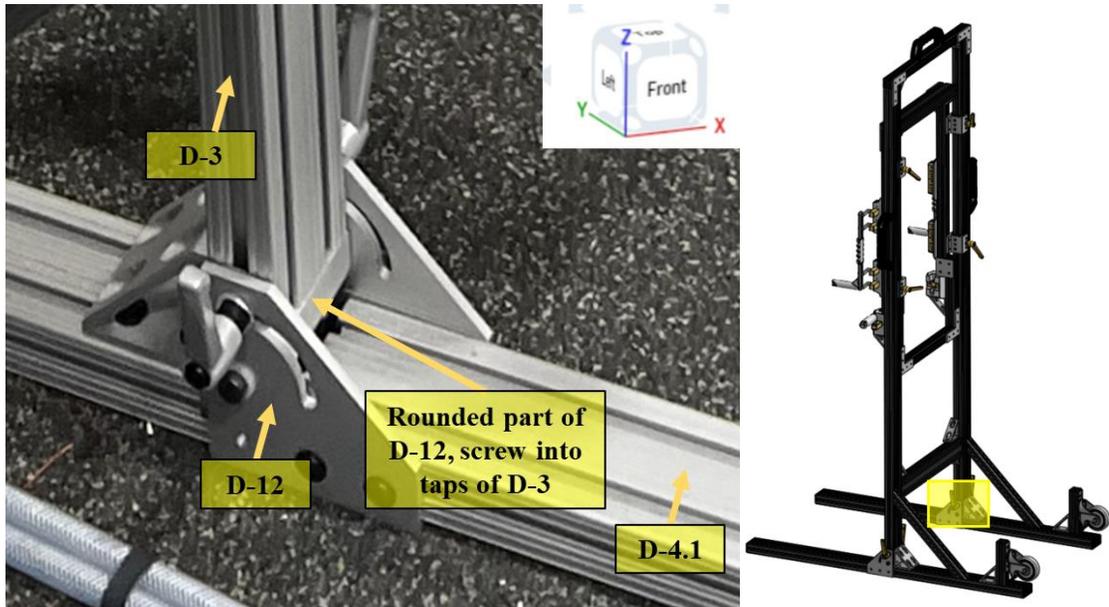


Figure 4-101. Attach Base Brace to Donning Stand Frame.

Assembling the back legs of the base

15. Grab (x2) of the D-4.1 base legs and slide the 45-degree (D-10, x2) angled support struts roughly halfway down the LATERAL-TOP slot of the base leg. **DO NOT FULLY TIGHTEN.**
16. Attach the wheelbase foot (D-2.2) and a 2x1 support bracket (D-8) and attach it to the LATERAL-TOP slot of the base leg, **BEHIND** the 45-degree support strut.
17. Attach the Caster Wheel (D-13) to the **BACK** slot of the wheelbase foot.
18. Attach a 2"x2" support brace (D-9) to the **FRONT EDGE** of the base leg on the **TOP** slot.
19. Slide the x2 base legs to the **BACK** slot of the outer vertical struts (D-3) to where the base leg sits flush with the front base legs.

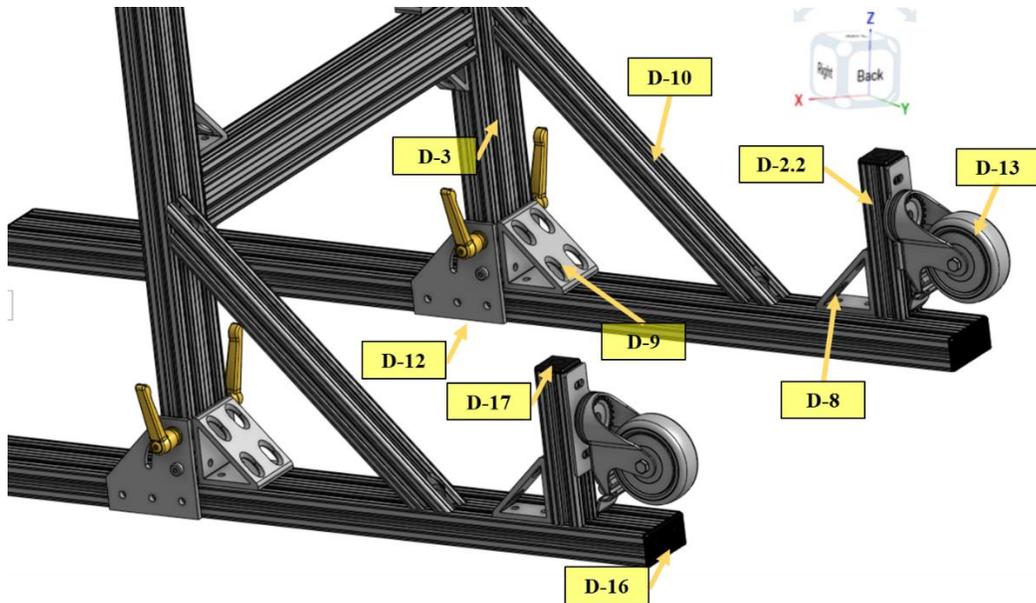


Figure 4-102. Attach Angled Support, Wheelbase, and Corner Support to Donning Stand Base Leg.

20. At this point, when it is sitting flush, tighten down the 45-degree support strut.
21. Attach end caps (D-16 and D-17) to base legs and wheel feet.

4.5.2.3 Manufacturing Instructions - Final Assembly

At this point, the user can stand the donning stand up. From here, the user should verify that the base legs are flat and stable. If the legs are wobbly, the user can adjust the positioning of the angled support brace and the base brace if needed to ensure it is stable. Finally, the user should verify all exposed corners have endcaps (D-16, D-17), and all the screws are tightened. The final product should look like Figure 4-



Figure 4-103. Final Assembly of the Donning Stand: CAD (Left) and Hardware Implemented View (Right).

4.6 Bill of Materials

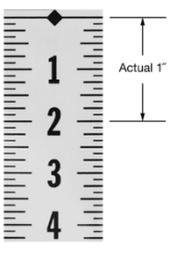
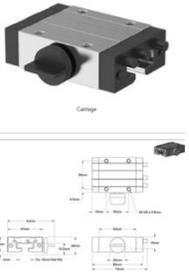
4.6.1 HS3

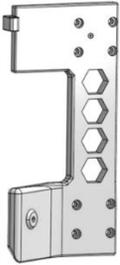
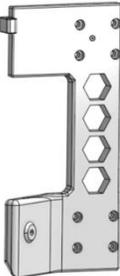
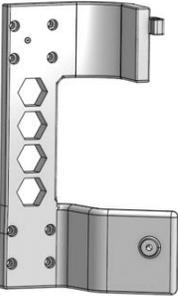
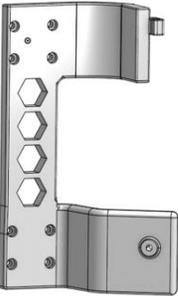
Based on the raw material prices as of 2025 August, the total cost for a single HS3 system (one soft suit with full size range of shoulder backpack harnesses, waist belts, and HUTs; a limited size ranges of peripheral system are included) is \$8,962 (excluding the donning stand). The following sections covers different HS3 subsystem Bill of Materials (BOM). HS3 3D printed parts are called out in the BOM for applicable parts. Please see ‘Print Settings’ callouts in Appendix H: 3D Printing and Slicer Settings for detailed settings. The BOM IDs are referenced in the construction section. It is assumed that user will have adequate shop tools for constructions and the tools are not included in the BOM herein.

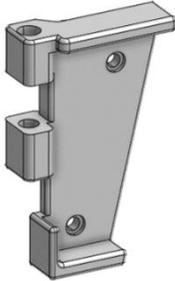
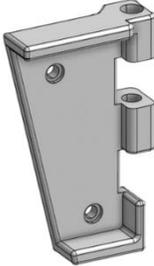
4.6.1.1.1 HUT System BOM

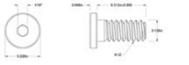
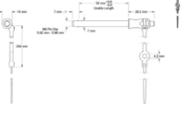
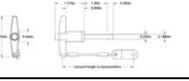
Table 4-32. HUT System BOM. Total Price per unit HS3 is estimated to be \$944.29.

BOM ID	Image	Part / Category	Item Description/ Specifications / Dimensions	Manufacturer/ Vendor	P/N	Unit Qty.	UoM	Unit Cost	Total Indv. Qty. Rqrd. Per Suit	Line Sub Total	Usage	Material/ Alloy	CAD File Name	Total Estimated Wt (kg)	Unit Print Time (days)	3DPT Settings Used*
H-1		Carriage Rails	15 mm Wide Guide Rail for 47 mm Wide Sleeve Bearing Carriage (Rails are cut to 16-18" in actual build but the default purchased item can be installed just the same to give more room for HUT height adjustment.)	McMaster-Carr	9867K12	2	Indv. (Each 500m Lg.)	\$ 45.00	2	\$ 90.00	Used w/ carriage carts to mount to and adjust HUT height; mounted to backplate via screws	Anodized AL	HS3V2.5 PLSS and HUT - 9867K12	1.09	N/A	N/A

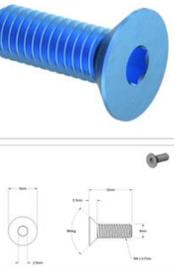
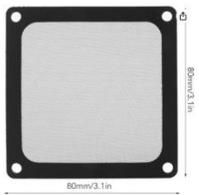
H-2		Fasteners/ Screws	Black-Oxide Alloy Steel Socket Head Screw 6-32 Thread Size, 9/16" Long	McMaster- Carr	91864 A086	1	Pack/ 25	\$ 14.7 5	12	\$ 14.75	Fasteners for mounting carriage rails to backplate	Black Oxide Alloy Steel	HS3V2.5 PLSS and HUT - 91864A086	0.017	N/A	N/A
H-3		Ruler	Half-Measure Adhesive- Back Ruler Vertical, Top- to-Bottom Reading Direction, 1- 1/2 Feet Length	McMaster- Carr	19425 A49	1	Indv.	\$ 3.44	2	\$ 3.44	Used for gauging incremental adjustments of HUT on carriage rails for making sure HUT is evenly adjusted and fit across PLSS backplate.	Adhesive, Plastic	N/A	N/A	N/A	N/A
H-4		Carriage Carts/ Sleeve Bearing	Locking Sleeve Bearing Carriage for 15 mm Wide Rail, ~18 ft.-lbs Capacity	McMaster- Carr	3249K 2	4	Indv.	\$ 66.8 3	4	\$ 267.3 2	Carriage carts mounted to HUT and rail struts for fine-tune size adjustment via carriage rail system	PTFE Plastic, Aluminu m	HS3V2.5 PLSS and HUT - 3249K2	0.8	N/A	N/A
H-5		Fasteners/ Screws	Alloy Steel Socket Head Screw Black-Oxide, M5 x 0.8 mm Thread, 22 mm Long	McMaster- Carr	91290 A248	1	Pack/ 50	\$ 12.0 8	16	\$ 12.08	Fasteners for mounting carriage rail strut to carriage rails carts	Black Oxide Alloy Steel	HS3V2.5 PLSS and HUT - 91290A248	0.072	N/A	N/A

H-6		3D Print	Carriage Rail Strut - Left, S/M (Need one set of left and right rail struts of either size.)	N/A	N/A	1	Indv.	N/A	1	N/A	Used for mounting HUT to carriage rail carts	IC3D ABS - Black	HS3V2.5 PLSS and HUT - HUT - Carriage Rail Struts (Left)	0.13	0.25	A
H-7		3D Print	Carriage Rail Strut - Right, S/M (Need one set of left and right rail struts of either size.)	N/A	N/A	1	Indv.	N/A	1	N/A	Used for mounting HUT to carriage rail carts	IC3D ABS - Black	HS3V2.5 PLSS and HUT - HUT - Carriage Rail Struts (Right)	0.13	0.25	A
H-8		3D Print	Carriage Rail Strut - Left, L/XL (Need one set of left and right rail struts of either size. L/XL Rail Struts adds 2-3" of extra chest depth for larger subjects.)	N/A	N/A	1	Indv.	N/A	1	N/A	Used for mounting HUT to carriage rail carts	IC3D ABS - Black	HS3V2.5 PLSS and HUT - HUT - Carriage Rail Struts (Left) (XL)	0.17	0.25	A
H-9		3D Print	Carriage Rail Strut - Right, L/XL (Need one set of left and right rail struts of either size. L/XL Rail Struts adds 2-3" of extra chest depth for	N/A	N/A	1	Indv.	N/A	1	N/A	Used for mounting HUT to carriage rail carts	IC3D ABS - Black	HS3V2.5 PLSS and HUT - HUT - Carriage Rail Struts (Right) (XL)	0.17	0.25	A

			larger subjects.)													
H-10		3D Print	HUT Pip Pin Adapter (left)	N/A	N/A	1	Indv.	N/A	1	N/A	Used as adapter for mounting HUT to carriage rail struts via spring-loaded pip pins	IC3D ABS - Black	HS3V2.5 PLSS and HUT - HUT - Pip Pin Adapter (Left)	0.016	N/A	A
H-11		3D Print	HUT Pip Pin Adapter (right)	N/A	N/A	1	Indv.	N/A	1	N/A	Used as adapter for mounting HUT to carriage rail struts via spring-loaded pip pins	IC3D ABS - Black	HS3V2.5 PLSS and HUT - HUT - Pip Pin Adapter (Right)	0.016	N/A	A
H-12		Tapered Heat Insert	Brass Tapered Heat-Set Inserts for Plastic 6-32 Thread Size, 0.25" Installed Length (Listed in PLSS Section)	McMaster-Carr	93365 A132	1	Pack/100	\$ 22.81	4	\$ 22.81	Used with fasteners for mounting aluminum carriage rails to PLSS backplate + mini T-slotted framing to PLSS walls	Brass	HS3V2.5 PLSS and HUT - 93365A132	0.003	N/A	N/A

H-13	 	Fasteners/ Screws	Ultra-Low-Profile Socket Head Screw Alloy Steel, 6-32 Thread Size, 5/16" Long	McMaster-Carr	90357A120	1	Indv.	\$ 4.84	4	\$ 4.84	Fasteners for mounting HUT pip pin adapters to back of HUT	Black-oxide Alloy Steel	HS3V2.5 PLSS and HUT - 90357A120	0.003	N/A	N/A
H-14	 	Spring-Loaded Pip Pin	Locking Quick-Release Pin for Tight Spaces 6 mm Diameter, 50 mm Usable Length	McMaster-Carr	93871A250	2	Indv.	\$ 37.62	2	\$ 75.24	Used for securing HUT to carriage rail struts	17-4 PH SS	HS3V2.5 PLSS and HUT - 93871A250	0.05	N/A	N/A
H-15	 	Spring-Loaded Pip Pin	T-Handle Locking Quick-Release Pin with Lanyard, 3/16" Diameter, 1" Usable Length	McMaster-Carr	93750A205	2	Indv.	\$ 28.27	2	\$ 56.54	Used for securing HUT to carriage rail struts	400 Series SS, 18-8 SS, 380 AL	HS3V2.5 PLSS and HUT - 93750A205	0.04	N/A	N/A
H-16		3D Print	Hard Upper Torso (HUT) - L/XL (One HUT for each size. Same chest depth and height but arm rings are closer to person on the small sized HUT.)	N/A	N/A	1	Indv.	N/A	1	N/A	Hard Upper Torso mockup	IC3D ABS - Black	HS3V2.5 PLSS and HUT - Large HUT	0.7	6	A,B

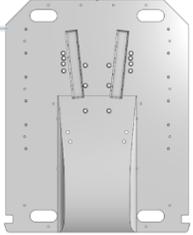
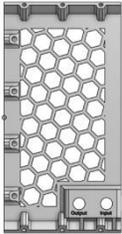
H-17		3D Print	Hard Upper Torso (HUT)-S/M (One HUT for each size. Same chest depth and height but arm rings are closer to person on the small sized HUT.)	N/A	N/A	1	Indv.	N/A	1	N/A	Hard Upper Torso mockup	IC3D ABS - Black	HS3V2.5 PLSS and HUT - Small HUT	0.7	6	A,B
H-18		3D Print	Hard Upper Torso - Visor	N/A	N/A	1	Indv.	N/A	1	N/A	HUT Visor for limited FOV immersion and ventilation fan mounting	IC3D ABS - Black	HS3V2.5 PLSS and HUT - HUT - Visor	0.3	0.6	A
H-19		Fasteners/Screws	Nylon Socket Head Screws 1/4"-20 Thread Size, 3/8" Long	McMaster-Carr	93334 A535	1	Pack/ 100	\$ 16.20	4	\$ 16.20	Fasteners for mounting Visor to HUT	Nylon Plastic	HS3V2.5 PLSS and HUT - 93334A535	N/A	N/A	N/A
H-20		Tapered Heat Insert	Brass Tapered Heat-Set Inserts for Plastic 1/4"-20 Thread Size, 0.3" Installed Length (Listed in PLSS Section)	McMaster-Carr	93365 A160	1	Pack/ 25	\$ 15.76	4	\$ 15.76	Used for mounting the visor to the HUT	Brass	HS3V2.5 PLSS and HUT - 93365A160	0.02	N/A	N/A

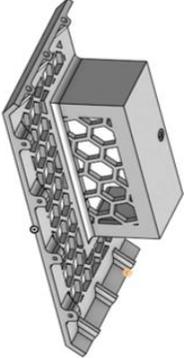
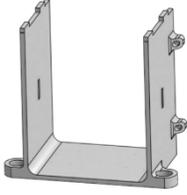
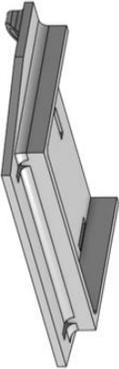
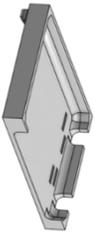
H-21		Tapered Heat Insert	Brass Tapered Heat-Set Inserts for Plastic M4 x 0.7 mm Thread Size, 4.7 mm Installed Length (Listed in PLSS Section)	McMaster-Carr	94180A351	1	Pack/100	\$ 21.82	4	\$ 21.82	Used for mounting visor fan and filter to 3D printed visor	Brass	HS3V2.5 PLSS and HUT - 94180A351	N/A	N/A	N/A
H-22		Fasteners/Screws	Alloy Steel Hex Drive Flat Head Screws Blue-Dyed Zinc-Plated, M4 x 0.7 mm Thread, 12 mm Long (Listed in PLSS Section)	McMaster-Carr	91304A113	1	Pack/50	\$ 9.62	4	\$ 9.62	Fasteners for visor fan and filter to 3D printed visor	Blue-Dyed Zinc-Plated Alloy Steel	HS3V2.5 PLSS and HUT - 91304A113	N/A	N/A	N/A
H-23		Fan Filter	5PCS PC Case Dust Mesh Filter, 80x80mm / 3.1x3.1in Nylon Dust Filter Cover, Magnetic Frame Computer Cooler Fan Dust Mesh Grill Black, Supports 80mm Ventilation Holes (Sandwiched between fan and 3D printed visor)	Amazon	B0CX2ZLTKS	1	Pack/5	\$ 9.11	1	\$ 9.11	Filter for visor fan	Plastic/Nylon mesh	HS3V2.5 PLSS and HUT - 80mm Fan Filter	N/A	N/A	N/A
H-24		Velcro	3M Dual Lock Reclosable Fastener SJ3560 (Clear, 1 in x 10 ft Roll) - Heavy Duty Adhesive	Amazon	B00AQ6ISIG	1	Indv.	\$ 24.86	1	\$ 24.86	Adhesive dual lock mounted on front right of HUT; used in conjunction with toggle	Adhesive, Plastic	N/A	N/A	N/A	N/A

			Interlocking Tape for Indoor/Outdoor Mounting								switch box to quickly attach-detach the LCG switch from the HUT when donning and doffing					
H-25		3D Print	Carriage Rail End Caps	N/A	N/A	4	Indv.	N/A	4	N/A	Used for capping the ends of the aluminum carriage rails (to mitigate sharp edges)	IC3D ABS - Black	HS3V2.5 PLSS and HUT - Carriage Rail End Caps	N/A	N/A	A
H-26		IC3D ABS (Black)	IC3D ABS 3D Printer Filament (10kg, 3mm, Black or White) (Caution: White ABS from vendor is more prone to warping.)	IC3D	IC3D ABS 3D Printer Filament	1	Indv.	\$ 200.00	1	\$ 200.00	3D printing filament for most HS3 parts Approximately 6kg of ABS needed for donning stand and entire HS3 3D printed parts (dependent on printer/slicer settings).	ABS	N/A	N/A	N/A	N/A
H-27		Ultimaker Tough PLA (White/Black)	UltiMaker S Series Tough PLA Material (750g)	Ultimaker // Dynamism	202300	2	Indv.	\$ 49.95	2	\$ 99.90	3D printing filament for some HS3 parts and most donning stand parts. Approximately 1kg of tPLA needed for donning stand parts.	Tough PLA	N/A	N/A	N/A	N/A

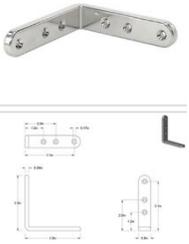
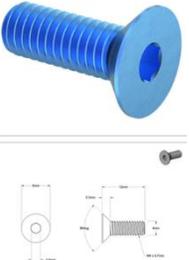
4.6.1.1.2 PLSS System BOM

Table 4-33. PLSS System BOM. Total Price per unit HS3 is estimated to be \$1837.07.

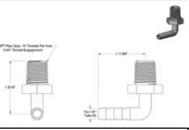
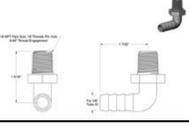
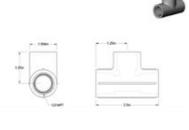
BOM ID	Image	Part / Category	Item Description/ Specifications / Dimensions	Manufacturer/ Vendor	P/N	Unit Qty.	Uo M	Unit Cost	Total Indv. Qty. Rqrd. Per Suit	Line Sub Total	Usage	Material/ Alloy	CAD File Name	Total Estimated Wt (kg)	Unit Print Time (days)	3DPT Settings Used*
P-1		3D Print	PLSS Backplate	N/A	N/A	1	Indv	N/A	1	N/A	Used as foundation for PLSS, HUT, and backpacking spine/hipbelt	IC3D ABS - Black	HS3V2.5 PLSS and HUT - PLSS - Backplate	0.969	1.5	A
P-2		3D Print	PLSS Left Wall	N/A	N/A	1	Indv	N/A	1	N/A	Structural outer walls of PLSS assembly	IC3D ABS - Black	HS3V2.5 PLSS and HUT - PLSS - Left Wall	0.256	0.5	A
P-3		3D Print	PLSS Right Wall	N/A	N/A	1	Indv	N/A	1	N/A	Structural outer walls of PLSS assembly	IC3D ABS - Black	HS3V2.5 PLSS and HUT - PLSS - Right Wall	0.256	0.5	A
P-4		3D Print	PLSS Bottom Wall	N/A	N/A	1	Indv	N/A	1	N/A	Structural outer walls of PLSS assembly	IC3D ABS - Black	HS3V2.5 PLSS and HUT - PLSS - Bottom Wall	0.208	0.375	A

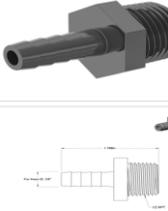
P-5		3D Print	PLSS Top Wall	N/A	N/A	1	Indv	N/A	1	N/A	Structural outer walls of PLSS assembly; COSMED mounting shelf	IC3D ABS - Black	HS3V2.5 PLSS and HUT - PLSS - Top Wall	0.289	0.7	A
P-6		3D Print	PLSS Bladder Compartment Shelf	N/A	N/A	1	Indv	N/A	1	N/A	Structural outer walls of PLSS assembly; bladder mounting shelf	IC3D ABS - Black	HS3V2.5 PLSS and HUT - PLSS - Bladder Compartment Shelf	0.33	0.6	A
P-7		3D Print	PLSS Battery Compartment Shelf (Anker 200W) (Only used if using selected battery: Anker 200W)	N/A	N/A	1	Indv	N/A	1	N/A	Structural outer walls of PLSS assembly; battery mounting shelf for Anker 200W power bank	IC3D ABS - Black	HS3V2.5 PLSS and HUT - PLSS - Battery Compartment Shelf (Anker 200W)	0.145	0.25	A
P-8		3D Print	PLSS Battery Compartment Shelf (Egrotech 300W) (Only used if using selected battery: Egrotech 300W)	N/A	N/A	1	Indv	N/A	1	N/A	Structural outer walls of PLSS assembly; battery mounting shelf for Egrotech 300W power bank	IC3D ABS - Black	HS3V2.5 PLSS and HUT - PLSS - Battery Compartment Shelf (Egrotech 300W)	0.198	0.25	A

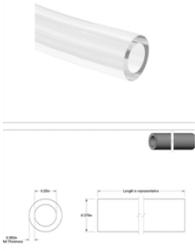
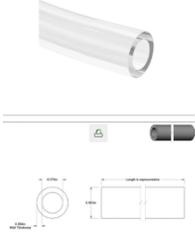
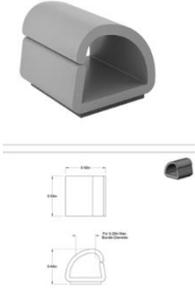
P-9		Neoprene Foam	Dualplex Neoprene Sponge Foam Rubber Roll Adhesive, 12x54 Inches X 1/4" Thick, Perfect Cosplay Padding, DIY Project Sheet - Easy Cut Adhesive Multi-Function Sealing Soundproof Rubber Foam Sheet	Amazon	B07WVRQ59Q	1	Indv	\$ 19.95	1	\$ 19.95	Used to insulate the bladder compartment for thermal cooling	Foam, neoprene	HS3V2.5 PLSS and HUT - Neoprene Foam	0.048	N/A	N/A
P-10		LCG - 3.5L Water Bladders	COMPCOOLER Single Chamber Quick Release Detachable Cuboid Bladder (3.5L) 0.4mm TPU Film (x1 bladder needed for operations but multiple bladders recommended for hot swap.)	Compcooler	COMP-SQB-35C	1	Indv	\$ 46.00	1	\$ 46.00	Used to store cooling/chilled water to Liquid Cooling Garment for HS3	TPU Plastic film, 0.4mm	HS3V2.5 PLSS and HUT - 3.5L LCG Bladder	3.25	N/A	N/A
P-11		Tapered Heat Insert	Brass Tapered Heat-Set Inserts for Plastic M4 x 0.7 mm Thread Size, 4.7 mm Installed Length	McMaster-Carr	94180A351	1	Pack /100	\$ 21.82	38	\$ 21.82	Used for mounting PLSS walls, shelves, and brackets to backplate via screws and pump to shelf.	Brass	HS3V2.5 PLSS and HUT - 94180A351	0.025	N/A	N/A

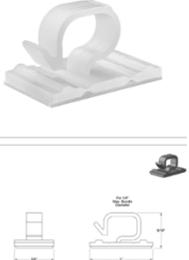
P-12		Bladder Shelf Bracket	Corner Bracket 304 Stainless Steel, 3-9/16" x 3-9/16" x 13/16" (Use blue-dyed M4 screws (P-14) to fasten to PLSS and bladder shelf, not the screws that come natively with the corner brackets.)	McMaster-Carr	15655A72	2	Indv	\$ 42.00	2	\$ 84.00	Used to support PLSS shelving	304 SS	HS3V2.5 PLSS and HUT - 15655A72	0.3	N/A	N/A
P-13		36W Diaphragm Water Pump	G Ganen 12V DC Fresh Water Pump with 2 Hose Clamps 12 Volt Diaphragm Pump Self Priming Sprayer Pump with Pressure Switch 4.5 L/Min 1.2 GPM 110 PSI Adjustable for RV Camper Marine Boat Lawn	Amazon	B07E35PTFR	1	Indv	\$ 18.99	1	\$ 18.99	Used to pump chilled water through liquid cooling garment	Plastic, Metal	HS3V2.5 PLSS and HUT - 36W Flow Pump	0.77	N/A	N/A
P-14		Fasteners/ Screws	Alloy Steel Hex Drive Flat Head Screws Blue-Dyed Zinc-Plated, M4 x 0.7 mm Thread, 12 mm Long	McMaster-Carr	91304A113	1	Pack /50	\$ 9.62	38	\$ 9.62	Fasteners for PLSS walls, shelves, water pump, bladder shelf brackets, visor fan, etc.	Blue-Dyed Zinc-Plated Alloy Steel	HS3V2.5 PLSS and HUT - 91304A113	0.048	N/A	N/A

P-15		Tapered Heat Insert	Brass Tapered Heat-Set Inserts for Plastic M5 x 0.8 mm Thread Size, 11.1 mm Installed Length	McMaster-Carr	94180A363	1	Pack /25	\$ 12.71	12	\$ 12.71	Used for connecting PLSS Wall corner sections together via screws	Brass	HS3V2.5 PLSS and HUT - 94180A363	0.027	N/A	N/A
P-16		Screws	Alloy Steel Socket Head Screw Black-Oxide, M5 x 0.8 mm Thread, 22 mm Long	McMaster-Carr	91290A248	1	Pack /50	\$ 12.08	12	\$ 12.08	Fasteners for connecting PLSS Wall sections together	Black-oxide Alloy Steel	HS3V2.5 PLSS and HUT - 91290A248	0.054	N/A	N/A
P-17		Panel-Mounted Fluid QD	Plastic Quick-Disconnect Tube Coupling for Air and Water Thru-Wall Plug, Shut-Off, 1/4 Size, for 1/4" Barbed Tube (Not compatible with fluid QDs from COMPCOOLER; must use MCMaster-CARR QDs. (1/4", 7/16", 1/4" config).)	McMaster-Carr	5012K94	2	Indv .	\$ 17.27	2	\$ 34.54	Used as connection between external water supply and internal PLSS water pump + diverting valves; mounts to 13/16" holes in PLSS bottom wall.	PU, Acetal Plastic	HS3V2.5 PLSS and HUT - 5012K94_Nut HS3V2.5 PLSS and HUT - 5012K94_QD	0.023	N/A	N/A

P-18	 <small>Female x Female x Female</small> 	Plastic 3-Way Diverting Valve	Compact Diverting Valve, 1/4 NPT Female x Female	McMaster-Carr	4757K52	2	Indv.	\$ 21.62	2	\$ 43.24	Used to swap liquid cooling system from internal/personal chilled water to external supplied water via panel-mounted fluid QDs	PVC Plastic	HS3V2.5 PLSS and HUT - 4757K52	0.058	N/A	N/A
P-19	 	Hose Fitting	Plastic Barbed Hose Fitting for Water, Elbow, 1/4" Hose ID, 1/4 NPT Male, 150 PSI	McMaster-Carr	5218K782	5	Indv.	\$ 1.60	5	\$ 8.00	Threads to diverting valve and connects to 1/4" tubing for water bladder and LCG garment	Polypropylene Plastic	HS3V2.5 PLSS and HUT - 5218K782	0.024	N/A	N/A
P-20	 	Hose Fitting	Plastic Barbed Hose Fitting for Water, Elbow, 3/8" Hose ID, 1/4 NPT Male, 150 PSI	McMaster-Carr	5218K789	1	Indv.	\$ 1.65	1	\$ 1.65	Threads to diverting valve and connects to 1/4" tubing for water bladder and water pump	Polypropylene Plastic	HS3V2.5 PLSS and HUT - 5218K789	0.006	N/A	N/A
P-21	 	Pipe Fitting	Standard-Wall PVC Pipe Fitting for Water Tee Connector, 1/2 NPT Female	McMaster-Carr	4880K154	2	Indv.	\$ 2.11	2	\$ 4.22	Used to connect and bridge 1/2 NPT to 1/4" ID hose fittings to LCG garment and pump + mounting thread for thermowell integration into LCG system	PVC Plastic	HS3V2.5 PLSS and HUT - 4880K154	0.08	N/A	N/A

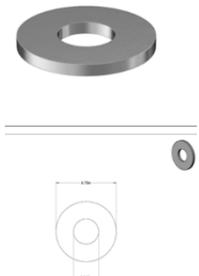
P-22		Thermowell	2pcs 1/2 Inch NPT Thermowell Weldless Stainless Steel Temperature Sensor Thermowell with Plastic Cap for Homebrew Brewing Beer Fermenter 50mm/2" Length	Amazon	B08QV4F8FF	1	Pack /2	\$ 9.99	2	\$ 9.99	Thermowells used for integrating DS18B20 sensors into liquid cooling pump system via mounting threads on 'P-22'.	Plastic, Stainless Steel	HS3V2.5 PLSS and HUT - 50mm Thermowell 1	0.3	N/A	N/A
P-23		Hose Fitting	Plastic Barbed Hose Fitting for Water, Adapter, 1/4" Hose ID, 1/2 NPT Male, 150 PSI	McMaster-Carr	5218K688	3	Indv .	\$ 0.99	3	\$ 2.97	Threads to PVC pipe tee connector for connecting hoses in liquid cooling pump system	Polypropylene Plastic	HS3V2.5 PLSS and HUT - 5218K688	0.023	N/A	N/A
P-24		Hose Fitting	Plastic Barbed Hose Fitting for Water, Adapter, 3/8" Hose ID, 1/2 NPT Male, 150 PSI	McMaster-Carr	5218K698	1	Indv .	\$ 1.06	1	\$ 1.06	Threads to PVC pipe tee connector for connecting hoses in liquid cooling pump system	Polypropylene Plastic	HS3V2.5 PLSS and HUT - 5218K698	0.008	N/A	N/A
P-25		Male Fluid QD	CPC male fitting 1/4" (two pcs)	COMPCOOLER	CPC male fitting 1/4" (two pcs)	1	Pack /2	\$ 12.00	2	\$ 12.00	Connects water tubing to water bladders and LCG garments	PU, Acetal Plastic	HS3V2.5 PLSS and HUT - COMPCOOLER Fluid QDs (Male)	0.013	N/A	N/A

P-26		1/4" Tubing	Soft Masterklear PVC Tubing for Air&Water 1/4" ID, 3/8" OD	McMaster-Carr	5233K56	1	25ft. Lg.	\$ 10.50	1	\$ 10.50	Used as tubing for liquid cooling system and pump connections.	PVC	N/A	N/A	N/A	N/A
P-27		3/8" Tubing	Soft Masterklear PVC Tubing for Air&Water 3/8" ID, 9/16" OD	McMaster-Carr	5233K64	1	25ft. Lg.	\$ 22.25	1	\$ 22.25	Used as tubing for liquid cooling system and pump connections.	PVC	N/A	N/A	N/A	N/A
P-28		Black Shielded Extension Tubing	COMPCOOLER Extension Tubing with sleeve protection Screw-in Connector (3ft and 6ft) (Cut off screw connections and directly connect the barded hose fittings instead.)	COMPCOOLER	COMP COOLER Extension Tubing with sleeve protection on Screw-in Connector (3ft and 6ft)	1	1 Meter	\$ 31.00	1	\$ 31.00	Female QDs connect to LCG garment while the other end connects to the hose fittings on the PVC tee connector for inlet-outlet return-flow.	PVC, ePFTE shielding	HS3V2.5 PLSS and HUT - LCG Hose Extension	N/A	N/A	N/A
P-29		Cable Holders	Cable Holders Adhesive-Back, Vinyl, 1/2" Long x 1/2" Wide x 7/16" High	McMaster-Carr	7565K31	1	Pack /25	\$ 7.50	7	\$ 7.50	Used for cable mgmt + tube mgmt.	Vinyl Plastic	N/A	0.005	N/A	N/A

P-30		Cable Holders	Cable Holders Adhesive-Back, Nylon, 1" Long x 5/8" Wide x 9/16" High	McMaster-Carr	7565K81	1	Pack /25	\$ 13.26	5	\$ 13.26	Used for cable mgmt + tube mgmt.; optionally used as hook point for PLSS cover/backpack rain cover.	Nylon plastic	N/A	N/A	N/A	N/A
P-31		Teflon Tape	Teflon Tape,PTFE Plumbers Tape,for Sealing,Plumbing,Sealant,Thread Seal for Shower Head,Water Pipe,Prevent Leakage,(1 Roll,1/2 Inch X 520 Inches).	Amazon	BODY5ZMRGF	1	Indv . Or Multi-pack	\$3.99	1	\$ 3.99	Used for securing/sealing threads on plumbing, hose fittings, etc., for the liquid cooling system.	PTFE (teflon)	N/A	N/A	N/A	N/A
P-32		Mini T-Slotted Framing	Miniature T-Slotted Framing Single Rail, 10 mm High x 10 mm Wide (Cut the t-slotted framing to 14.2".)	McMaster-Carr	5969N15	2	Indv . (Each 18" Lg.)	\$ 11.75	2	\$ 23.50	Used for structural rigidity of PLSS Walls.	6063 Aluminum	HS3V2.5 PLSS and HUT - 5969N15	0.071	N/A	N/A
P-33		Mini T-Slotted Framing	Miniature T-Slotted Framing Single Rail, 10 mm High x 10 mm Wide (Cut the t-slotted framing to 21 1/8" and then a cut a 45deg angle off each end of the rail. Refer to CAD for drilling 1/4" holes	McMaster-Carr	5969N16	2	Indv . (Each 24" Lg.)	\$ 15.43	2	\$ 30.86	Used for structural rigidity of PLSS Walls.	6063 Aluminum	HS3V2.5 PLSS and HUT - 5969N16	0.105	N/A	N/A

			across T-slotted framing as to allow for fasteners to thread through.)													
P-34		Tapered Heat Insert	Brass Tapered Heat-Set Inserts for Plastic 6-32 Thread Size, 0.25" Installed Length	McMaster-Carr	93365A132	1	Pack /100	\$ 22.81	22	\$ 22.81	Used with fasteners for mounting aluminum carriage rails to PLSS backplate + mini T-slotted framing to PLSS walls	Brass	HS3V2.5 PLSS and HUT - 93365A132	N/A	N/A	N/A
P-35		Fasteners/ Screws	Socket Head Screws with Flat Washer Black-Oxide Alloy Steel, 6-32 Thread Size, 1/2" Long	McMaster-Carr	90344A135	1	Indv .	\$ 5.26	10	\$ 5.26	Fasteners for mounting mini T-slotted framing to PLSS walls	Black-Oxide Alloy Steel	HS3V2.5 PLSS and HUT - 90344A135	0.02	N/A	N/A
P-36		Fasteners/ Screws	M3 Self-Aligning Nut, for Single Rail Miniature T-Slotted Framing	McMaster-Carr	5969N21	1	Pack /20	\$ 18.00	16	\$ 18.00	Fasteners for mini T-slotted framing joints	17-4 PH SS	HS3V2.5 PLSS and HUT - 5969N21	0.006	N/A	N/A
P-37		Corner Bracket	Corner Bracket for Single Rail Miniature T-Slotted Framing	McMaster-Carr	5969N42	8	Indv .	\$ 4.76	8	\$ 38.08	Corner brackets for mini T-slotted framing joints	Zinc	HS3V2.5 PLSS and HUT - 5969N42	0.008	N/A	N/A

P-38		Fasteners/ Screws	5mm Long, Button Head Screw for Single Rail Miniature T- Slotted Framing	McMaster- Carr	5969N 23	1	Pack /40	\$ 9.09	16	\$ 9.09	Screws for mini T- slotted framing joints	Zinc- Plated Steel	HS3V2.5 PLSS and HUT - 5969N23	0.008	N/A	N/A
P-39		Fasteners/ Screws	Plastic-Head Thumb Screws Large-Grip, 1/4"-20 Thread Size, 1/2" Long	McMaster- Carr	91185 A803	1	Pack /100	\$ 12.1 3	1	\$ 12.13	Fastener for mounting COSMED K5 metabolic cart onto the PLSS top wall; heat insert for COSMED is installed in the device itself and secured to the top wall by friction fit.	Acetal Plastic, 18-8 SS	HS3V2.5 PLSS and HUT - 91185A803	N/A	N/A	N/A
P-40		Tapered Heat Insert	Brass Tapered Heat-Set Inserts for Plastic 1/4"-20 Thread Size, 0.3" Installed Length	McMaster- Carr	93365 A160	1	Pack /25	\$ 15.7 6	6	\$ 15.76	Used for fastening the spine/ backpacking frame to the PLSS backplate via screws	Brass	HS3V2.5 PLSS and HUT - 93365A160	0.02	N/A	N/A
P-41		Fasteners/ Screws	Alloy Steel Low-Profile Socket Head Screw Hex Drive, Black Oxide, 1/4"-20 Thread Size, 3/4" Long	McMaster- Carr	92220 A185	1	Pack /50	\$ 12.9 1	6	\$ 12.91	Fasteners for mounting the spine/ backpacking frame to the PLSS backplate	Black- oxide Alloy Steel	HS3V2.5 PLSS and HUT - 92220A185	0.03	N/A	N/A

P-42		Washers	17-7 PH Stainless Steel Washer for 1/4" Screw Size, General Purpose, 0.312" ID, 0.750" OD	McMaster-Carr	91860A029	1	Pack /10	\$ 13.34	6	\$ 13.34	Washers to be used with fasteners for mounting the spine/backpacking frame to the PLSS backplate	17-4 PH SS	HS3V2.5 PLSS and HUT - 91860A029	0.03	N/A	N/A
P-43		Backpacking Spine/Frame	KUIU Carbon Fiber Frame (recommend ordering a set of Reg, Tall, X-Tall sizes) (Refer to Detailed Test Procedures or manufacturer for sizing chart.)	KUIU	KUIU Carbon Fiber Frame	3	Indv	\$ 199.00	3	\$ 597.00	Used for waist/hip offloading system of PLSS and HUT	Carbon fiber and resin - Spread Tow/stacked layering, 500 Denier CORDURA® Strap webbing, Velcro	HS3V2.5 PLSS and HUT - Backpacking Frame	0.35	N/A	N/A
P-44		Padded Backpacking Harness	PRO Suspension (recommend ordering a set of S/M, L/XL, Women's O/Ss) (Refer to Detailed Test Procedures or manufacturer for sizing chart.)	KUIU	PRO Suspension	3	Indv	\$ 199.00	3	\$ 597.00	Used for waist/hip offloading system of PLSS and HUT	500D CORDURA® Ripstop Fabric and Webbing, Duraflex, YKK zippers, Spacer air mesh	N/A	0.6	N/A	N/A
P-45		Hose Clamps	25 Pack Stainless Steel Hose Clamps, 1/4 inch to 1/2 inch Worm Gear Metal Hose Clamps for Pipe, Dryer Repair, Tubing and Fuel Line	Amazon	B09B M1MN FX	1	Pack /25	\$ 9.99	16	\$ 9.99	Used for clamping down tubing in liquid cooling system to barbed hose fittings for pump and tee connectors.	301 SS, Zinc-Plated Steel screw	HS3V2.5 PLSS and HUT - Hose Clamp, 0.25" HS3V2.5 PLSS and HUT - Hose Clamp, 0.375"	N/A	N/A	N/A

P-47		Buckles and Straps	Buckles and Straps Set 1": 6 Yards of Thick Nylon Webbing, 6-Pack Heavy Duty Adjustable Quick Side Release Plastic Buckles, 12 Tri-Glide Slide Clips, Black (1-Inch Combo Set)	Amazon	B08LD8CJ8D	1	Pack /6	\$ 22.99	2-3 buckles, ~3ft of webbing	\$ 22.99	Buckles, slides, and webbing used to make belt straps to secure battery bank and water bladder to PLSS shelving and prevent shifting/falling out.	Plastic, Polyester	HS3V2.5 PLSS and HUT - Webbing for Battery HS3V2.5 PLSS and HUT - Webbing for LCG	N/A	N/A	N/A
P-48		Backpack Cover	Toy Walker Waterproof Backpack Rain Cover, 12000mm Ultra-Waterproof, Upgraded Ultra-Strong Multilayers, Antislip Buckle Strap	Amazon	JW-1979234234	1	Indv .	\$9.99	1	\$9.99	Used to cover PLSS internals and shield them from sand, debris, dust, water, etc.	Nylon	N/A	N/A	N/A	N/A

4.6.1.1.3 Electrical System BOM

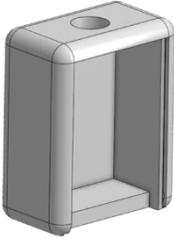
Table 4-34. Electrical System BOM. Total Price per unit HS3 is estimated to be \$356.89.

BOM ID	Image	Part / Category	Item Description/ Specifications / Dimensions	Manufacturer/ Vendor	P/N	Unit Qty.	UoM	Unit Cost	Total Indv. Qty. Rqrd. Per Suit	Line Sub Total	Usage	Material/ Alloy	CAD File Name	Total Estimated Wt (kg)	Unit Print Time (days)	3DPT Settings Used*
E-1		300W Power Bank	EGRETECH Plume 300 Portable Power Station 300W/260Wh (Optional: Preferred option for HS3. currently unavailable from vendor; currently not used but easily swappable with E-2)	Egretch	EGRETECH Plume 300 Portable Power Station	1	Indv.	\$ 169.00	1	\$ 169.00	Alternate Battery for powering sensors and water pump	Li-Ion Battery, Plastic Housing	HS3V2.5 PLSS and HUT - Egretch 300W Power Bank HS3V2.5 PLSS and HUT - Egretch 300W Power Bank Handle	4.85	N/A	N/A
E-2		200W Power Bank	Anker SOLIX C200 DC Power Bank Station, 192Wh Portable Power Station, LiFePO4 Battery, 200W Solar Generator (Default power bank option for HS3. Anker battery requires use of DC motor controller for water pump; Egretch battery does not need the DC motor controller - only the DC to	Amazon	Anker SOLIX C200 DC Power Bank Station	1	Indv.	\$ 119.99	1	\$ 119.99	Battery for powering sensors and water pump	Li-Ion Battery, Plastic Housing	HS3V2.5 PLSS and HUT - 200W Anker Power Bank	4.21	N/A	N/A

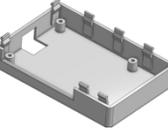
			bare-wire connection.)													
E-3		DC motor controller	<p>AITRIP 2PCS 6V-30V 8A DC Motor Speed Controller 6V 12V 24V PWM Stepless Speed Control Switch Adjustable Driver Regulator with Duty Cycle LED Digital Display & Knob</p> <p>(Only use with Anker power bank, not Egrettech battery)</p>	Amazon	B098WKHD75	1	Pack/2	\$ 13.99	1	\$ 13.99	Used for controlling motor speed and regulating current/voltage of water pump draw; connect to USB-to-bare-wire and bare-wire-to-water pump	Plastic, Metal	HS3V2.5 PLSS and HUT - DC Motor Controller HS3V2.5 PLSS and HUT - Potentiometer	0.11	N/A	N/A
E-4		Male DC Plug to Bare Wire Pigtails Cable	<p>GINTOOYUN 2 Pack 90 Degree DC Power Pigtails Cable, Right Angle DC 5.5mm x 2.1mm Male Plug to Bare Wire Open End Power Supply Replacement Repair Cord, for Monitors, LED Strip Light, Camera, 3FT 1m</p> <p>(Only compatible with Egrettech battery, not Anker battery)</p>	Amazon	B0B6HT23WK	1	Pack/2	\$ 9.99	1	\$ 9.99	Used to connect water pump to Egrettech power bank; wire from 36W port to water pump	PC+ABS/PVC	N/A	N/A	N/A	N/A
E-5		16 AWG Wire	NAOEVO 16 Gauge Wire 2 Conductor Electrical Wire, 16	Amazon	B0CGHF2BSD	1	Indv.	\$ 12.99	1	\$ 12.99	Wiring for toggle switch, DC motor controller,	PC+ABS/PVC, tin-coated copper	N/A	N/A	N/A	N/A

			AWG Stranded PVC Cord, 12V Low Voltage/Tinned Copper/Flexible Cable for Automotive Wiring, Lamp Cord, Marine Cable (15FT)								and water pump					
E-6		Female DC to Pigtails	DC Power Pigtails Cable, 3FT DC 5.5MM x 2.1MM Female Plug to Bare Wire Open End Power Wire Supply Repair Cable, 16 AWG Barrel Connector Pigtail for CCTV Security Camera, DVR, LED Strip Light Etc-2 Pcs(F)	Amazon	B08PYT6HZ2	1	Pack/2	\$ 9.99	1	\$ 9.99	Wire from DC motor controller to USB-C Male DC cable	PC+ABS/PVC, copper	N/A	N/A	N/A	N/A
E-7		USB-C to Male DC	USB C to DC 5.5mm x 2.1mm Power Cable Cord, USB C Input to DC 12V Out Charging Cable, Work with PD Charger and PD Power Bank, Output DC 12V 3A	Amazon	B0CBNQN7CR	1	Indv.	\$ 7.99	1	\$ 7.99	Wire from Anker battery (100W USB-C) to female DC pigtails cable	PC+ABS/PVC, copper	N/A	N/A	N/A	N/A
E-8		microUSB to USB-C cable	CableCreation Short Micro USB to USB C Cable 0.65 FT, 2-Pack OTG 480Mbps Type C to MicroUSB	Amazon	B0BX X1L8G7	1	Indv.	\$ 13.49	1	\$ 13.49	Wire from Anker Battery (20W USB-C) to button switch for Raspberry Pi	PC+ABS/PVC, copper	N/A	N/A	N/A	N/A

			Cord Compatible with MacBook Pro Air Galaxy S22 Pixel 5 & More, 0.2M Black													
E-9		Button Switch for Raspberry Pi	<p>CanaKit Raspberry Pi 3 PiSwitch (Micro USB)</p> <p>(Only compatible with Raspberry Pi gen 3's; other switches available for gen 4 and higher)</p>	CanaKit	CanaKit Raspberry Pi 3 PiSwitch (Micro USB)	1	Indv.	\$ 7.95	1	\$ 7.95	Power switch for Raspberry Pi; in-line with microUSB to USB-C cable and connected to Rpi	Plastic, PC+ABS/PVC	HS3V2.5 PLSS and HUT - Raspberry Pi 3Bplus CanaKit Switch USB-C	N/A	N/A	N/A
E-10		Toggle Switch	<p>DaierTek Waterproof Toggle Switch 12V DC 30A Heavy Duty 2 Pin ON Off SPST with Weatherproof Boot Cap Cover for Auto Car Marine Boat - 2 Pack</p>	Amazon	B07T6XWZKN	1	Pack/2	\$ 7.99	1	\$ 7.99	Toggle switch for water pump; wired in-line with water pump and DC motor controller	Metal, bakelite, brass	HS3V2.5 PLSS and HUT - Toggle Switch	0.01	N/A	N/A
E-11		Toggle Switch Guard	<p>Twidec/3Pcs Rocker Toggle Switch 12V 20A Heavy Duty Racing Car Automotive Auto SPST ON/Off Toggle Switch Blue LED Light Illuminated 3Pin with Blue Waterproof Safety Cover ASW-</p>	Amazon	B07VL7KSZP	1	Pack/3	\$ 9.99	1	\$ 9.99	(Optional) Toggle switch guard for LCG; also comes with switches but not used for build.	Plastic, Metal	HS3V2.5 PLSS and HUT - Toggle Switch Guard	N/A	N/A	N/A

			07DBUBUM Z														
E-12		3D Print	Toggle Switch Box Lid	N/A	N/A	1	Indv.	N/A	1	N/A	Used for encasing the wiring of the toggle switch; also used with Dual Lock to attach box to front side of HUT for easy mounting of LCG switch for subject access	IC3D ABS - Black	HS3V2.5 PLSS and HUT - LCG Switch Box (Housing)	0.06	0.08	A	
E-13		3D Print	Toggle Switch Box	N/A	N/A	1	Indv.	N/A	1	N/A	Used for encasing the wiring of the toggle switch; also used with Dual Lock to attach box to front side of HUT for easy mounting of LCG switch for subject access	IC3D ABS - Black	HS3V2.5 PLSS and HUT - LCG Switch Box (Lid)	0.02	0.03	A	
E-14		Electrical Lug QDs	TICONN 100 Pcs Nylon Spade Quick Disconnect Connectors Kit, Electrical Insulated Terminals, Male and Female Spade Wire Crimp Terminal Assortment Kit (Blue connectors for 16 AWG wire)	Amazon	B08BZ 972B5	1	Pack/ 100	\$ 9.95	4	\$ 9.95	Used for joining wired ends together instead of soldering; allows for easy swap out of electrical hardware if damaged	Nylon, brass, tin	N/A	N/A	N/A	N/A	

E-15		CPAP Tubing	Mars Wellness Universal CPAP Hose - 6 Foot - Universal Tube Compatible with Most Machines - 1 Pack (Other expandable shielding for electrical wires can be used in place (i.e., ePTFE teflon))	Amazon	B0BQSPD7YL	1	Indv.	\$ 11.99	1	\$ 11.99	Used as a shielding for the 16 gauge wire connected to the toggle switch for the water pump	Rubber, plastic	N/A	0.08	N/A	N/A
E-16		Electrical Tape	Amazon Basics Vinyl Electrical Adhesive Tape, High Temp Flame Retardant, 3/4 in x 60 ft x 0.007in (19 mm x 18.3 m x 0.18mm), Black, 6-Pack (Previously Amazon Commercial Brand)	Amazon	B08B4GVVQJ	1	Pack/6	\$ 10.36	1	\$ 10.36	Used to cover electrical QDs as well as hold the end of the CPAP tubing to the electrical box	Vinyl, adhesive	N/A	N/A	N/A	N/A
E-17		Raspberry Pi 3B+	Raspberry Pi 3 - Model B+ - 1.4GHz Cortex-A53 with 1GB RAM	Adafruit	3775	1	Indv.	\$ 35.00	1	\$ 35.00	Microcontroller for LCG sensor code and data offloading	Various	HS3V2.5 PLSS and HUT - Raspberry Pi 3Bplus	N/A	N/A	N/A
E-18		Fasteners/Screws	Male-Female Threaded Hex Standoff, M2.5, 10mm long	McMaster Carr	93655A096	4	Indv.	\$1.68	4	\$ 6.72	Fasteners for mounting the Rpi board to the Rpi housing (bottom).	18-8 SS	HS3V2.5 PLSS and HUT - 93655A096	N/A	N/A	N/A
E-19		Fasteners/Screws	M2.5, 5mm long, 18/8 Stainless Steel Socket Head Screw	McMaster Carr	91292A009	1	Pack/100	\$6.00	4	\$ 6.00	Fasteners for mounting the Proto HAT to the Rpi	18-8 SS	HS3V2.5 PLSS and HUT - 91292A009	N/A	N/A	N/A

E-20		DS18B20 Sensors	BOJACK DS18B20 Temperature Sensor Module Kit with Waterproof Stainless Steel Probe for Raspberry Pi	Amazon	B09NVWNLQ	2	Indv	\$ 8.99	2	\$ 17.98	LCG temperature probe for inlet-outlet temperature sensing	Various	HS3V2.5 PLSS and HUT - DS18B20 sensor HS3V2.5 PLSS and HUT - DS18B20 sensor module	N/A	N/A	N/A
E-21		Perma-Proto HAT	Perma-Proto HAT	Digikey	1528-1369-ND	1	Indv	\$ 4.95	1	\$ 4.95	Used for wiring/soldering the DS18B20 sensors and their module kits to the Rpi board.	Various	HS3V2.5 PLSS and HUT - adafruit_perma_proto_hat	N/A	N/A	N/A
E-22		LEMO Connectors	CONN RCPT MALE 3P GOLD SLDR CUP	DigiKey	NOR1416-ND	2	Indv.	\$ 9.80	2	\$ 19.60	Used as mountable electrical connection between inside of Rpi housing and outside for DS18B20 sensors	Metal, copper alloy, nickel, gold, silver	HS3V2.5 PLSS and HUT - lemoconnector	N/A	N/A	N/A
E-23		3D Print	Raspberry Pi Housing (Top)	N/A	N/A	1	Indv.	N/A	1	N/A	Housing for Rpi and electronics	IC3D ABS - Black	HS3V2.5 PLSS and HUT - Raspberry Pi Housing (Bottom)	0.028	0.05	A
E-24		3D Print	Raspberry Pi Housing (Bottom)	N/A	N/A	1	Indv.	N/A	1	N/A	Housing for Rpi and electronics	IC3D ABS - Black	HS3V2.5 PLSS and HUT - Raspberry Pi Housing (Top)	0.028	0.05	A
E-25		Adhesive Pad	Square 3M Double Sided Adhesive Pads,100Pack Double Sided Sticky Pads Super-Sticky Adhesive Foam Pads, 1.06 x 1.06 Inch Strong Pad Heavy	Amazon	N/A	1	Pack/100	\$ 7.99	2	\$ 7.99	Stick to the Rpi housing (bottom) and then to the inside of the PLSS as a means of mounting the Rpi unit and housing inside the	Adhesive, foam	N/A	N/A	N/A	N/A

			Duty Mounting Adhesive								PLSS above the battery					
E-26		USB Fan	ANEXT, USB Fan, USB Computer Fan, Silent Fans for Receiver DVR PlayStation Xbox Computer, (80mm,White) (During operation, only use 'High' (H) setting. Remove metal grates and rubber feet before mounting to visor.)	Amazon	BOBZ VDP3PY	1	Indv.	\$ 11.99	1	\$ 11.99	Ventilation fan for visor; to provide air flow or cooling and dust/sand mitigation for head and eyes	Plastic, Metal, Rubber feet	HS3V2.5 PLSS and HUT - USB Cooling Fan - Blades HS3V2.5 PLSS and HUT - USB Cooling Fan - Housing HS3V2.5 PLSS and HUT - USB Cooling Fan - FAN AC Infinity Multifan 80mm	0.2	N/A	N/A

4.6.1.1.4 Soft Goods System BOM

Table 4-35. Soft Goods System BOM. Total Price per unit HS3 is estimated to be \$4180.61.

BOM ID	Image	Part / Category	Item Description/Specifications/Dimensions	Manufacturer/ Vendor	P/N	Unit Qty.	UoM	Unit Cost	Line Item Cost / Sub Total	Total Indv. Qty. Rqrd. Per Suit	Usage	Material/ Alloy	CAD File Name	Weight per line item (lbs)	Print Settings
S-1		Custom Softsuits	Custom Softsuits (Recommend to construct one large size, and one small size)	Constructed Using Materials listed below for one suit	N/A	1	Indv.	\$3,700.00	\$3,700.00	1	Softsuit for HS3	Constructed Using Materials listed below for one suit	N/A	N/A	N/A
S-2		Custom Softsuits Construction Materials	Ottotex® Waterproof Canvas (White)	Fabric Wholesale	SV570594	4	Yard	\$9.99	\$39.96	2 yard per suit	Primary material for custom softsuit, see softgoods	(1) Content: 100% Polyester, 100% Polyvinyl Chloride (PVC) Backing (2) Width:60/61 inches (3) Weight: 390 GSM (4) Thickness:	See Softgoods Fabric Key <1>	N/A	N/A

											fabric key	0.55 mm (5) Density: 600 x 600			
S-3		Custom Softsuits Construction Materials	<u>56" 2-Ply Ultrex Fabric (Mid-Weight Nylon - 4 oz/yr^2 with micro porous coating, waterproof breathable)</u>	Seattle Fabrics	<u>FU2-WHITE</u>	10	yard	\$13.95	\$139.50	8 yard per suit	Primary material for custom softsuit, see softgoods fabric key	Ultrex (2-Ply) Two-part system of densely woven fabric, micro-porous polyurethane coating and a DWR (durable water repellent) finish. Waterproof, windproof, and breathable.	See Softgoods Fabric Key <2>	N/A	N/A
S-4		Custom Softsuits Construction Materials	<u>Sew on Hook and Loop Style 1 Inch Non-Adhesive Back Nylon Strips Fabric Fastener Non-Adhesive Interlocking Tape White, 12.6 Yard (Select different options for different width)</u>	Amazon	(ASIN, P/N) 1" (B07PXJT25K, YR-SHK-12M-WH1) 2" (B07PVGJC1X, CA-SHK-5Y-WH2) 4" (B07Q1W2DTK, CA-SHK-3Y-WH4)	1" (x1) 2" (x1) 4" (x1)	roll	\$13.95	\$41.85	Need per suit: 1" (3 yd), 2" (3 yd), 4" (2 yd)	see softgoods fabric key	Nylon, Polyester: Velcro (soft, white)	See Softgoods Fabric Key <3>	N/A	N/A
S-5		Custom Softsuits Construction Materials	Sew on velcro (hook side, white)	Amazon	Included in S-4	covered by above	covered by above	-	-	Need per suit: 1" (3 yd), 2" (3 yd), 4" (2 yd)	see softgoods fabric key	Nylon, Polyester: Velcro (hook, white)	See Softgoods Fabric Key <4>	N/A	N/A
S-6		Custom Softsuits Construction Materials	<u>Elastic Band for Sewing 1/2 Inch Wide 12 Yards, Durable & Soft High Elasticity Stretch Elastic Bands Cord for Sewing, Waistbands,</u>	Amazon	B0BYS79NDM	1/2" x 12 yard	roll	\$6.99	\$6.99	Need: [1/2" x 14"] x2 per suit	see softgoods fabric key	Elastic (white)	See Softgoods Fabric Key <5>	N/A	N/A

			<u>Pants, DIY Crafts, White : Arts, Crafts & Sewing</u>												
S-7		Custom Softsuits Construction Materials	<u>Sawoake 2PCS #5 46 Inch Separating Jacket Zippers for Sewing Coats Jacket Zipper White Molded Plastic Zippers Bulk Tailor DIY Sewing Tools for Garment/Bags/Home Textile</u>	Amazon	Lagre Suit: B0B65H 6QTT (46") Small Suit: B0B65J ZT6R (35")	1	pack of 2	\$3.99	\$3.99	Large Suit: (46" long, zipper #5) x1 per suit Small Suit: (35" long, zipper #5) x1 per suit	see softgoods fabric key	Zipper #5, white	See Softgoods Fabric Key <6> - Zipper A	N/A	N/A
S-8		Custom Softsuits Construction Materials	<u>KGS Nylon Zippers for Sewing Crafts Size: 7 Inch Color: White 20 Pieces per Pack Single Color #3 Nylon Zippers for Making Bags, Pouches, Pillow Covers and Sewing Craft Projects</u>	Amazon	B08RY MRJWF	1	pack of 20	\$7.49	\$7.49	(7" long, zipper #3) x6 per suit	see softgoods fabric key	Zipper #3, white	See Softgoods Fabric Key <7> - Zipper B	N/A	N/A
S-9		Custom Softsuits Construction Materials	<u>EVA Foam Cosplay - (2mm to 10mm) - Black or White - 14" x 39" Sheet - Ultra High Density 85 kg/m3 - by The Foamory (White, 2mm - Thickness) : Arts, Crafts & Sewing</u>	Amazon	B08YX YD3W4	1	Indv	\$18.99	\$18.99	1	HUT Arm Covers, see softgoods fabric key	High Density EVA Foam (5 mm thick, Ultra High Density 85 kg/m3, white)	See Softgoods Fabric Key <8>	N/A	N/A
S-10		Custom Softsuits Construction Materials	<u>Sew-All, All Purpose Thread 547 Yards-Black GUTERMANN Thread 3 pack (White)</u>	Amazon	B01DT6 ZOJ8, Model# g-10	1	pack of 3	\$15.98	\$15.98	1	all softgoods sewing	Polyester, 546 yard	N/A	N/A	N/A

S-11		Gloves	Warrior Burn Lacrosse Gloves	Warrior / Dick's Sporting Goods	<u>21WAR</u> <u>MBRN</u> <u>GLVXX</u> <u>XXXLX</u> <u>P</u>	1	Pair	\$109.99	\$109.99	1	Gloves for HS3, recommend x1 L and x1 M	N/A	N/A	N/A	N/A
S-12		Gloves	Glove system	Made in house	NA	1	Pair	-	-	1	Gloves for HS3, recommend x1 L and x1 M	N/A	N/A	0.46	N/A
S-13		Soft Goods	HUT Canvas Cover	Made in house	NA	2	each	-	-	2	HUT Arm Covers to prevent rubbing sleeves on HUT	Canvas and EVA foam	N/A	0.18	N/A
S-14		3D Print	Gloves - Wrist Rings - Male	N/A	N/A	2	Indv.	\$5.60	\$11.20	2	Used to connect wrist ring on softsuit to wrist ring on gloves as friction-fit connector (attached to suit)	IC3D ABS White	h3po-pn-xxxx-glv-disc-a	0.28	0.2mm layer height 90 mm/s 265degC extruder temp. 110degC build plate temp. Wall and top/bot layer count: 3 Tri-hexagon infill, 20% density 50% overhang angle 10% support density Brim w/ 30 lines, distance 0.15

S-15		3D Print	Gloves - Wrist Rings - Female	N/A	N/A	2	Indv.	\$7.20	\$14.4	2	Used to connect wrist ring on softsuit to wrist ring on gloves as friction-fit connector (attached to glove)	IC3D ABS White	h3po-pn-xxxx-glv-disc-b	0.36	0.2mm layer height 90 mm/s 265degC extruder temp. 110degC build plate temp. Wall and top/bot layer count: 3 Tri-hexagon infill, 20% density 50% overhang angle 10% support density Brim w/ 30 lines, distance 0.15
S-16		Gloves	<u>Manzella Men's Lightweight Gore-Tex Infinium Glove, Touchscreen Capable with Windproof Protection Against Cold Weather at Amazon Men's Clothing store</u>	Amazon, Manzella Productions, Inc.	O618M	1	Pair	\$37.95	\$37.95	1	Inner glove for HS3, recommend x1 L and x1 M	100% Polyester (shell), 91% Polyester + 9% thermalplastic polyurethane	NA	0.099	
S-17		Gloves	<u>Amazon.com: GloveTacts Ultra Thin Conductive Touch Screen Stickers for Gloves: The Easiest Way to Make Gloves Touch Compatible : Cell Phones & Accessories</u>	Amazon, GloveTacts	RGC-06CSP	2	package	\$16.99	\$33.98	2	Optional : for glove to VR controller integration, conductive touch screen sticker	Conductive Film	NA	0.0172	NA
S-18		Knee Pads	3 Pairs Foam Knee Pad Inserts,Cargo Pants Knee Pads,Gardening Knee Pads 9.45"x6.6"x0.7"(L-Durable)	Amazon	<u>B0878XGY1X</u>	1	3 Pairs	\$25.99	\$25.99	1	Used for knee pads for soft suit garments, for elbow	Ethylene Vinyl Acetate (EVA)	N/A	0.14	N/A

											pads, just cut around to fit				
S-19		Adhesive	Amazon.com : super 77	Amazon, 3M	7256456	1	can	\$21.86	\$21.86	1	Used to adhere the sew on Velcro to 3DPT parts	aerosol spray	N/A	N/A	N/A

Note: A few less desirable alternatives to S-3 are available in case the S-3 option is out of stock or depending on needs.

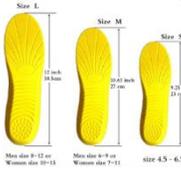
- A less breathable option: [2-Layer Waterproof Breathable Polyester Fabric - Optic White \(Rockywoods Fabrics\)](#)
- A thinner/see-through option : [Ottertext Nylon Ripstop Fabric PU Coated 70 Denier 1.9oz 62/63" Wide Waterproof Tent Water Repellent Dustproof Airtight Inflatable Flag Tarp Cover Excellent Fabric for Kites \(1 Yard, White\)](#)

4.6.1.1.5 Peripheral System BOM

If budget allowed, test team recommends expanding the size range coverages for the peripheral system items. The BOM below lists the minimum quantity recommended for one operational HS3 system with minimum number of peripheral system sizes. Additional sizes are always helpful to improve subject suit fit experience.

Table 4-36. Peripheral System BOM. Total Price per unit HS3 is estimated to be \$1643.48.

BOM ID	Image	Part / Category	Item Description/Specifications/Dimensions	Manufacturer/ Vendor	P/N	Unit Qty.	UoM	Unit Cost (\$)	Line Item Cost Sub Total (\$)	Total Indv. Qty. Rqrd. Per Suit	Usage	Material/ Alloy	Per unit weight (lbs)
R-1		Boots	Korkers Men's Darkhorse Fishing / Wading Boot, Includes Interchangeable Felt & Kling-On Soles (recommend picking a minimum of two sizes among the size range and uses insertable insoles to expand the size range)	Amazon	B01M24M464	1	1 Pair	\$209.99	\$209.99	2	Boots for HS3	Synthetic Outer, Rubber Sole	4.3

R-2		Boots	<p>Korkers Devil's Canyon Wading Boots - Athletic and Glove-like Fit - Includes Interchangeable Felt and Kling-On Soles</p> <p>(recommend picking a minimum of two sizes among the size range and uses insertable insoles to expand the size range)</p>	Amazon	B00E4G3PPI	1	1 Pair	\$209.99	\$209.99	2	Boots for HS3	Synthetic Outer, Rubber Sole	2.9
R-3		Boots	<p>Korkers Women's Darkhorse Wading and Fishing boot- Includes Interchangeable Kling-On & Studded Kling-On Soles</p> <p>(recommend picking a minimum of two sizes among the size range and uses insertable insoles to expand the size range)</p>	Amazon	B083CB3RRZ	1	1 Pair	\$249.99	\$249.99	2	Boots for HS3	Synthetic Outer, Rubber Sole	3
R-4		Padded Insoles	<p>Shoe Insoles, Memory Foam Insoles, Providing Excellent Shock Absorption and Cushioning for Feet Relief, Comfortable Insoles for Men and Women for Everyday Use, M [US M: 6-9/W: 7-11]</p>	Amazon	B073QF96ZZ	1	1 Pair	\$9.98	\$9.98	2	Used as padded insole for boots (in case subjects are between sizes or need extra volume to fill the boot comfortably without slippage)	Velvet	0.22
R-5		Baselayer	<p>32 Degrees Men's Lightweight Baselayer Crew Top Long Sleeve Form Fitting 4-Way Stretch Thermal</p> <p>(Recommend expanding size inventory for entire subject population)</p>	Amazon	B0BFRTKM Y3	1	Indv.	\$18.88	\$18.88	1	Baselayer to be worn under Liquid Cooling Garment for HS3	40% Polyester, 34% Acrylic, 22% Rayon, 4% Spandex	N/A

R-6		Baselayer	32 Degrees Men's 2-Pack Performance Lightweight Thermal Baselayer Legging Pant (Recommend expanding size inventory for entire subject population)	Amazon	B09R97MGL6	1	2 Pack	\$19.99	\$19.99	1	Baselayer to be worn under Liquid Cooling Garment for HS3	40% Polyester, 34% Acrylic, 22% Rayon, 4% Spandex	N/A
R-7		LCG - Full Body Garment	COMPCOOLER Full Body Cooling Garment	Compcooler	COMP-LCG-FBG-BK-XX	1	Indv.	\$199.99	\$199.99	1	Liquid cooling garment for HS3	Nylon, Spandex, PVC tubing	1.8
R-8		Elbow Brace	FEATOL Elbow Brace for Tendonitis and Tennis, Adjustable Golfers Elbow Brace for Men and Women, Pain Relief for Cubital Tunnel Syndrome, Bursitis, Ulnar Nerve Entrapment (Black, Medium)	Amazon	B09ZPM3JHF	2	Indv.	\$12.06	\$24.12	1 Pair	Used for restricted ROM for elbows	Neoprene, Steel Spring, Velcro Strap	0.33
R-9		Knee Brace	Modvel ELITE Knee Brace for Women & Men with Side Stabilizers - Patella Gel Pads Brace for Meniscus Tear for Knee Pain Support, ACL Knees Braces for Men Running, Workout, Arthritis & Joint Recovery	Amazon	B084WV5SZQ	2	Indv.	\$29.86	\$59.72	1 Pair	Used for restricted ROM for knees	Elastic, Patella Gel Pad, Velcro Strap	0.44
R-10		Foam Waist Belt	Pool Floats Back Swim Floating Belt EVA Foam Swimming Training Aid Aerobics Exercise Belt Kickboard for Adult Kids	Amazon	B07377FJ57	1	Indv.	\$16.98	\$16.98	1	Used as restricted ROM device for waist/torso	Foam	0.23

R-11		Crotch Pad Assembly	6 Pack Foam Pool Noodles – 48” x 2.5” Hollow Core – Extra Dense, Durable	Amazon	ON-Oodles-6PACK	1	6-pack	\$28.99	\$28.99	1	Used as restricted ROM device for waist/torso	Polyethylene Foam	2.5
R-12		Belt Loop	Duty Belt Keepers w/Double Snaps for 1.5"/1.75"/ 2"/2.25" Wide Utility Belt Loop Stays Nylon Tactical Belt Holder Retainer Police Security Law Enforcement Military Accessories	Amazon	B0CJ5CW7GW	1	4-pack	\$9.99	\$9.99	2	Used to keep Waist Inhibitor in place, underneath custom soft suit (installed inside at waist)	Nylon	N/A
R-13		Webbing + Buckles	2" Heavy-Duty Buckle & Straps Set: 6-Pack Side Release Plastic Buckles, 6 Yards of Thick Nylon Webbing, 12 Tri-Glide Slide Clips, No Sewing Required (2" Combo Set)	Amazon	B09JS7M29Y	1	6-pack	\$22.99	\$22.99	1	Used to install crotch pad assembly to waist inhibitor	Webbing: 100% Polyester Buckle: Plastic	N/A
R-14		Communication System	Wireless Bone Conduction Headphones	Amazon	SHOKZ OpenRun	1	Indv.	\$129.95	\$129.95	1	Used for two-way voice	Nickel-Titanium Alloy, Plastic, Silicone	0.06
R-15		Mevo Camera	Mevo Start Camera	LogiTech	Mevo Start	1	Indv.	\$399.99	\$399.99	1	Camera for 1st person POV; mounted to HUT	N/A	0.5
R-16		Camera Mount + Screws	UTEBIT Mini Ball Head, Tripod Head with 1/4" hot Shoe, 360° Rotatable Ball Heads Camera Mount Adapter, Aluminium 20mm Ballhead Compatible with Tripods, Monopods, HTC Vive, SLR Cameras Loading 6.6lb	Amazon	B06XKW7V14	1	Indv.	\$9.99	\$9.99	1	Used for mounting Mevo camera to HUT via screw fasteners	Aluminum	0.3

R-17		Treadmill Adaptation	GM CLIMBING 1 inch Nylon Tubular Webbing Tape CE UIAA Certified 4000lb Heavy Duty for Climbing Rescue Rope Works Survival Outdoor General Purposes	Amazon	GM161130	1	Indv.	\$21.95	\$ 21.95	1	Used with fireman knot to create a low-profile safety harness for positioning subject on treadmill	Nylon (UIAA certified)	0.75
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4.6.2 Donning Stand

Based on the raw material prices as of 2025 August, the estimated cost to produce one unit of HS3 donning stand is \$1804 (assuming all 3D printed parts are printed in-house and thus only raw filament price per print object weight is used).

Table 4-37. HS3 Donning Stand BOM. Total Price per unit HS3 donning stand is estimated to be \$1804.

BOM ID	Image	Part / Category	Item Description/Specifications/Dimensions	Manufacturer/ Vendor	P/N	Unit Qty.	UoM	Unit Cost	Line Sub Total	Total Indv. Qty. Rqrd.	Usage	Material/ Alloy	CAD File Name	Print Time per Unit (days) Print Settings (incl rough print volume and printer used)
D-1		Frame	Single 4-Slot Hollow Rail, Silver, 1.5" x1.5", 8'	McMaster Carr	47065T102	1	Indv.	\$46.50	\$46.50	Cut pieces: -(x2)30" -(x1) 27 5/8"	Cut for single width	Aluminum		n/a
D-1.1		Cut from D-1	Single 4-Slot Hollow Rail, Silver, 1.5" x1.5", 30"	n/a	n/a	2	Indv.	n/a		2	Inner Main Vertical	Aluminum	hs3v25_D_1.1_0820_Int_Vert1	n/a
D-1.2		Cut from D-1	Single 4-Slot Hollow Rail, Silver, 1.5" x1.5", 27 5/8"	n/a	n/a	1	Indv.	n/a		1	Outer Upper Horizontal	Aluminum	hs3v25_D_1.2_0820_Int_Horz	n/a
D-2		Frame	Single 4-Slot Hollow Rail, Silver, 1.5" x1.5", 6'	McMaster Carr	47065T102	1	Indv.	\$60.50	\$60.49	Cut pieces: -(x1)21 1/16" -(x2) 11 1/4" -(x2) 7"	Cut for single width	Aluminum		n/a
D-2.1		Cut from D-2	Single 4-Slot Hollow Rail, Silver, 1.5" x1.5", 21 1/16"	n/a	n/a	1	Indv.	n/a		1	Inner Lower Horizontal	Aluminum	hs3v25_D_2.1_0820_Int_Horz_Bot	n/a

D-2.2		Cut from D-2	Single 4-Slot Hollow Rail, Silver, 1.5" x1.5", 11 1/4"	n/a	n/a	2	Indv.	n/a		2	Inner Lower Vertical	Aluminum	hs3v25_D_2.2_0820_Int_Vert2	n/a
D-2.2		Cut from D-2	Single 4-Slot Hollow Rail, Silver, 1.5" x1.5", 7"	n/a	n/a	2	Indv.	n/a		2	Base wheel foot	Aluminum	hs3v25_D_2.3_0820_Out_Wheel	n/a
D-3		Frame	1.50" X 3.00" Lite T-Slotted Profile, 84" long, (Added Machining Services 5/16-18 D X 1.25" End Taps Left End)	8020.net	1530-Lite	2	Indv.	\$109.00	\$218.90	2	Main vertical members, 84"; Added Machining Services 5/16-18 D X 1.25" End Taps Left End	Aluminum	hs3v25_D_3_Out_0820_Vert	n/a
D-4		Frame	Double 6-Slot Hollow Rail, Silver, 3" x1.5", 4'	McMaster Carr	47065T108	3	Indv.	\$56.90	\$170.70	Cut pieces: -(x4) 24" -(x1) 21 9/16" -(x1) 21 1/16"	Feet/Cross Members	Aluminum		n/a
D-4.1		Cut from D-4	Double 6-Slot Hollow Rail, Silver, 3" x1.5", 24"	n/a	n/a	4	Indv.	n/a	n/a	4	4 feet/legs for base (this will use 2 of the 3 D-4 rails)	Aluminum	hs3v25_D_4.1_0820_Out_leg	n/a
D-4.2		Cut from D-4	Double 6-Slot Hollow Rail, Silver, 3" x1.5", 21 9/16"	n/a	n/a	1	Indv.	n/a	n/a	1	Outer Lower horizontal	Aluminum	hs3v25_D_4.2_0820_Out_Horz_Top	n/a
D-4.3		Cut from D-4	Double 6-Slot Hollow Rail, Silver, 3" x1.5", 21 1/16"	n/a	n/a	1	Indv.	n/a	n/a	1	Inner Upper horizontal	Aluminum	hs3v25_D_4.3_0820_Out_Horz_Bot	n/a
D-5		Frame	Silver Square Surface Bracket for 3" High Rail	McMaster Carr	47065T258	2	Indv.	\$14.80	\$29.58	2	Inner Frame	Aluminum	hs3v25_D_5_Sq_Bracket	n/a
D-6		Frame	Silver Flush 90 Degree Angle Bracket for 1.5" High Rail	McMaster Carr	3136N158	6	Indv.	\$19.40	\$116.50	6	Frame Corners	Aluminum	hs3v25_D_6_3x3agl_Plate	n/a

D-7		Frame	Silver Gusset Bracket, 1-1/2" Long for 1-1/2" High Rail	McMaster Carr	47065T679	6	Indv.	\$11.60	\$69.30	6	Frame Corners	Aluminum	hs3v25_D_7_Corner_Brace	n/a
D-8		Frame	Silver Gusset Bracket, 3" Long for 1-1/2" High Rail T-Slotted Framing	McMaster Carr	47065T762	6	Indv.	\$18.10	\$108.70	6	Base and Frame Corners	Aluminum	hs3v25_D_8_2x1_Corner_Brace	n/a
D-9		Frame	Gusset Bracket, 3" Long for 3" High Double/Quad Rail T-Slotted Framing	McMaster Carr	47065T906	2	Indv.	\$28.80	\$57.56	2	Base	Aluminum	hs3v25_D_9_2x2_Corner_Brace	n/a
D-10		Frame-Base	Silver Diagonal Brace for 1.5" High Single Rail, 18" Long	McMaster Carr	47065T702	2	Indv.	\$37.30	\$74.58	2	Base angle supports	Aluminum	hs3v25_D_10_0820_agl_support	n/a
D-11		Frame-Sliding Carriage	Sleeve Bearing, 1.5" High Rail, 1 Flange, 2-13/16" Long, Silver	McMaster Carr	47065T955	4	Indv.	\$82.50	\$330.00	4	Slide Carriage	Aluminum	hs3v25_D_11_slide_carriage	n/a
D-12		Frame-Base	Locking Pivot for 3" High Double/Quad Rail, 90 Degree, L Handle	McMaster Carr	3136N221	2	Indv.	\$78.00	\$156.00	2	Leg Brace	Aluminum	hs3v25_D_12_base_brace	n/a
D-13		Frame-Base	Plate Mount Swivel Caster, Total Lock, 40mm and 1.5" High Rail	McMaster Carr	5537T435	2	Indv.	\$66.20	\$132.40	2		Rubber	hs3v25_D_13_wheel	n/a
D-14		Frame	Sure-Grip Pull Handle for 1.5 and 40mm High Rail, 9-7/16" Long	McMaster Carr	5537T629	3	Indv.	\$16.30	\$48.99	3		Plastic	hs3v25_D_14_Frame_Handle	n/a
D-15		Frame-Sliding Carriage	1-Arm Hand Brake for Bearing for 1.5" High and 3" High Rail, Yellow	McMaster Carr	6812N306	2	Indv.	\$22.10	\$44.16	2	Slide Carriage Brake	Zinc	hs3v25_D_15_slide_carriage_handle	n/a
D-16		Frame	End Cap for 3" High Double Rail	McMaster Carr	3136N21	4	Indv.	\$3.25	13.00	4	Exposed ends	ABS Plastic	hs3v25_D_16_Cap_Wide	n/a
D-17		Frame	End Cap for 1-1/2" High Single Rail	McMaster Carr	3136N21	6	Indv.	\$2.66	\$15.96	6	Exposed Ends	ABS Plastic	hs3v25_D_17_Cap_Single	n/a
D-18		Frame	Phillips Flat Head Screws for Sheet Metal	McMaster-Carr	90033A210	1	Pack of 100	\$7.40	\$7.38	18	Secure door latches	Black-Oxide Steel	N/A	n/a
D-19		Hard Capture	Button Head Hex Drive Screw, 5/16"-18 Thread, 2-1/4" Long	McMaster-Carr	91255A589	1	Pack of 100	\$11.10	\$11.09	4	Secure hard capture	Black-Oxide Steel	hs3v25_D_19_HC_screw	n/a
D-20		Hard Capture, Soft Capture	Prime-Line E 2440 Passage Door Latch, 9/32 In. and 1/4 In. Square Drive, Steel,	Amazon		10	Indv.	\$3.83	\$38.30	10	capture PLSS to donning stand	Steel	hs3v25_D_20_latch	n/a

			Chrome Finish (Single Pack)											
D-21		3D print-Soft Capture	Soft Capture Actuator Lever-Handle	n/a	n/a	2			\$6.00	2	Actuate soft capture	Tough PLA	hs3v25_D_21_SC_Handle	20% Infill, 8 hours
D-22		3D print-Soft Capture	Soft Capture Handle Connector	n/a	n/a	8			\$1.28	8	connect soft capture lever to mechanism	Tough PLA	hs3v25_D_22_SC_Adapter	20% Infill, 30 min
D-23		3D print-Soft Capture	Soft Capture Mount	n/a	n/a	4			\$12.16	4	house the door latch for the soft capture	Tough PLA	hs3v25_D_23_SC_Housing	20% Infill, 7 hours
D-24		3D Print-Hard Capture	Hard Capture Mount	n/a	n/a	2			\$9.72	2	house the door latch for the hard capture	Tough PLA	hs3v25_D_24_HC_Housing	20% Infill, 10 hours
D-25		3D Print-Hard Capture	Hard Capture Handle	n/a	n/a	2			\$5.2	2	fit overtop the alloy key for hard capture mechanism	Tough PLA	hs3v25_D_25_HC_handle	20% Infill, 3 hours
D-26		0820 Fasteners	0820 Fasteners	McMaster Carr	5158N25	3	Pack of 4	\$4.00	\$12.00	12 nuts, 10 screws	Secure 3dp parts to donning stand	Steel	n/a	n/a
D-27		Hard Capture	HARFINGTON 2pcs L-Shaped Square Head Wrench 7mm Carbon Steel L-Key	HARFINGTON/ Amazon	hta240925hh000014	1	pack of 2	\$7.99	\$7.99	2	actuate hard capture	Steel	hs3v25_D_27_HC_lever	n/a

5 Usage of HS3

This section provides hand-on instructions and examples on how to use the HS3 safely, cleanly, and correctly. Example procedures, a training template, and hazard analysis templates are provided as a user guide, though should be individually tailored for specific tests implementing the HS3.

5.1 Detailed Test Procedure

The example detailed test procedure (DTP) presented below is separated into sections to include preparation, donning, usage, and doffing of the HS3 system. The DTP is intended to be a step-by-step process checklist to ensure proper and safe usage of the system. DTP sections have columns for both familiarization and test sessions. It is recommended that subjects undergo a sizing and familiarization session prior to conducting data collection tasks with HS3. This section shows the following operation procedures when using HS3 with two test subjects:

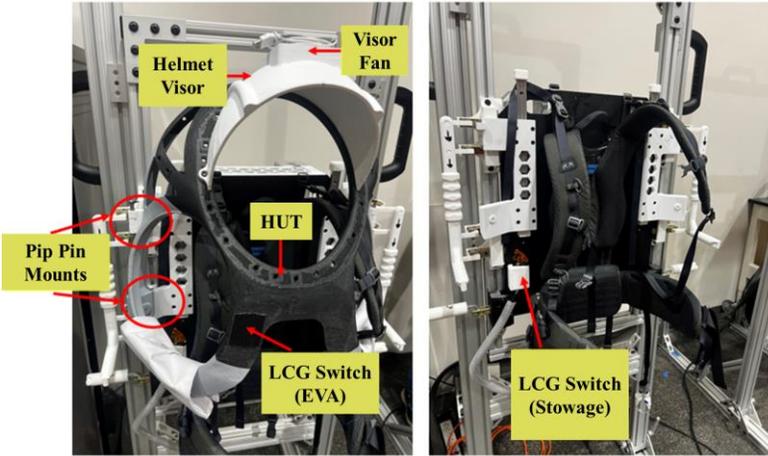
- Pre-test checklist
- Donning Procedures
- Doffing Procedures
- Clean-up Procedures
- Supplemental Procedures in Appendix: Emergency, safety harness, sizing procedures

5.1.1 Pre-test Checklist (T-1 Day to Test)

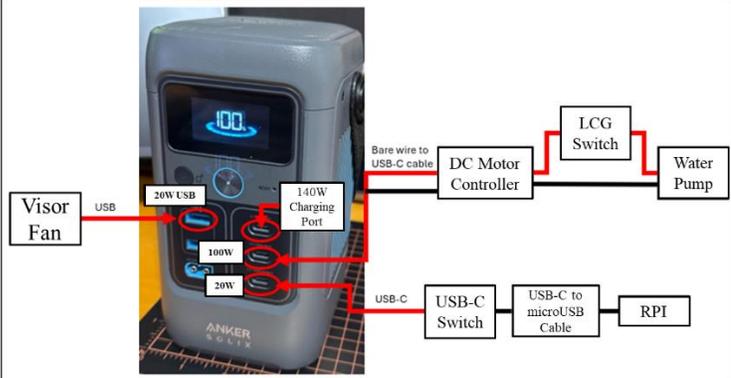
Table 5-1. Pre-test Checklist (T-1 Day to Test) DTP

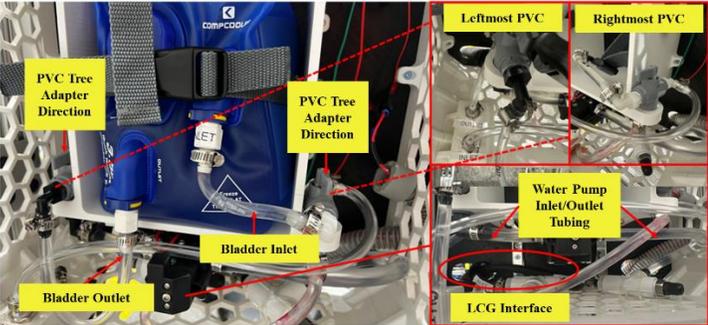
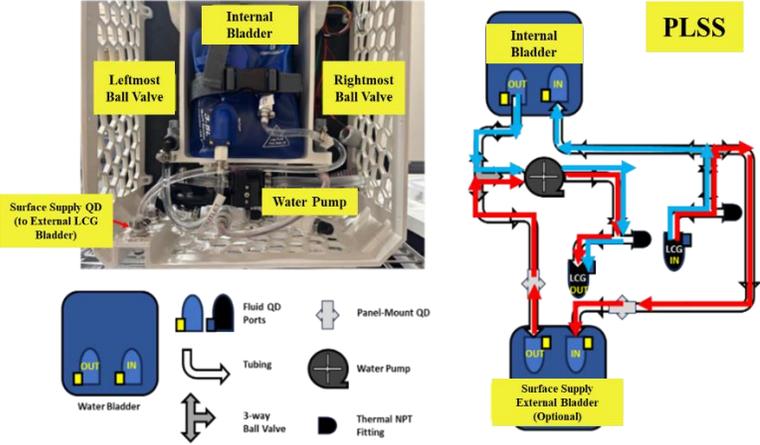
Note: EV1 and EV2 designations are for test operators assigned to assist donning.

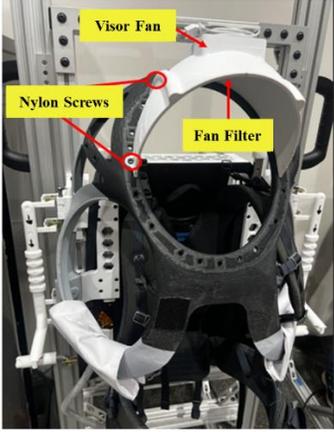
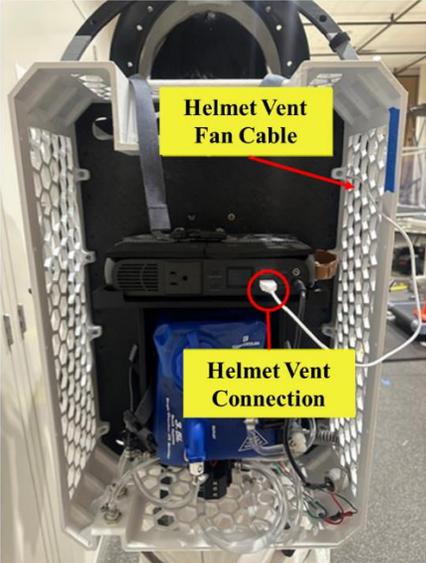
Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS																				
EV1	EV1	A.1	<p>Verify all batteries are full and/or charge the following batteries:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) PLSS Power Bank + (x1) backup <p>As applicable per study:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x2) Bone conduction headset + (x1) backup <input type="checkbox"/> (x3-4) Jabra Evolve headsets for test team <input type="checkbox"/> (x2) MEVO camera <input type="checkbox"/> (x2) RUNN Sensor + (x1) Samsung tablet <input type="checkbox"/> (x2) COSMED K5 metabolic cart and (x1) spare battery <input type="checkbox"/> (x2) Polar H10 puck and (x2) chest strap 	<p><i>200W Anker Power bank is the current power bank installed into PLSS.</i></p>																				
EV2	EV2				EV1	EV1	A.2	<p>Verify COSMED mask assembly is staged (as applicable):</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) Mask sizing caliper <input type="checkbox"/> (FAM) (x2) Masks (best guess sizes), (x2) head strap <input type="checkbox"/> (TEST) Full mask/turbine assembly per FAM's best size 		EV2	EV2	EV1	EV1	A.3	<p>Prep/freeze LCG bladders:</p> <ul style="list-style-type: none"> <input type="checkbox"/> Fill (x4) square 3.5L bladders with DI water up to 2.5 L. Ensure the bladder is filled below max fill line with water when held. Do not burp out any air. <input type="checkbox"/> Place filled bladders into the freezers laying upright (hose ports and cap facing upright) and flattened. <input type="checkbox"/> Verify a very distinct air bubble under the inlet & outlet ports. <div style="text-align: center;">  </div> <p>Figure 5-1. LCG Bladders in Freezer (left), Air Bubble (right).</p>	<p><i>External Cooling Option:</i> Fill external cooling bladders with DI water or use a cooling cart.</p>	EV2	EV2	EV2	EV2	EV1	EV1	A.4	<p>Verify integrity and functionality of donning stand:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x2) 8020 AL guided hand brakes/height adj. handles + (x2) backup. <input type="checkbox"/> (x2) Handles for hard capture (HC) + (x2) backup prints. <input type="checkbox"/> (x2) Handles for soft capture (SC) + (x2) backups. <input type="checkbox"/> (x8) Door latch adapters for SC handles
EV1	EV1	A.2	<p>Verify COSMED mask assembly is staged (as applicable):</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) Mask sizing caliper <input type="checkbox"/> (FAM) (x2) Masks (best guess sizes), (x2) head strap <input type="checkbox"/> (TEST) Full mask/turbine assembly per FAM's best size 																					
EV2	EV2				EV1	EV1	A.3	<p>Prep/freeze LCG bladders:</p> <ul style="list-style-type: none"> <input type="checkbox"/> Fill (x4) square 3.5L bladders with DI water up to 2.5 L. Ensure the bladder is filled below max fill line with water when held. Do not burp out any air. <input type="checkbox"/> Place filled bladders into the freezers laying upright (hose ports and cap facing upright) and flattened. <input type="checkbox"/> Verify a very distinct air bubble under the inlet & outlet ports. <div style="text-align: center;">  </div> <p>Figure 5-1. LCG Bladders in Freezer (left), Air Bubble (right).</p>	<p><i>External Cooling Option:</i> Fill external cooling bladders with DI water or use a cooling cart.</p>	EV2	EV2	EV2	EV2				EV1	EV1	A.4	<p>Verify integrity and functionality of donning stand:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x2) 8020 AL guided hand brakes/height adj. handles + (x2) backup. <input type="checkbox"/> (x2) Handles for hard capture (HC) + (x2) backup prints. <input type="checkbox"/> (x2) Handles for soft capture (SC) + (x2) backups. <input type="checkbox"/> (x8) Door latch adapters for SC handles 	<p>Verify all fasteners are donning stand tightened, not de-threaded, installed, intact.</p>	EV2	EV2	
EV1	EV1	A.3	<p>Prep/freeze LCG bladders:</p> <ul style="list-style-type: none"> <input type="checkbox"/> Fill (x4) square 3.5L bladders with DI water up to 2.5 L. Ensure the bladder is filled below max fill line with water when held. Do not burp out any air. <input type="checkbox"/> Place filled bladders into the freezers laying upright (hose ports and cap facing upright) and flattened. <input type="checkbox"/> Verify a very distinct air bubble under the inlet & outlet ports. <div style="text-align: center;">  </div> <p>Figure 5-1. LCG Bladders in Freezer (left), Air Bubble (right).</p>	<p><i>External Cooling Option:</i> Fill external cooling bladders with DI water or use a cooling cart.</p>																				
EV2	EV2																							
EV2	EV2																							
EV1	EV1	A.4	<p>Verify integrity and functionality of donning stand:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x2) 8020 AL guided hand brakes/height adj. handles + (x2) backup. <input type="checkbox"/> (x2) Handles for hard capture (HC) + (x2) backup prints. <input type="checkbox"/> (x2) Handles for soft capture (SC) + (x2) backups. <input type="checkbox"/> (x8) Door latch adapters for SC handles 	<p>Verify all fasteners are donning stand tightened, not de-threaded, installed, intact.</p>																				
EV2	EV2																							

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
			<ul style="list-style-type: none"> <input type="checkbox"/> (x2) HC door latch + 3DT HC mount + (x2) backups. <input type="checkbox"/> (x8) SC door-latch + 3DT SC mount + (x8) backups. 	Verify hazard tape placed on feet of donning stand.
EV1	EV1	A.5	<p>Verify HS3 HUT components are staged:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x2) Large and (x2) small 3DP HUT + backup of each <input type="checkbox"/> (x2) Upper pip pins & (x2) lower pip pins, staged. <input type="checkbox"/> (x2) Pip pin mount adapters fastened on HUTS with x4 screws <input type="checkbox"/> (x2) Backup pip pin mounts for HUT to struts. <input type="checkbox"/> (x1) Helmet visor, secured by (x4) screws + (x1) backup visor. <ul style="list-style-type: none"> o Verify (x1) visor fan and fan filter installed. <input type="checkbox"/> (x2) HUT arm canvas padding/covers for arm holes. <input type="checkbox"/> (x1) MEVO camera tripod mount, installed on HUT.  <p>Figure 5-2. Front of HS3 w/ HUT (left), w/o HUT (right).</p>	<ul style="list-style-type: none"> <input type="checkbox"/> Verify no loose/missing/visually damaged/de-threaded/frayed fasteners, junctions, heat inserts, material, etc. <input type="checkbox"/> Verify all fasteners tightened, not de-threaded, installed, intact. <input type="checkbox"/> Verify all waistbelt, shoulder, and chest straps loosened. <input type="checkbox"/> Upper pip pins: long, silver pins, 50mm Lg. Lower pip pins: T-handle (black) pins, 30 or 50mm Lg.
EV2	EV2		<p>Verify PLSS and Spine Harness assembly:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) PLSS 3DP backplate on donning stand <input type="checkbox"/> (x1) Padded harness + (x1) spine, installed with (x6) screws and washers to backplate. <input type="checkbox"/> (x2) Aluminum rails installed to PLSS backplate. <input type="checkbox"/> (x4) Rail carriages fastened on rails, (x2) rail struts <input type="checkbox"/> (x4) 3DPT AL rail guards capped on ends 	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
			<div> </div> <p>Figure 5-3. Front PLSS Components.</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) PLSS 3DPT power bank housing + (x1) backup. <input type="checkbox"/> (x4) PLSS 3DPT wall panels + (x1) backup of each. <input type="checkbox"/> (x1) PLSS 3DPT bladder compartment + (x1) backup <input type="checkbox"/> (x2) Bladder compartment Shelf Brackets, installed <div> </div> <p>Figure 5-4. Back of HS3 and PLSS Components.</p>	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1	A.6	<p>Verify PLSS electronics installed, plugged in, w/ wiring secured:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) PLSS power bank (see Figure 5-5) <input type="checkbox"/> (x1) DC motor controller, wired with bare wire-to-USB-C cable to 100W port, LCG switch, and water pump. <input type="checkbox"/> (x1) Visor fan connected to battery via 20W USB-A port <input type="checkbox"/> (x1) Water pump connected to motor controller via 16 AWG wires. <input type="checkbox"/> Check pump connected to motor controller. <input type="checkbox"/> (x1) LCG switch with plastic guard fed through front-bottom right of PLSS and protective tubing + (x1) optional Switch guard installed. Mounted to backplate (temporarily). LCG switch connected to motor controller. <p>Optional Sensors per study:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) RPi + (x1) USB-C button switch and microUSB cable connected to battery 20W USB-C port. <input type="checkbox"/> (x2) DS18B20 thermal sensors secured into NPT fittings in water cooling system at T-adaptor PVC and plugged into RPi system. 	<p>Visor fan will be unplugged when donning/doffing HUT with subject.</p> <p>Plastic guard is removed for Anker Solix power bank config.</p>
EV2	EV2		 <p>Figure 5-5. Battery Connection Diagram. User Interface (left), PLSS Wiring Config (right) – Anker 200W.</p>	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1	A.7	<p>Verify HS3 PLSS LCG system staged, secured, and installed:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) Water pump with 3/4" tubing on inlet and outlet. <input type="checkbox"/> (x2) Black, shielded LCG interface tubing with female QD routed through bottom left backplate hole of PLSS. <input type="checkbox"/> (x2) PVC pipe T-adapters secured with metal hose clamps and (x2) NPT thermowell fittings, 50mm. Facing the PLSS: <input type="checkbox"/> Leftmost diverting ball valves + lever: <ul style="list-style-type: none"> ▪ (x1) Surface Supply Outlet [backward] ▪ (x1) Bladder outlet port [forward] ▪ (x1) Pump-to-LCG outlet [downward] <input type="checkbox"/> Rightmost diverting ball valves + lever: <ul style="list-style-type: none"> ▪ (x1) Surface Supply Inlet [backward] ▪ (x1) LCG inlet [downward] ▪ (x1) Internal Bladder inlet port [forward]  <p style="text-align: center;">Figure 5-6. PLSS LCG System.</p>	<p>External Cooling Option: (x1) Neoprene waterproof lunch bag system w/ holes and Velcro attachment, staged.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Verify no loose/missing connections, plugs, hose clamps, etc <input type="checkbox"/> Verify no visual damage/fraying on O-rings. <input type="checkbox"/> Verify all water hose have metal hose clamp and secured
EV2	EV2		<ul style="list-style-type: none"> <input type="checkbox"/> (x2) Bottom panel-mounted fluid male QDs installed on bottom left of bottom shelf of PLSS: surface supply inlet/outlet <input type="checkbox"/> (x2) Male-to-female Surface Supply QDs for external LCG bladder (External Bladder is not shown in picture)  <p style="text-align: center;">Figure 5-7. LCG System: Tube Connections and Configs. Figure 5-7 Legend: red: external cooling, blue: internal cooling)</p>	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1	A.8	<p>Verify HS3 Helmet Ventilation System staged and installed:</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) Visor fan on 3DPT visor, attached to HUT with (x4) nylon screws. <input type="checkbox"/> (x1) Fan filter installed underneath fan/interior of visor.  <p style="text-align: center;">Figure 5-8. Ventilation Configuration.</p>	<p>Verify no missing, poor, or damaged connections and 3DPT adapters.</p> <p>Verify no broken, loose, de-threaded connections or parts.</p>
EV2	EV2		<p>Verify power to PLSS electrical components.</p> <p><u>PLSS Power Bank:</u></p> <ul style="list-style-type: none"> <input type="checkbox"/> Verify charged by holding (if powered OFF) or pressing (if in sleep mode) the power button until LED display comes on. <input type="checkbox"/> Verify battery percentage is >90% battery. <p><u>Helmet Vent Fan:</u></p> <ul style="list-style-type: none"> <input type="checkbox"/> Plug into USB-A 20W port on battery. <input type="checkbox"/> Slide the inline fan switch to “H” (high). <input type="checkbox"/> Verify fan is functioning and providing flow.  <p style="text-align: center;">Figure 5-9. Helmet Vent Fan Cable Connection.</p>	<p>Do NOT power ON water pump without connection to LCG or dummy loop. The water pump stalls if the pump is switched on in a closed loop.</p>
EV1	EV1	A.9		
EV2	EV2			

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
			<p><u>LCG flight switch:</u></p> <ul style="list-style-type: none"> <input type="checkbox"/> After installing 3.5 L bladder, connect LCG interface female QD's to LCG male QD's. <u>A secure connection is indicated by a 'click'</u> <input type="checkbox"/> Toggle switch forward and back to turn on water pump. <input type="checkbox"/> Allow the pump to run for 1 minute. <input type="checkbox"/> Observe for any leaks, water/condensation buildup, etc. <input type="checkbox"/> If no leaks are observed, toggle switch forward and back to turn off water pump. <input checked="" type="checkbox"/> If leaks are observed, note the location/tube connection before turning off the water pump. Address as necessary and repeat above steps until no leaks observed. <div style="text-align: center;">  </div> <p>Figure 5-10. LCG Flight Switch.</p> <p><u>Raspberry Pi & Thermal Sensors (If applicable)</u></p> <ul style="list-style-type: none"> <input type="checkbox"/> Press push-button USB-C switch to turn on RPi. <input type="checkbox"/> Verify data is collecting. <input type="checkbox"/> Press push button USB-C switch to turn off RPi. 	
EV1	EV1	A.10	<p>Verify LCG garments staged (correct size):</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) M/L full-body and (x1) XL/2XL full-body LCG, staged, + (x1) backup of each size (XS/S, 3XL/4XL) <input type="checkbox"/> <u>Ensure no fraying or missing O-rings on fluid QDs.</u> <input type="checkbox"/> <u>Ensure no ripped stitching for inside tubing.</u> <input type="checkbox"/> <u>Ensure no leaks observed when testing cooling system.</u> <p>Verify HS3 soft goods staged (correct size):</p> <ul style="list-style-type: none"> <input type="checkbox"/> (x1) S/M and (x1) L/XL HS3 custom soft suit + backup of each <input type="checkbox"/> (x1) Waist inhibitor belt with crotch pool noodle (15 in. - default) + (x1) backup (10 in., 18in) <input type="checkbox"/> (x1) Comfort liner gloves <input type="checkbox"/> (x2) Elbow braces and (x2) Knee braces. <input type="checkbox"/> (x1) Head buff cover and/or (x1) sweat headband 	<p>Verify/Clean laundry, including soft suit and LCG garments the days before each session.</p> <p>Verify all components has no visual damage/fraying</p>

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV2	EV2		<input type="checkbox"/> (x1) Hiking boots, correct size, + insoles, if needed. <input type="checkbox"/> (x4) Padding installed; (x2) on knees, and (x2) on elbows. <input type="checkbox"/> Verify soft suit access ports to LCG on left side are open <input type="checkbox"/> (x4) Velcro patches installed to cover old ventilation holes <input type="checkbox"/> (x4) Wrist ring installed: two on the soft suit, and two on the gloves. As applicable: <input type="checkbox"/> (x1) Treadmill safety harness + (x1) backup. <input type="checkbox"/> (x2) Wire gate carabiners for safety harness temp stowage. <input type="checkbox"/> (x1) Dual carabiner spreader bar, installed to Tuff Tread. <input type="checkbox"/> Verify unused soft suit holes covered with Velcro patches. Verify subject(s) garments staged: <input type="checkbox"/> TCU (thin/base layer) tops and bottoms staged, if subject(s) does not bring own exercise clothing. <input type="checkbox"/> Boot socks, provided by subject(s).	Verify friction fit between soft suit and gloves. Verify adhesive Velcro is not ripping apart or loose.
EV1	EV1	A.11	As applicable: MEVO Camera and app setup <input type="checkbox"/> Verify micro-SD card inserted into MEVO camera. <input type="checkbox"/> Turn on camera and open MEVO app on device: phone/tablet. <input type="checkbox"/> Turn on Wi-Fi, Bluetooth, and location on device. <input type="checkbox"/> Turn on DO NOT DISTURB for notifications on device. <input type="checkbox"/> Plug device into USB charger. <input type="checkbox"/> Open the MEVO app on device. The camera will begin connecting to the app. <input type="checkbox"/> In the MEVO app, press “stream via cellular data” to connect MEVO to Wi-Fi. (<i>FIRST TIME ONLY: Select network and input password to Wi-Fi network.</i>) <input type="checkbox"/> Verify MEVO is connected to Verizon hotspot Wi-Fi and ID#.	For dual ops, perform step using separate phone/tablet. MEVO Camera ID #1: <hr/> MEVO Camera ID #2: <hr/>
EV2	EV2		<input type="checkbox"/> Verify MEVO app is streaming the camera feed to the device <input type="checkbox"/> Press the ellipses button, then “Settings”. <input type="checkbox"/> Ensure “NDI Mode” is turned on at 1080p 7.5 Mbps speeds. Close settings. The record button should now say “NDI”. <input type="checkbox"/> Open NDI Tools webcam app. <input type="checkbox"/> Ensure the PC and MEVO camera are on the same network <input type="checkbox"/> Select “MEVO” as Source 1 in the NDI app.	
EV1	EV1	A.12	Verify sensors/hardware are staged, clean, and operational.	<i>As applicable per study</i>
EV2	EV2			
EV1	EV1	A.13	Verify consumables are staged, and abundant (Recommended consumables below). <input type="checkbox"/> (x1) Fabric sanitizing spray. <input type="checkbox"/> (x1) Cooler, cleaned. <input type="checkbox"/> Clorox wipes. <input type="checkbox"/> Nitrile gloves.	

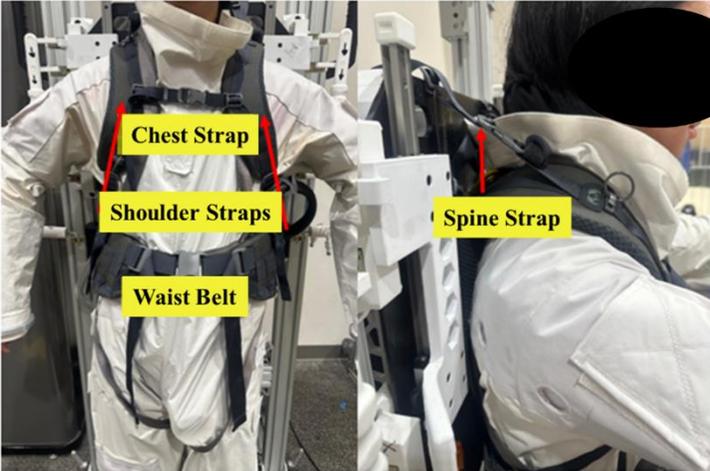
Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV2	EV2		<input type="checkbox"/> Scissors. <input type="checkbox"/> (x1) Laundry bag or trash bag for dirty laundry. <input type="checkbox"/> (x1) Flat head and (x1) Philips screwdriver kits. <input type="checkbox"/> Allen keys (sizes 7/64, 5/16, 5/8, etc.) <input type="checkbox"/> (x1) Trauma shear: for emergency use and for cutting items; <u>verify it is sharp.</u> <input type="checkbox"/> (x1) Soft tailor measurement tape.	

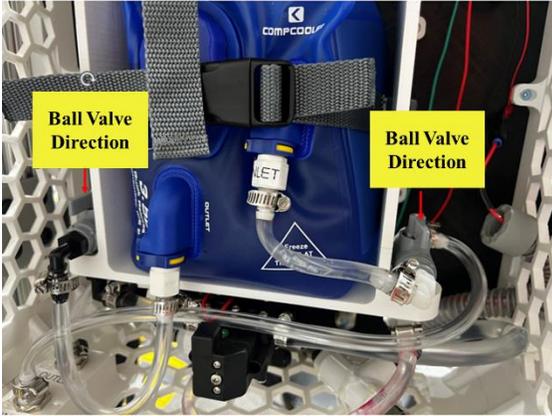
5.1.2 Donning Procedures (Familiarization and Test Sessions; Day of Event)

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
	EV1	B.1	Assist the subject(s) in donning any physiology sensors used in testing.	Study usage specific for sensor usage.
	EV2			
EV1	EV1	B.2	Ask the subject(s) to don garments and any physiologic sensors used: <input type="checkbox"/> (x1) TCU <input type="checkbox"/> (x1) Boot socks <input type="checkbox"/> (x1) Hair buff and/or sweat headband	
EV2	EV2			

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1	B.3	<p>Don LCG garment.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Have subject(s) don LCG; assist with zipper in front. <input type="checkbox"/> Verify LCG fluid QDs are on subject(s) left side. <p>Don elbow braces (x2) and knee braces (x2).</p> <ul style="list-style-type: none"> <input type="checkbox"/> Assist with donning; ensure braces are not restricting blood flow by being too tight (“red” colored side is touching subject). <p>Don ‘waist inhibitor’ foam waistbelt.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Assist with donning; ensure belt loop is snug. <input type="checkbox"/> Connect saddle strap through the legs of the subject <input type="checkbox"/> Ensure the pool noodle between the leg is secured by adjusting the slides along the strap to the desired position. <input type="checkbox"/> Verify pool noodle is not protruding more than 4 inches in front or behind the subject. <input type="checkbox"/> Ensure waist inhibitor is below subject(s) hips/waist as to not interfere with HS3 waistbelt/spine positioning and offloading. <input type="checkbox"/> <u>Ensure fluid QDs for LCG are above the waist inhibitor belt.</u>  <p>Don HS3 soft suit (from the back).</p> <ul style="list-style-type: none"> <input type="checkbox"/> Have subject(s) step into soft suit garment – ensure zipper is on backside of subject(s). <input type="checkbox"/> Feed LCG hoses through the opening on the left side of the soft suit; secure hoses in hole using Velcro. <input type="checkbox"/> Zip up back zipper carefully. <input type="checkbox"/> Ensure waist inhibitor is below subject(s) hip/waist. <input type="checkbox"/> Adjust the vertical Velcro (x4) flaps to secure loose material. <input type="checkbox"/> Roll loose fabric on neck of soft suit down, secure with Velcro. 	<p>(TEST ONLY) Log the time of complete soft suit donning:</p> <p>EV1:</p> <p>EV2:</p> <p>If the pool noodle between the legs does not fit in the small soft suit due to limited crotch size of suit, downsize to a smaller pool noodle.</p>

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV2	EV2		<p><input type="checkbox"/> Verify soft suit knee pad placement by having the subject(s) practice kneeling on both legs and confirm proper placement.</p> <p>Don boots.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Ensure the foot stirrup on the soft suit is underneath the subject(s) foot once donning boots. <input type="checkbox"/> Assist the subject(s) in tucking excess fabric from soft suit into boots, then tightening the boots. <p>Don safety harness.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Demonstrate to subject(s) how to don safety harness. <input type="checkbox"/> Have subject(s) step into/put on harness – refer to Section 9.4 for instructions. <input type="checkbox"/> Use a small carabiner to temporarily secure loose ends of the safety harness at the subject(s) upper back. <div> </div> <p>Figure 5-12. Donning of Soft Suit, Boots, and Safety Harness.</p>	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1		<p>Ingress subject(s) into/don HS3 soft goods mounted to backplate: waistbelt, shoulder straps, chest strap.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Ensure all straps are loosened before subject(s) donning. <input type="checkbox"/> Ensure 3DP HUT is disconnected from the HS3 assembly before subject(s) donning. <input type="checkbox"/> Ensure height of donning stand frame matches with subject(s) waist height before subject(s) donning. Lock frame into place using the handles (x2) on the back of the donning stand. <input type="checkbox"/> Adjust shoulder padding height and spine as needed. <ul style="list-style-type: none"> o <u>Ensure no large gaps are between shoulder and padding. Maximize contact while not tightening down straps. Lumbar pad is nested in lower back.</u> <input type="checkbox"/> Have subject(s) back into the donning stand. <input type="checkbox"/> Have subject(s) feed arms through shoulder straps into a comfortable position. <input type="checkbox"/> Connect, tighten waistbelt above the waist inhibitor belt. <ul style="list-style-type: none"> o Ensure waistbelt sits properly onto subject(s) iliac crest/hips. o Ensure safety harness sits BELOW waist belt and all straps. <input type="checkbox"/> Assist with tightening shoulder straps down with even tightness on both shoulders. <input type="checkbox"/> Assist with connecting, tightening upper chest strap underneath subject(s) chin. <input type="checkbox"/> Assist with adjusting, tightening the straps on top of the spine to the top of the shoulder padding to correct vertical posture/leaning (approx. 30-45deg angle – snug but not too tight). <ul style="list-style-type: none"> o Ensure the safety harness sits underneath all strap buckles and padding. o <u>Ensure LCG fluid QD's are not kinked (at 90deg bend) and are accessible.</u> 	
EV2	EV2	B.4	 <p>Figure 5-13. Straps for Waistbelt, Shoulders, Chest, Spine.</p>	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1	B.5	<p>Install 3.5L bladder for LCG into PLSS.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Retrieve DI H₂O-filled 3.5L bladders (x2) from the cooler. <input type="checkbox"/> Wipe off condensation from surfaces using towel. <input type="checkbox"/> Place onto the LCG shelf in the PLSS. <ul style="list-style-type: none"> ○ If bladder does not fit, run or add warm water to the bladder and shake gently. <input type="checkbox"/> Secure the bladder using the belt buckles. <input type="checkbox"/> Connect the internal tubing to the bladder. Verify connection per figure below and “click” sound. <ul style="list-style-type: none"> ○ From left Ball valve, plug in the fluid QD hose into the “Outlet” port of the LCG bladder. ○ From right Ball valve, plug in the fluid QD hose into the “Inlet” port of the LCG bladder. ○ “Left -> Outlet, Right -> Inlet” ○ <u>Ensure O-rings on male fluid QD’s intact.</u> <input type="checkbox"/> Verify no kinks in tubing once connected to bladders. <input type="checkbox"/> Ensure ball valves pointed away from subject. (points towards the operator who is facing the PLSS)  <p>Figure 5-14. (From Section A) Bladder Tubing Configuration.</p>	<p>(TEST ONLY) Log the time of complete LCG + tubing donning:</p> <p>EV1:</p> <p>EV2:</p>

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV2	EV2		<p>Connect fluid QD's from LCG garment to PLSS.</p> <ul style="list-style-type: none"> □ Connect the (x2) male fluid QD's from the LCG garment into the (x2) female fluid QD's fed from the bottom left of the PLSS/Backplate. <ul style="list-style-type: none"> ○ <u>Ensure O-rings on fluid QD's intact, no visual damage.</u> ○ Secure with Velcro to shoulder strap, avoid kinking tubing.  <p>Figure 5-15. HS3 Shoulder Strap to Fluid QD Connection.</p> <ul style="list-style-type: none"> □ Power on PLSS Power Bank by pressing/holding 3 seconds on the power button until the LED display lights up. □ Verify switch and no leaks or bubbles after attaching HUT 	
EV1	EV1	B.6	<p>Have the subject(s) egress the donning stand.</p> <ul style="list-style-type: none"> □ Lower the inner frame of the donning stand using the braking handles and by having the subject do a partial (quarter) squat. Break the handles on the inner frame. □ Gently press the handles of the hard capture mechanism forward about 30 degrees (<u>handle #1</u>). □ Have the subject(s) lift the PLSS by standing on their tip toes, then release the handles on the hard capture mechanism. □ Ensure the HS3 backplate base clears the hard capture mechanism before proceeding. 	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV2	EV2		<div> </div> <p>Figure 5-16. HS3 Backplate Clearance.</p> <ul style="list-style-type: none"> □ Subject(s) or operator to gently press down on the two handles of the soft capture mechanism to release the backplate from the donning stand completely <u>handle #2</u>). □ Have the subject(s) lean forward and slowly walk forward and straight out of the donning stand. □ Subject(s) can walk normally once cleared of the donning stand frame. □ (As needed) Adjust shoulder straps, waistbelt, and chest straps for better fit once guided out of donning stand by doing a diver's tuck <div> </div> <p>Figure 5-17. Steps for Egressing Donning Stand.</p>	

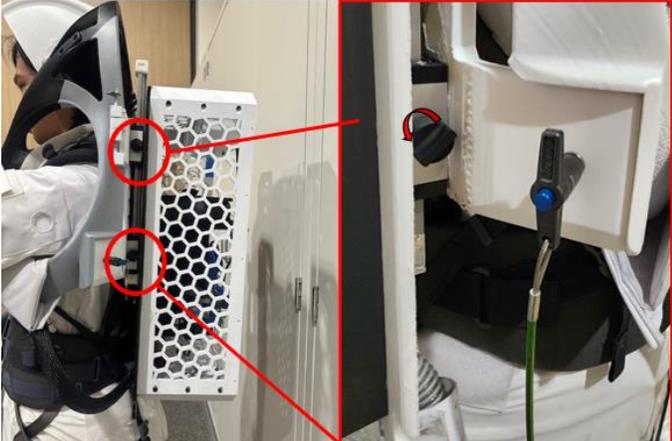
Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1		<p>Connect HUT to Backplate. Assist with donning the HUT.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Have subject(s) hold arms out in front of them at chest level. <input type="checkbox"/> Wrap HUT arm canvas covers (x2) around the bottom of the arm holes to mitigate friction from 3DP HUT pieces. <input type="checkbox"/> Assist subjects(s) to feed arms and head through HUT holes. <input type="checkbox"/> Use the spring-loaded pip pins (x4 per HS3) to fasten the HUT at its connection points to the struts on the backplate carriage rails. <input type="checkbox"/> Connect visor fan (x1) to USB port in PLSS and power inline sliding switch to “H” (high). <p>Adjust HUT Height via the Carriage Rail System.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Loosen the thumb screws (x4) CCW on the rail carriages (x4) mounted to the aluminum rails on the backplate. <input type="checkbox"/> Gently slide the HUT and carriages up or down the rail to adjust the height based on subject(s) fit. <ul style="list-style-type: none"> <input type="checkbox"/> DO NOT FORCE CARRIAGES TO MOVE <input type="checkbox"/> Adjust up if subject(s) crown/hair are touching the inner dome of the helmet visor. <input type="checkbox"/> Adjust down if subject(s) chin/neck are stiff or straightened or if the chin is close/resting on HUT helmet ring. 	<p>(TEST ONLY) Log the time of complete HUT/helmet visor donning:</p> <p>EV1:</p> <p>EV2:</p>
EV2	EV2	B.7	<ul style="list-style-type: none"> <input type="checkbox"/> Head should be centered in helmet “bubble space. <input type="checkbox"/> Arms should be centered in arm holes during T-pose <input type="checkbox"/> Ensure the carriages/HUT are even before finishing adjustment. <input type="checkbox"/> Tighten the thumb screws (x4) on the carriages once the fit is proper to finish height adjustment of the HUT. 	

Figure 5-18. HUT Connections + Height Adjustment Carriages.

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1		<p>Verify switch and cooling system no leaks/bubbles</p> <ul style="list-style-type: none"> <input type="checkbox"/> Detach the switch from the back. 	
EV2	EV2	B.8	<div style="text-align: center;">  </div> <p>Figure 5-19. (from Section A). LCG Switch Stowage Location.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Demonstrating to subject, close switch to turn on LCG <input type="checkbox"/> Watch for bubbles or leaks for 1 minute. <input type="checkbox"/> Demonstrating to subject, flip switch open to turn off system. <input type="checkbox"/> Attach switch to Velcro on HUT horizontal, as depicted below. <div style="text-align: center;">  </div> <p>Figure 5-20. LCG Switch HUT Location.</p>	
EV1	EV1	B.9	<p>If applicable:</p> <ul style="list-style-type: none"> <input type="checkbox"/> Verify the MEVO camera is securely mounted to the HUT. <input type="checkbox"/> Verify the MEVO camera feed is streaming. 	
EV2	EV2			
EV1	EV1	B.10	<p>Have the subject(s) don the bone conduction headphones.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Verify Bluetooth connection via comm check. Reconnect if needed. 	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV2	EV2			
EV1	EV1	.11	<p>Don comfort gloves/HS3 gloves.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Subject(s) don 'comfort gloves' (x2). <input type="checkbox"/> Subject(s) don the appropriately sized HS3 gloves (x2). Assist with securing the fingers/pushing fingers across to correct fit. <input type="checkbox"/> Secure the 3DPT wrist gauntlet (x2) via friction fit to the wrist rings (x2) installed on the soft suit arms. <input type="checkbox"/> Secure the Velcro covers on the gloves/no loose fabrics. 	<p>(TEST ONLY) Log the time of complete glove donning:</p> <p>EV1:</p> <p>EV2:</p>
EV2	EV2		 <p style="text-align: center;">Figure 5-21. Glove Fit and Connections.</p>	
EV1	EV1	B.12	<p>Final Verifications/Checkouts.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Verify the safety harness is not loading onto any HUT or soft suit/shoulders or waistbelt components. <input type="checkbox"/> Verify stowage of any loose fabrics, straps, etc. 	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV2	EV2		<input type="checkbox"/> Verify carabiner for safety harness slack accessible from back. <input type="checkbox"/> Verify soft suit knee pad position is comfortable <input type="checkbox"/> Verify with subject(s) on any needs for final adjustments <input type="checkbox"/> Verify subject(s) comms are still operational/GO. Cover the PLSS with white dust cover. If using COSMED, do NOT cover air inlet on top of COSMED K5 cart (black rubber cap by antenna).	
				
			Figure 5-22. PLSS with Dust Cover Installed.	
EV1	EV1	B.13	Take pictures (front, left, right, back) + T-pose + kneeling of subject(s) when HS3 is fully donned/configured.	
EV2	EV2			
	EV1	B.14	Start MEVO Camera recording via MEVO app on phone/tablet by pressing the SD card button, then the red “Record” button.	
	EV2			

5.1.3 Doffing Procedures (Familiarization and Test Sessions)

Table 5-2. HS3 Doffing Procedures

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1	C.1	Assist with doffing the gloves/glove liners. <input type="checkbox"/> Disconnect wrist rings from soft suit and gloves. <input type="checkbox"/> Gently pull at the fingertips of the gloves to doff gloves. <input type="checkbox"/> Remove glove liners to the dirty laundry bag.	(TEST ONLY) Log the time of complete glove doffing: EV1: EV2:
EV2	EV2			

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1	C.2	<p>Remove the LCG switch</p> <ul style="list-style-type: none"> <input type="checkbox"/> Detach the switch from the HUT. <input type="checkbox"/> Attach the switch to the back of the PLSS, ensuring switch will clear donning stand latches. <input type="checkbox"/> Power off LCG with switch. 	<p>(TEST ONLY) Log the time of LCG power off EV1: EV2:</p>
EV2	EV2		 <p>Figure 5-23. (from Section A). LCG Switch Stowage Location.</p>	
EV1	EV1	C.3	<p>Assist with doffing the HUT.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Release/pull up and out the spring-loaded pip pins (x4) fastening the HUT to the backplate struts/carriage rail mounts. <input type="checkbox"/> Subject(s) hold their arms out straight at chest level. <input type="checkbox"/> Pull the HUT off the subject(s) through the arm/ head holes. 	<p>(TEST ONLY) Log the time of complete HUT/helmet visor doffing: EV1: EV2:</p>
EV2	EV2			
EV1	EV1	C.4	<p>Doff earbuds/headset and return to charging station after cleaning/sanitizing.</p>	
EV2	EV2			
EV1	EV1	C.5	<p>Dock the HS3 PLSS into the donning stand.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Guide/Align subject(s) slowly back into the donning stand. <input type="checkbox"/> Have subject(s) lean forward and step on their tip toes. <input type="checkbox"/> Align HS3 backplate into the hard capture mechanism. <ul style="list-style-type: none"> o Have subject(s) slowly walk back into donning stand until grooves are partially slotted in hard capture mechanism. Have the subject(s) straighten back to snap into soft capture, then lower themselves into hard capture. 	<p>Ensure the hard capture mechanism and the soft capture mechanisms are ALL engaged/locked in place before continuing to doff the HS3 from the subject(s).</p>
EV2	EV2		 <p>Figure 5-24. Steps for Ingress Donning Stand.</p>	
EV1	EV1	C.6		

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV2	EV2		<input type="checkbox"/> Place a dry towel underneath LCG QDs to catch water <input type="checkbox"/> Disconnect LCG QDs from the left side of the LCG garment	
EV1	EV1	C.7	Loosen/disengage all soft straps <input type="checkbox"/> Loosen waistbelt; disengage belt. <input type="checkbox"/> Loosen shoulder straps and spine-to-shoulder straps. <input type="checkbox"/> Loosen chest/neck strap; disengage belt. <input type="checkbox"/> If carabiner is clipped into soft handle on spine, disengage carabiner.	
EV2	EV2			
EV1	EV1	C.8	Have subject(s) slowly egress donning stand. <input type="checkbox"/> Ensure no loose straps/safety harness pull or tug or are hooked onto HS3/donning stand.	
EV2	EV2			
EV1	EV1	C.9	Assist with doffing the soft goods. <input type="checkbox"/> Have subject(s) drop/doff safety harness to floor. <input type="checkbox"/> Remove Velcro strap from fluid QD's fed outside the soft suit. <input type="checkbox"/> Have subject(s) sit down and doff boots (pull/click circular tab outward to release lacing). <input type="checkbox"/> Have subject(s) stand up. Unzip soft suit to doff. <input type="checkbox"/> Assist with doffing elbow braces (x2) and knee braces (x2) and waist inhibitor belt (x1).	
EV2	EV2			
EV1	EV1	C.10	Have subject(s) doff garments and any physiologic sensors and change into fresh clothes. <input type="checkbox"/> Have subject(s) unzip LCG garment and doff. <input type="checkbox"/> Any physiology sensors used <input type="checkbox"/> (x1) TCU (thin) top and bottom <input type="checkbox"/> (x1) Boot socks <input type="checkbox"/> (x1) Hair buff/sweat headband	Ask subject(s) to change in locker room area.
EV2	EV2			

5.1.4 Clean-up Procedures

Table 5-3. HS3 Clean-up Procedures

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
EV1	EV1	D.1	Power down and charge all devices.	As applicable per study
EV2	EV2			
EV1	EV1	D.2	Empty out LCG garment and LCG bladders. <input type="checkbox"/> Empty out LCG garment by hooking up empty bladder to the liquid cooling system, then powering ON switch #1 for 1 minute. Power OFF, then disconnect bladders and LCG garment. <input type="checkbox"/> Dispose of water in all bladders down a clean sink. <input type="checkbox"/> Hang and allow bladders to air dry.	
EV2	EV2			

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
		D.3	<p>Sanitize/laundry softgoods.</p> <ul style="list-style-type: none"> <input type="checkbox"/> Fabric spray the following items, then allow to air dry. <ul style="list-style-type: none"> ○ (x1) Soft suit – Spray outside and inside ○ (x1) LCG ○ (x1) Pair of HS3 gloves ○ (x1) Safety harness ○ (x1) Pair of boots ○ (x1) Pair of glove liners ○ (x1) Hair buff <input type="checkbox"/> After air dry, wash items below after 10 uses. <ul style="list-style-type: none"> ○ Soft suit (x1) – Machine wash/dry. ○ LCG (x1) – Machine wash/dry. ○ Pair of glove liners (x1) – Machine wash/dry. ○ Hair buff (x1) – Machine wash/dry. ○ TCU (thin) tops and bottoms (x1) – Machine wash/dry. 	<p>If dual ops: double quantity require for cleanup</p> <p>Remove 3DPT adapters from soft suit and knee/elbow before spraying/washing.</p> <p>Wash in a <u>delicate laundry bag (cold temp.)</u>, then dry <u>them on a delicate cycle/low temp.</u></p>
		D.4	Sanitize headphones and any biosensors applied to study using a Clorox disinfectant wipe.	

5.2 Maintenance and Cleaning

5.2.1 HS3 Maintenance

For maintaining HS3 hardware, the thermal control system is required to be purged after every use. Purging this system prevents any particulate buildup within thermal tubing from the water pump to the LCG. To purge water from the system, an empty bladder must be connected to the water pump with the LCG installed. Run the system until water from LCG is collected in the bladder. Note that not all water will be completely removed from the system and droplets of water may be seen in the cooling lines to the pump.

For long-term maintenance, after 10 use cycles, laundering is required. The soft suit, LCG, glove liners, hair buff, and athletic clothing can be laundered in a delicate laundry bag in cold temperature water and dried on delicate low heat cycle. Prior to laundering soft suit, removal of 3DPT adapters and padding is required to avoid damage.

5.2.2 HS3 Cleaning

Due to multiple subjects using HS3 and the associated risks of contamination, sanitization is required after each use. Soft goods such as the soft suit, LCG, safety harness, boots, glove liners, and hair buff must be sanitized using Clorox fabric spray then allowed to air dry.

Optional bioinformatic sensors (COSMED metabolic cart) with direct skin contact requires use of a Neutral Disinfectant Cleaner or similar, per manufacturer recommendations. When using Neutral Disinfectant, read all manufacturer instructions and warnings to prevent damage to hardware or hazard to subjects.

5.2.3 3D Print Parts Maintenance - Acetone Patching

This section documents and details the how to repair 3D prints or bond multi-part prints through the preparation, use, and safety considerations for Acrylonitrile Butadiene Styrene (ABS)-Acetone mixtures.

5.2.3.1 Overview

Acetone is an effective solvent for ABS. When combined, the acetone partially dissolves the ABS, allowing it to act as an adhesive, filler, or surface smoother depending on the mixture ratio. This process is applicable for ABS-based 3D prints.

5.2.3.2 Hazards and Warnings

Use proper personal protective equipment (PPE) when grinding/cutting ABS. Common hazards are listed below.

Table 5-4. Hazard Warnings for ABS Repair Process

Type	Hazard description	Suggested Mitigation
Fire	<p>FLAMMABLE</p> <ul style="list-style-type: none"> ❖ Vapor trails are flammable, and flashback may occur. ❖ Vapor can be explosive in enclosed areas. ❖ Acetone is highly flammable. Keep away from heat, sparks, and open flames. ❖ Water may be ineffective against fire. 	<ul style="list-style-type: none"> ➤ Always work in a well-ventilated area or use respirator. ➤ Extinguish with dry chemical, alcohol foam, or carbon dioxide. ➤ Store container in Flame-proof cabinet.
Exposure	<p>DO NOT INDUCE VOMITING CALL FOR MEDICAL AID</p> <ul style="list-style-type: none"> ❖ Irritating to eyes, nose, and throat. ❖ If inhaled, may cause difficult breathing or loss of consciousness. ❖ Liquid is irritating to eyes. 	<ul style="list-style-type: none"> ➤ Move to fresh air. ➤ Stopped breathing: give artificial respiration. ➤ Difficult breathing: give oxygen. ➤ Flush eyes out with water.
Water Pollution	<ul style="list-style-type: none"> ❖ Dangerous to aquatic life in high concentrations. ❖ May be dangerous if it enters water intakes. 	<ul style="list-style-type: none"> ➤ Treat as industrial solid/hazardous waste when managing unusable product.

For more information on Acetone, refer: ([ACT.pdf](#))

5.2.3.3 Materials

The amount of acetone and ABS required will vary based on the repair type and size. See table below for common solution options.

Table 5-5. ABS-Acetone Solution Types

Type	Usage	Consistency	gram ABS / 10 mL Acetone
Juice	Adhering prints to the bed.	Milky	1 g ABS / 10 mL acetone
Glue	Small layer separations and bonding multi-part prints.	School Glue	2 g ABS / 10 mL acetone
In-house rec.	Noticeable layer separations/warping	Goopy Paste	4 g ABS / 10 mL acetone
Slurry	Gap filling and structural patching.	Thick Paste	5 g ABS / 10 mL acetone

Alternatively, a patch can be printed to be fused onto the print using acetone as a glue.

Table 5-6. Materials for ABS-Acetone

#	Materials	Notes
1	100% pure acetone	In an acetone-compatible, airtight container.
2	ABS filament or scrap	Cut into small pieces to aid in dissolving faster
3	Mixture storage container	An acetone-compatible, airtight container.
4	Eye protection, respirator, and nitrile gloves	Personal Protection Equipment (PPE)
5	Optional: Mixing stick or stirring tool	Mixing by swirling within the container is sufficient.
6	Optional: Scale and beaker	For more precise measurement accuracy.

5.2.3.4 Procedure

1. Cut ABS into smaller pieces to speed up dissolution.
2. Set up in a well-ventilated area with all PPE properly donned.
3. Add acetone to a container at the desired volume, label with the ABS-Acetone ratio.
4. Measure and add ABS to the acetone based on target mixture, listed in Table 5-5. ABS-Acetone Solution Types
5. Mix using a stir stick or cap the container and mix by swirling.
6. Seal the container and let sit overnight (~8 hours). Stir occasionally if desired.
7. Adjust the ratio by adding more acetone or ABS if mixture is not at desired consistency.

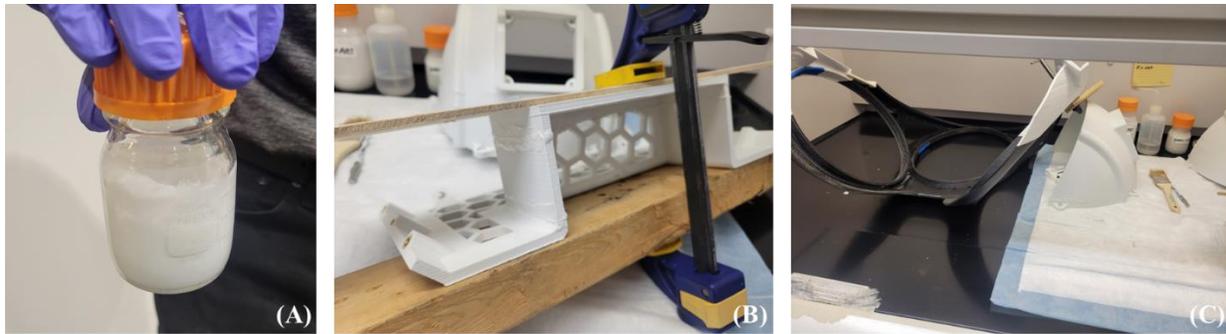


Figure 5-25. ABS 3DPT Repair.

(A) ABS glue mixture, (B) apply appropriate pressure to facilitate the curing process, and (C) conduct ABS 3DPT repair in well-ventilated area (e.g., vent hood).

5.2.3.5 Usage

1. Apply solution with a brush or tool in well-ventilated area with all PPE properly donned.
2. For bonding, apply to both surfaces and clamp together for 5-10 mins. Let cure for 12-24 hours.
3. For gap repairs, completely fill the void. Allow 15-30 minutes for surface curing and 24-48 hours for core structural strength.
4. ABS solution cures best at room temperature. Elevated temperatures may reduce bond strength.

5.2.3.6 Storage

1. Store labeled mixture in a sealed, acetone-compatible container (glass or low-density polyethylene).
2. Keep the mixture away from heat and sunlight.
3. If the mixture begins to thicken, add acetone and stir.
4. Reapply glue layers if bonding effectiveness decreases.

5.3 Recommended Training

When operating or maintaining the HS3 hardware during testing sessions, operators shall be competent in performing the corresponding duties correctly and safely. Operator training objectives include the review/operation of DTP steps, test checklists (TCL) for specific studies, and awareness of hazardous conditions and responses for a given study. It is recommended that operators complete end-to-end dry runs, following the DTP and TCL, a minimum of two times prior to subject test sessions. Also, it is recommended operators be familiar with emergency egress/test termination choreography to perform in a timely manner.

5.4 Storage

For all HS3 modular systems, keep stored in dry, room temperature environment. For ease of locating, 3DPT systems can be installed and stored on the donning stand while soft goods can be storage in a cabinet or clothing rack. It is suggested to hang all fabric materials where possible.

5.5 Hazard

There are potential hazards associated with HS3 donning, use and doffing (both nominal and emergency egress). **Hazardous conditions could lead to personal injury or hardware damage, and NASA is not responsible for injury or misuse of the HS3.** To mitigate such conditions, the controls listed in Table 9-6 in Appendix F: HS3 Hazards and Controls for Reference should be followed accordingly; all hazards for specific tests need to be assessed by institutions conducting the test.

6 Characterization

Two HS3 characterization pilot studies have been completed to date: the HS3 1.0 Study (2024 “HS3 Characterization” Study) [12] and the HS3 2.0 Study (2025 “HS3 Configuration Update” Assessment Study). The two studies use the same test protocol, timeline, environment, procedures, and sensors. **The objectives of the characterization studies were to:**

1. Benchmark HS3 workload performance envelope (physical, cognitive, and thermal).
2. Characterize HS3 subsystem operational capacity and characteristics.
3. Determine suit simulation fidelity via subjective feedback.

Numerous critical suit upgrades were identified during the HS3 1.0 study (n=8), and these changes were implemented into the HS3 2.0 suit subsequently. Thus, the HS3 2.0 study aimed to characterize changes in the above three objectives due to suit hardware upgrades and iterations. The HS3 2.0 study was conducted as a short point verification test series (n=3) including repeat subjects from the original 1.0 cohort. All subjects had suited experience in high-fidelity pressurized space suits in 1G ground analogs, partial-G analogs, and/or in spaceflight. Although additional critical comments from HS3 2.0 led to HS3 2.5 suit hardware upgrades, the types of changes were not considered significant enough to affect the three objectives above, and the net change between 2.0 to 2.5 is expected to be enveloped by HS3 1.0 and 2.0 results.

This section presents the HS3 1.0 and 2.0 test characterization pilot study methods and results to help benchmark the HS3 performance and capability related to the three objectives above. HS3 Characterization Testing Methods

6.1.1 Test protocol and timeline

Eight subjects (5F, 3M) with prior pressurized suited experience participated in the characterization testing for HS3. One of the subjects was an active-duty NASA Astronaut, while the other seven were experienced test subjects with experience in 1G suit simulators (EXCON ATLAS) and pressurized space suits (EMU, xEMU, MKIII) in a wide range of environments (field, ARGOS, NBL, partial gravity simulator (POGO), and/or parabolic flight). The subject range covered from 31% female to the 96% male in respect to stature, and 11% female to 95% male in weight. See Table 6-1 for subject demographics.

**Table 6-1. Subject Demographics of the HS3 1.0 Characterization Study.
(3 subjects from HS3 1.0 study cohort participated in HS3 2.0 study)**

Subject Demographics							
	Age (years)	Weight (lbs)	Height (in)	Peak HR (bpm)	VO2 Peak (ml/kg/min)	Body Fat (%)	BMI
Mean	37.5	161.7	67.8	185.4	37.5	28.5	24.5
SD	6.0	31.5	3.5	8.8	5.1	3.6	2.5

The characterization assessment involved a 3-hour simulated EVA in the non-VR B21 APACHE space. [6]. Each subject had a familiarization session prior to their data collection simulated EVA. The EVA timeline was largely based of the Physical and Cognitive Exploration Simulations (PACES) procedures that are commonly used in HH&P EVA testing [14, 15, 16]).

The study built in 3-minute rest periods between stand-alone tasks so that subject's physiological measures could return to baseline and data were attributable to specific tasks and task types. The EVA tasks were designed so that subjects could reach a steady state workload. Additionally, the selected tasks were representative of EVA tasks that crew will conduct on planetary exploration missions. Certain parameters, such as walking speed, distance, gradient/resistance, and task order, were controlled to reduce confounding factors to the data analysis. Table 6-2 Table 6-2 shows the simulated EVA timeline for the HS3 characterization study.

Table 6-2. EVA Timeline for HS3 Characterization Study
(Note: equipment hot swap occurs as needed, so exact time varied)

EVA Timeline Tasks	Planned Task Time
Pre-test + Sensor Setup	1:00
Pre-Test Data Collection + Suit Donning	0:55
Baseline Data Collection/Mounting	0:05
Traverse station 1: 500m (Resistance 3/4)	0:10
2.5-min Break + Surveys	0:03
Task Board Station	0:05
2.5-min Break + Surveys	0:03
Traverse station 2: 500 m (Resistance 7/8)	0:10
2.5-min Break + Surveys	0:03
Geology Station 1: Trenching	0:05
2.5-min Break	0:03
Geology Station 2: Chip Sample hammering)	0:05
2.5-min Break	0:03
Geology Station 3: Raking	0:05
2.5-min Break + Surveys	0:03
Traverse station 3: 500m (Resistance 5/6)	0:10
2.5-min Break + Surveys	0:03
Object Relocation station: 10lb Small, rocks	0:03
2.5-min Break + Surveys	0:03
Object Relocation station: 20lb Large, rocks	0:03
2.5-min Break + Surveys	0:03
Suit Doffing	0:15
Post test surveys + data collection (cognition)	0:30
Data Download + Cleanup	0:30
Total Planned Time (Test team, End to End)	4:20
Total Planned Time (Subject, End to End)	3:10
Total Planned Time (Subject Suited Time)	1:45

6.1.2 Test environment and procedures

6.1.2.1 Environment

HS3 was tested in the APACHE facility, which provides a 1G simulated planetary EVA environment. This facility at the NASA Johnson Space Center, consists of a 6.1-meter x 4.6-meter sandbox and a passive treadmill (Skillmill Connect, Technogym, Italy). Within the sandbox, a variety of EVA task simulations were placed for this study such as a task board station, geology station, and payload transfer station as shown in Figure 6-1.

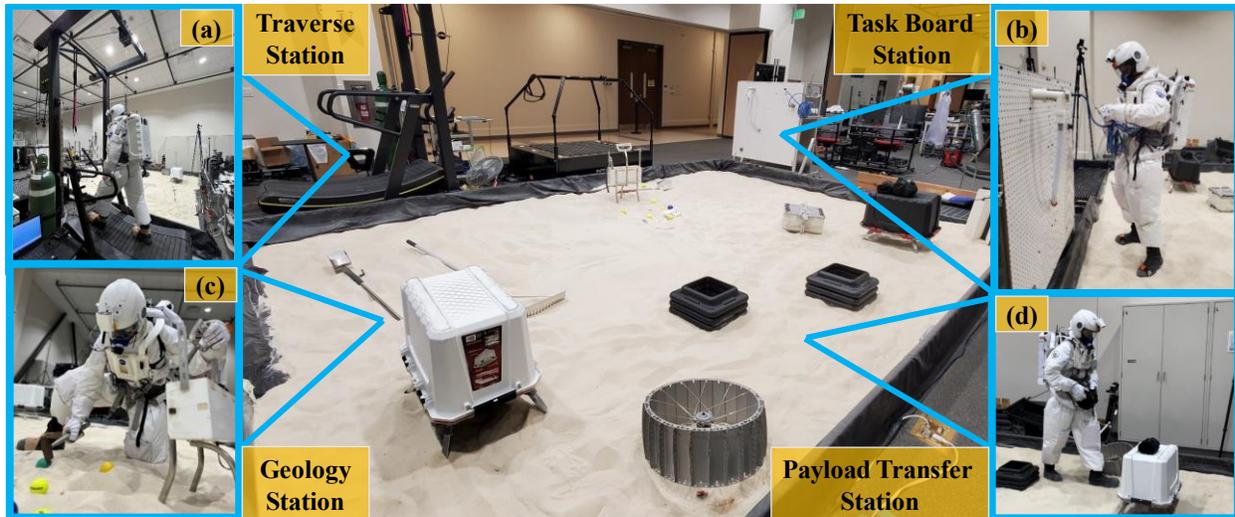


Figure 6-1. APACHE Test Environment.

a) Traverse station, b) Task board station, c) Geology station, and d) Payload transfer station (objective relocation)

Traverse station

This station utilizes a curved, passive treadmill (Skillmill Connect, Technogym, Italy) with ten user-controllable incremental resistance levels. To evaluate the effects of the HS3 on physical workload, the test used three resistance levels that mimic equivalent traverse terrain grade commonly simulated in the ARGOS lunar suited simulation. Resistance 5/6 setting is also relatable to shirtsleeve Martian workload.

These resistances have been compared to both the JSC rock yard and different percent-grade inclines on a motorized treadmill used for ARGOS pressurized suited testing. The gait trends at ARGOS matched the resistance levels for the passive treadmill according to Table 6-3. To keep the traverse station comparable and to simulate lunar suited walking speeds, the subject were instructed to self-

Table 6-3. Passive treadmill resistance levels with comparable gait trends of the ARGOS motorized treadmill percent grade inclines [6].

Passive Treadmill Resistance Level	Motorized Treadmill % Grade at ARGOS
3/4	0%
5/6	10%
7/8	20%

pace at 2 mph for the HS3 characterization study [6].

The subjects performed traverse tasks at various passive treadmill resistance level shown in Table 6-3 for distances ranging from 500 to 2000m along the task timeline shown earlier Table 6-2. These traverses were spaced between tasks to simulate an EVA mission timeline where tasks were in dispersed locations.

Subjects were equipped with a custom-made full body safety harness system (GM1611 25mm Tubular webbing, GM Climbing, Beijing, China). The tubular webbing was made of High Tenacity Nylon 6,6 materials rated to 4000 lbs (17.8 kN) and UIAA certified (UIAA-103). The ends of the harness were joined by a water knot as shown in Figure 6-2 Figure 6-2, which has a 64% efficiency of load, supporting an effective load of 2560 lbf. The harness was connected to the APACHE passive treadmill as a subject positioning system using two carabiners with 25 kN major axis strength (Petzl OK Oval Screw-Gate Locking Carabiners, REI Inc) to keep subject centered on the treadmill during traverse tasks.

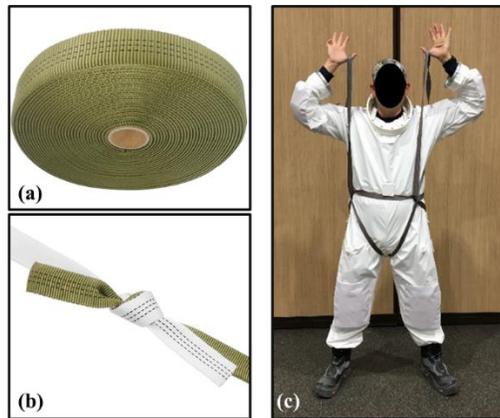


Figure 6-2. Safety Harness.

a) Nylon Webbing, b) Water Knot, and c) Fireman's Harness

Geology station

This station consisted of subjects using a tool caddy, scoop, rake, hammer, and simulated rock samples (medicine balls). To evaluate the mobility and functionality of the HS3, trenching, hammering, and raking tasks are performed to simulate relevant geology tasks for early lunar EVA missions. The subject used the scoop tool to trench an area (4' x 4'), a hammer to collect the chip samples, and a rake to perform racking task, as shown in Figure 6-3.

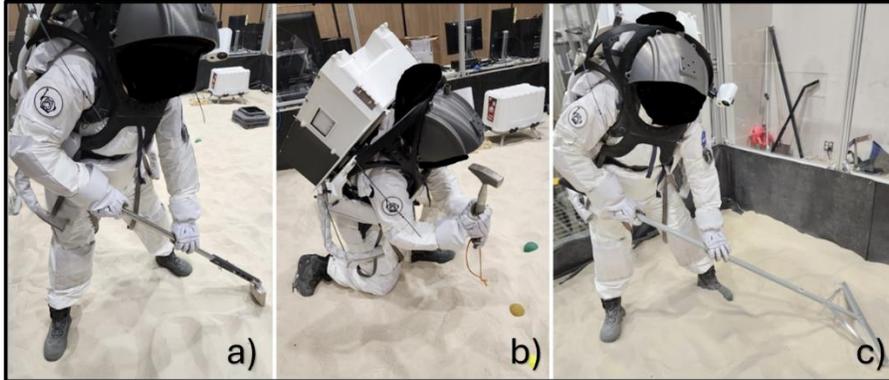


Figure 6-3: Geology Station Tasks.
 a) trenching, b) hammering, c) raking

Task board station

This station consists of a 3D printed model NASA zero-gravity lever (NZGL) connector, a 3D printed simulated radioisotope thermoelectric generator (RTG), thick gauge copper wire ties to mimic flight cable ties, and a 3D printed fluid quick disconnect (FQD) with cables. To evaluate the dexterity of the HS3, the test provided a five-minute block where the subject completed a circuit to mate and de-mate the NZGL connector, connect the NZGL cable to the RTG, and perform cable management with copper wire ties, mating and de-mating a FQD cable and stowing cables. These tasks simulated common engineering and maintenance tasks during EVA.

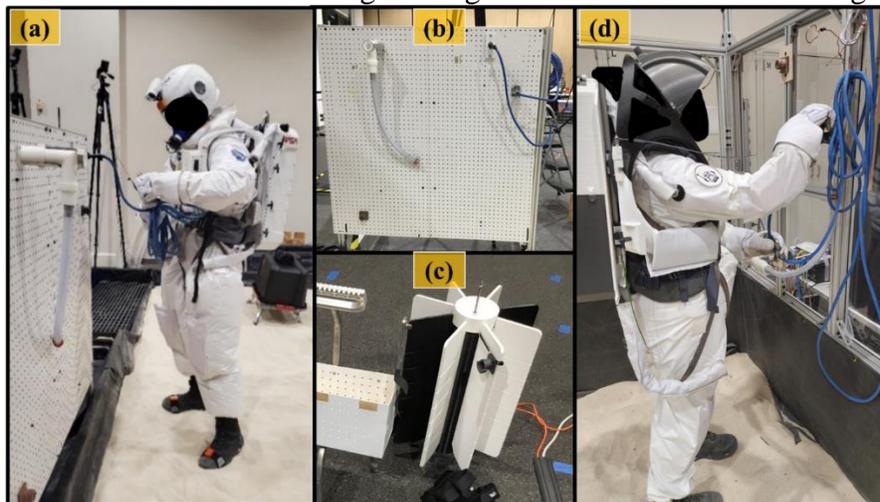


Figure 6-4: Task board Station Setup.

a) Subject using the task board, b) task board layout, c) RTG simulator, d) alternative task board setup.

Payload transfer station (object relocation station)

The payload station consisted of black weight bags of 7 and 13 lbs. (averaging to be 10 lbs.), yellow weight bags of 17 and 23 lbs. (averaging to be 20 lbs.), and two small platform containers. To test the subjects' coordination in the HS3, the bags were moved between two platforms approximately 5 meters apart. Between the two platforms, there were 16" x 16" x 8" "half-cube" obstacles placed off-centered along the walking path to simulate obstacle avoidance during EVA, as in Figure 6-5.



Figure 6-5: Object Relocation Station Setup

6.1.2.2 Sensor Instrumentation and Data Collection

The table below shows a summary of all the variables collected during HS3 characterization study (Table 6-5).

Table 6-4. Variables Collected During the HS3 Characterization Study and Associated Equipment.

Available Measures	Equipment or Survey	Data	Domain
Pre-exposure injury	Suit Exposure Worksheet	Suited experience	Suited experience comparison
Suit Weight	Subject weight and suited weight	$W_{\text{SUITED}} - W_{\text{SUBJECT}} = W_{\text{HS3}}$	Suit/Test characteristics metric
Cognitive Measures	Digit Symbol Substitution Task (DSST)	Response Time (ms), Response Accuracy, throughput	Cognitive workload
	Psychomotor Vigilance Task (PVT)	Response Time (ms)	
Metabolic Rate	COSMED K5	Rolling Avg (BTU/hr)	Physical workload
Heart Rate	Polar H10 Chest Strap	Rolling Avg (BPM)	Physical workload
PLSS temperature/humidity	Vaisala HMP7	PLSS temperature (°C), relative humidity (%)	Suit/Test characteristics metric
LCG coolant temperature	LCG suit cooling performance: PT100 RTD Amplifier MAX31865	LCG inlet/outlet temperature (°C)	Suit/Test characteristics metric
Skin Temp/In-Suit Humidity	Skin Temp/In-Suit Humidity: iButton	Mean skin temperature (°C)	Suit/Test characteristics metric
Task Time	Smart Timeline Tracker	task start and end timestamps	Suit/Test characteristics metric

Traverse speed/distance	RUNN Treadmill Sensor (RUNN-A-77-AA)	Speed (mph)/Distance (miles)	Physical workload
Simulation Quality ⁴	Simulation Quality	From 1-5	Suited experience comparison
Simulation Acceptability ⁵	Simulation Acceptability (copper-harper rating)	From 1 -10	Suited experience comparison
Comfort Scale Rating	Comfort Scale	From 1-7	Suited experience comparison
Perceived physical workload	Borg Rating of Perceived Exertion Scale (RPE)	From 6-20	Physical workload
Subjective Cognitive Measures	NASA Task Load Index (TLX) ⁶	mental demand, physical demand, temporal demand, performance, effort, frustration	Cognitive workload
	Bedford Workload Rating	From 1-10	
Fatigue Rating	Fatigue Scale	From 1 -10	Suited experience comparison
Thermal acceptability	Thermal sensation, preference, acceptability, comfort	+/-3, +/-2, 1/0, 1-6	Suited experience comparison
Suit Fit Survey	Suit fit evaluation	SUIT Database	Suited experience comparison
Post-exposure injury	Suit Exposure Worksheet		Suited experience comparison
Suit Experience Survey	Comparison w/ previous suited experience	0 – 10 scale	Suited experience comparison

Metabolic Rate and Heart Rate

Metabolic rate (MR) and heart rate (HR) were used as metrics to evaluate physical workload. MR was collected with the COSMED K5 portable metabolic analyzer (COSMED, Rome, Italy). The COSMED performed a MR calculation internally.

HR was measured using the Polar H10 heart rate chest strap (Polar Electro, Kempele, Poland), and used to calculate the %HRmax. The HR data was transmitted via Bluetooth to a PC/monitor display station, to monitor that the subject did not exceed the 85% HRmax threshold.

Thermal Data

Skin temperature was collected to assess thermal performance on the HS3 cooling loop. Four thermal DS1923 Hygchron Temperature and Humidity Sensors (iButtonLink Technology, Whitewater, WI USA) measured temperature at the lower chest, upper arm, quadricep, and calf, directly on the skin every one minute. Mean skin temperature (MST) was then calculated using the Ramanathan Method [15, 17].

$$MST = 0.3(T_{chest} + T_{arm}) + 0.2(T_{thigh} + T_{leg})$$

To measure the PLSS temperature and humidity, a Vaisala HMP7 sensor was used, measuring LCG coolant temperature with resistive detectors RTD, PT100 RTD Amplifier MAX31865) in the 1.0 and 2.0 configurations. The 2.5 configuration uses DS18B20 temperature detector probes.

Treadmill Speed Sensor

To measure the treadmill speed and walking cadence, an external treadmill sensor (Runn Inc, Model: Runn-A-77-AA. P/N R214903014) was attached to the top of the treadmill belt.

Cognitive Measures

To measure Cognitive Fatigue, subjects completed a subset of the full NASA Cognitive Test Battery, including the Digit Symbol Substitution Task (DSST) and Psychomotor Vigilance Task (PVT) [18]. These were measured before and after the EVA on test day.

The DSST is a test that assesses onboard processing in working memory and low-level visual search. In this task, the subject was presented with a legend that pairs symbols with numbers. The subject was then shown a random symbol and had to quickly select the matching number.

The PVT is a test that assesses vigilant attention. In this task, the subject was to monitor a box, hitting a button as soon as a millisecond counter appears. The subject was instructed to hit the button as quickly as possible without errors of commission.

Cognitive measures were also taken with the Bedford workload rating and NASA Task Load Index (TLX) [19, 20]. The Bedford workload rating provides the subject with a decision tree to a ten-point rating of their perceived cognitive workload. The TLX is a six-dimension rating as listed below:

1. Mental demand: how much thinking, deciding, or calculating was required?
2. Physical demand: how intense was the physical activity?
3. Temporal demand: how much time-based pressure was felt?
4. Effort: how hard was it to sustain the level of performance?
5. Performance: how successful was the task completed?
6. Frustration: how discouraging was the task?

Subjective Surveys

To receive user feedback, subjects completed several subjective surveys. These surveys, commonly used in ground-based EVA analogs include simulation quality, task acceptability, Rating of Perceived Exertion (RPE), Comfort rating, Thermal ratings, and a fatigue rating. These are administered throughout the testing session, according to the schedule below.

Suit Experience Survey evaluated the effectiveness of the HS3 compared to suited analog environments within a scale between 0 (shirt-like) and 10 (suit-like). Subjects with suited experience ranked the HS3 after their test session to compare tasks to their experience in a pressurized suit. This survey is collected via interviewing the subject post EVA.

Suited Experience Subjective Survey – 1st Sheet

Instruction:

1. Reflect on your HS3 session.
2. Complete of one survey for each suit and each environment you have.

Name of previous suited experience: in _____ environment
 (e.g., environments = lunar ARGOS, NBL, 1G...), fill out one sheet per environment.

List all types of suits you used in the above environment: _____

Rank the following activities in HS3 with the following scoring scale:



	Stationary	Traverse	Geology	Object Relocation
Cognitive workload (average)				
Physical workload (average)				
Overall Comfort				
Communication (How well do you hear/talk)				
Thermal environment				
Visibility (field of view)				
Balance				
Range of motion (Mobility restriction)				
Motion (Force/torque required)				
Restricted dexterity (Gloves)				
Overall EVA immersion				

Comments: Please note anything else that you noticed that different from your previous suited experience.

Figure 6-6. Subjective Suited Experience Survey.

Simulation quality asks the subject to which extent the accuracy of the analog environment, mockups, and simulation procedures/operations compares to a suited, partial gravity exploration EVA. The scale, shown in Figure 6-7 is a scale from one to five. Ratings of 1-3 indicate that the simulation is viable and the data can be used. Ratings of 4-5 indicate that the simulation needs improvement and/or the data have significant limitations. In the cases of ratings in this range, the subject was asked to provide a comment identifying those limitations.

No Limitations	Minor Limitations	Marginal Limitations	Significant Limitations	Major Limitations	No Rating
Simulation quality (e.g. hardware, software, procedures, comm, environment) presented either zero problems or only minor ones that had no impact to the validity of test data	Some simulation limitations or anomalies encountered, but minimal impact to the validity of test data	Simulation limitations or anomalies made test data marginally adequate to provide meaningful evaluation of test objectives (please describe)	Significant simulation limitations or anomalies precluded meaningful evaluation of major test objectives (please describe)	Major simulation limitations or anomalies precluded meaningful evaluation of all test objectives (please describe)	Unable to assess simulation
1	2	3	4	5	NR

Figure 6-7. Simulation Quality Scale.

Simulation task acceptability assesses the reliability and efficiency of using the facility, tools, and procedure to complete an EVA task. The scale, shown in Figure 6-8 is a scale from one to five. Ratings of 1-3 indicate that the simulation is viable and the data can be used. Ratings of 4 or greater indicate that the simulation needs improvement and/or the data have significant limitations. In the cases of ratings in this range, the subject was asked to provide a comment identifying those limitations.

Examples of deficiencies: inefficiency, high mental workload, increased physical exertion.

Totally Acceptable		Acceptable		Borderline		Unacceptable		Totally Unacceptable	
No improvements necessary and/or No deficiencies		Minor improvements desired and/or Minor deficiencies		Improvements warranted and/or Moderate deficiencies		Improvements required and/or Unacceptable deficiencies		Major improvements required and/or Totally unacceptable	
1	2	3	4	5	6	7	8	9	10

Acceptability Ratings should reflect the extent to which the condition overall was considered an “Acceptable” approach to conducting human exploration and the extent to which improvements, if any, are desired or required.

Operational Acceptability : Able to reliably conduct operations with accurate exchange of all pertinent information and without excessive workload or (in-sim) avoidable inefficiencies or delay.

Task Acceptability : Able to reliably complete a task without significant discomfort, exertion, fatigue, or avoidable inefficiencies, and without risk of injury to self or damage to equipment.

Figure 6-8. Simulation Task Acceptability Scale.

The Borg Rating of Perceived Exertion (RPE), comfort, and thermal measures scales provide insight into the subject’s perceived effort and physical state. These scales are shown in Figure 6-9. The RPE is a subjective rating of the physical workload that a subject feels when performing a task. The comfort rating assesses any physical discomfort that the subject feels when in the suit. The Thermal rating assesses the subject’s perspective of the suit’s cooling ability.

(a)	<table border="1"> <tr><td style="background-color: #008000; color: white; text-align: center;">6</td><td>No exertion at all</td></tr> <tr><td style="background-color: #90EE90; text-align: center;">7</td><td>Extremely light</td></tr> <tr><td style="background-color: #90EE90; text-align: center;">8</td><td></td></tr> <tr><td style="background-color: #90EE90; text-align: center;">9</td><td>Very light</td></tr> <tr><td style="background-color: #90EE90; text-align: center;">10</td><td></td></tr> <tr><td style="background-color: #90EE90; text-align: center;">11</td><td>Light</td></tr> <tr><td style="background-color: #90EE90; text-align: center;">12</td><td></td></tr> <tr><td style="background-color: #FFFF00; text-align: center;">13</td><td>Somewhat hard</td></tr> <tr><td style="background-color: #FFFF00; text-align: center;">14</td><td></td></tr> <tr><td style="background-color: #FFA500; text-align: center;">15</td><td>Hard (heavy)</td></tr> <tr><td style="background-color: #FFA500; text-align: center;">16</td><td></td></tr> <tr><td style="background-color: #FF0000; color: white; text-align: center;">17</td><td>Very hard</td></tr> <tr><td style="background-color: #FF0000; color: white; text-align: center;">18</td><td></td></tr> <tr><td style="background-color: #FF0000; color: white; text-align: center;">19</td><td>Extremely hard</td></tr> <tr><td style="background-color: #FF0000; color: white; text-align: center;">20</td><td></td></tr> </table>	6	No exertion at all	7	Extremely light	8		9	Very light	10		11	Light	12		13	Somewhat hard	14		15	Hard (heavy)	16		17	Very hard	18		19	Extremely hard	20		(b)	<table border="1"> <tr><th colspan="7">Comfort</th></tr> <tr> <td style="background-color: #008000; color: white; text-align: center;">Greatest Imaginable Comfort</td> <td style="background-color: #90EE90; text-align: center;">Very Comfortable</td> <td style="background-color: #FFFF00; text-align: center;">Slightly Comfortable</td> <td style="background-color: #FFA500; text-align: center;">Neither Comfortable nor Uncomfortable</td> <td style="background-color: #FFA500; text-align: center;">Slightly Uncomfortable</td> <td style="background-color: #FF0000; color: white; text-align: center;">Very Uncomfortable</td> <td style="background-color: #FF0000; color: white; text-align: center;">Greatest Imaginable Discomfort</td> </tr> <tr> <td style="background-color: #008000; color: white; text-align: center;">1</td> <td style="background-color: #90EE90; text-align: center;">2</td> <td style="background-color: #FFFF00; text-align: center;">3</td> <td style="background-color: #FFA500; text-align: center;">4</td> <td style="background-color: #FFA500; text-align: center;">5</td> <td style="background-color: #FF0000; color: white; text-align: center;">6</td> <td style="background-color: #FF0000; color: white; text-align: center;">7</td> </tr> </table>	Comfort							Greatest Imaginable Comfort	Very Comfortable	Slightly Comfortable	Neither Comfortable nor Uncomfortable	Slightly Uncomfortable	Very Uncomfortable	Greatest Imaginable Discomfort	1	2	3	4	5	6	7																								
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2	Warm					6	Very uncomfortable																																																																							
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Figure 6-9. Scales for: a) RPE, b) Comfort, c) Thermal.

Fatigue rating scale is a measure of overall weariness, both cognitively and physically. While the comfort rating looks at local discomfort, this looks at the subject’s overall exhaustion. See Figure 6-10.

No Fatigue		Minor Fatigue		Moderate Fatigue		Significant Fatigue		Extreme Fatigue	
Performance not compromised		Performance not compromised		Performance will likely be compromised if continued		Performance is compromised		Unable to continue with adequate performance	
1	2	3	4	5	6	7	8	9	10

Figure 6-10. Fatigue Scale.

6.2 Data Processing and Statistical analysis

6.2.1 Data Processing

The main categories of metrics presented in this report are: (1) HR, (2) MR, (3) mean skin temperature, (4) LCG inlet/outlet temperature (ΔT_{LCG} via resistance temperature detector sensor), (5) subjective suited experience surveys, (6) PVT and DSST cognitive measures from the Cognition Test Battery [18].

HR (beats per minute, bpm) data were logged locally on the device at 1 Hz and uploaded to both an internal database (“HIPPO app”) and COSMED Omnia software. All data were downloaded as single run .csv exports (including clock time and HR). The COSMED K5 device recorded many physiological measurements at different time intervals ranging from 0.5Hz to 0.25 Hz using the mixing mode setting, and among those measurements, oxygen consumption (VO_2 ; mL/min) and carbon dioxide production (VCO_2 ; mL/min) were saved in a separate file as 10-second sliding means. Then, using the Peronnet equation [21], energy expenditure (BTU/h) was calculated as follows:

$$\text{Energy expenditure } \left(\frac{\text{BTU}}{\text{h}}\right) = (4.039 \times VO_2 + 1.157 \times VCO_2) \times \frac{60 \times 3.968}{1000} \quad (1)$$

Skin temperature data were logged locally on the device at 0.1 Hz and transmitted to a local receiver for exporting. Data were exported as single run .csv exports (including elapsed time and skin temperature). Timeline data were captured separately using an excel timeline (Smart Timeline Tracker). Timeline data were reported as phase-elapsed time (PET). Task categories were assigned to each “block” of steps in the timeline per Section 6.1.1.

Data were processed using MATLAB R2023a (MathWorks, Natick, MA), using custom-developed scripts for individual subject and group analyses, respectively. These scripts performed several key steps in processing the data, described below.

- All data were time-sync’d with specific timeline steps in the transformed 24-hour format.
- After the time synchronization, data were aligned with specific EVA task labels documented by the test team during test execution.
- Initial task start was determined from both the time information in the raw COSMED file and manually marked event descriptions.
- Zero, not a number (NaN), and/or abrupt peak values in all data were removed and restored using a linear interpolation method appropriately in accordance with best practices. An

outlier was defined when as a data point was more than three standard deviations away from the mean of the dataset. Values exceeding this threshold were excluded.

- HR data was filtered using a 4th order butterworth filter to remove motion artifact. Skin temperature data were recalculated using a 60-second moving average.
- Descriptive statistics (Mean, StDev, Max, Min, Range, Variance, 10%Perc., 25%Perc., 50%Perc., 75%Perc., 90%Perc., and Interquartile Range) of all data were then calculated and labeled for each task category.
- Individual subject and group analysis graphics were provided on a per-task and combined tasks categorization basis (where all similar tasks are combined, e.g., traverse, geology).

For the HS3 2.0 Configuration Update pilot study, 3 subjects were selected from the original HS3 1.0 characterization study cohort based on subject availability (1 male, 2 females; including 1 active-duty astronaut crew member). %HR (calculated using maximum HR derived from pre-test cycle VO₂ peak tests) was used to infer HS3 physical workload. Absolute MR was selected to benchmark suit performance and consumable comparison. For task-based analysis, the 50th percentile data within each task block was used to characterize the most representative performance of a subject. This approach removes outlier values such as rising/trailing edges. Thermal, cognition, sensor, and subjective data were processed in the same manner between HS3 1.0 and 2.0 characterization studies to show comparison. Note: In HS3 2.0 study, one test was terminated early without completing the object relocation tasks due to the PLSS main battery necessitating recharge mid test; however, critical data points were collected and thus no re-test was required.

6.2.2 Statistics

Linear mixed-effects modeling (LMM) was performed to compare the n=3 results in HS3 2.0 with respect to the n=8 in HS3 1.0. For each task block (3-5 minutes), 30% of the data is trimmed to minimize rising edge impacting the assessment of physiology state at equilibrium. The LMM approach enables an unbalanced dataset, and thus one can leverage the HS3 1.0 subjects that do not have 2.0 data by fitting models. Compared to the paired sample testing for only the n=3 repeated subjects, LMM offers additional information to increase model fidelity and thus making better predictions for the 2.0 population trends by including the entire HS3 1.0 n=8 cohort. The following parameters are modeled as fixed effects: HS3 1.0 versus 2.0, EVA task type, and interaction terms (i.e., different EVA tasks impacted by HS3 versions). Individual subject variation is modeled as random effects. Robust standard errors allowed non-homogenous variance across combinations.

The “population” workload presented in this report show the LMM model results, which provide predictions in population mean (50% quantile) response for HS3 2.0. A limited portion of the subject data is presented via paired sample approach to show individual trends within a subject. In LMM, random effects can also provide comparison for specific subject comparison, but it is not shown in this report.

6.3 HS3 Characterization Data

6.3.1 Performance Envelope of the HS3

The HS3 1.0 and 2.0 data create the boundary cases for a range of HS3 configurations, resulting in measured envelopes for HS3 1.0 and 2.0 as well as the predicted envelope for the HS3 2.5 suit. Figure 6-11 illustrates the HS3 performance envelopes. The use of the performance envelope concept helps future users to estimate the HS3 workload and performance without testing through all possible suit configurations identified in this report. The envelope represents the given HS3 configuration's 50-percentile population characteristics in physical workload, cognitive workload, thermal responses, suit-like experience, and suit performance. Table 6-5 shows the major factors that impact the performance envelope, with suit weight and thermal configuration being the most critical parameters. As a result, any one HS3 configuration's performance can be interpolated and extrapolated around the performance envelope, which is essential due to the modular nature of HS3. Future quantitative performance characterization tests of other HS3 configurations can help enhance the quantitative prediction precision for the envelopes.

The HS3 2.5, which is the version constructed in this report, is assumed to be enveloped by the HS3 1.0 and 2.0 data sets. Table 6-5 and Table 6-6 show the estimated performance envelope for HS3 2.5.

Table 6-5. Major Factors Affecting the Performance Envelopes of the HS3 Configurations.

Factors	HS3 1.0	HS3 2.0	HS3 2.5
Suit Loaded Weight	Lower	Higher	In between 1.0 and 2.0
Thermal Capability	Worst (half body LCG w/ vent.)	Best (Full body LCG w/vent.)	Like 2.0 (full body LGG w/o body vent.)
Suit-Like Range of Motion	Weakest	Better (waist & joint inhibitors)	Best (2.0 + hip inhibitor)
Non-suit like Artifacts	Helmet + HUT (Neck loading artifact)	xEMU like HUT (no neck artifact)	Like 2.0
CG Loading on Subject	Worst	Better	Like 2.0
Predicting HS3 2.5 Performance Envelope			
Subjective Suited Experience	Worst	Better	Best
Physical Workload	Lowest (due to weight and CG)	Highest (due to weight and CG)	In between 1.0 and 2.0
Cognitive Workload	Similar	Similar	Similar
Thermal Workload	Worse	Better	Same as 2.0
Suit Performance	Worse	Better	Same as 2.0

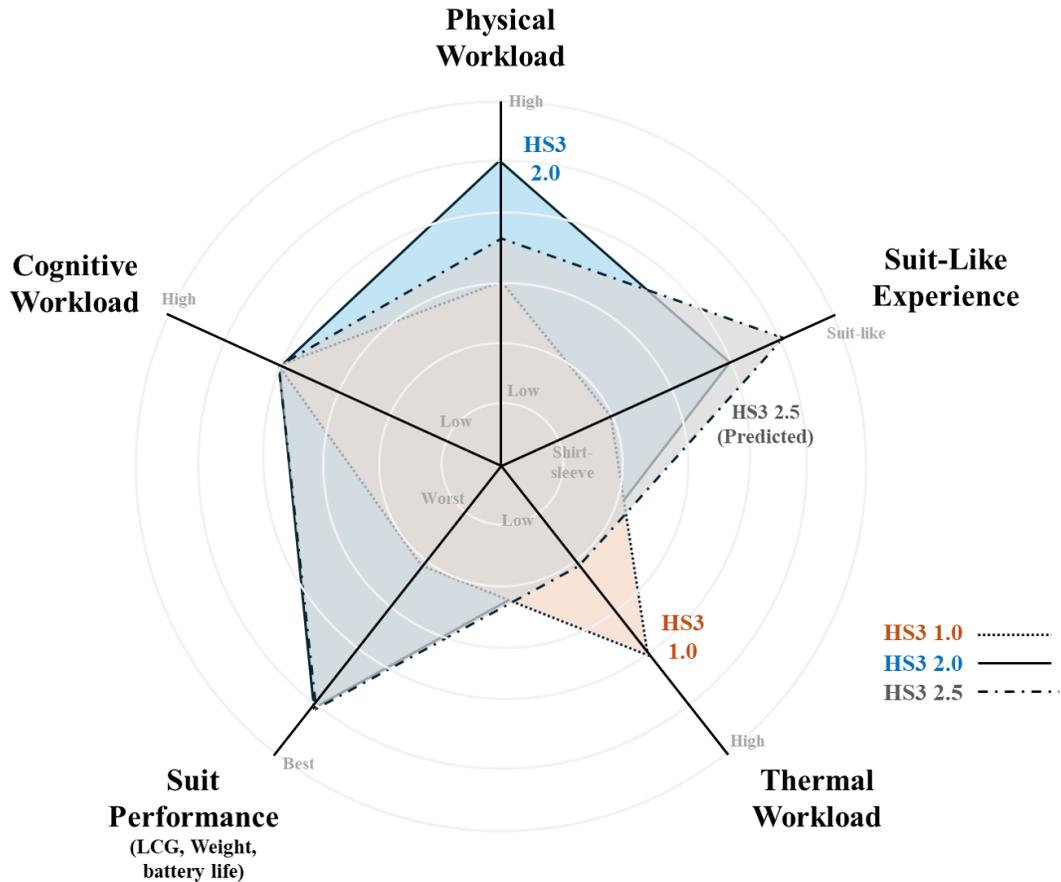


Figure 6-11. Graphical Representation of HS3 Performance Envelopes for Various Configurations.

This is a qualitative visualization (not to scale). HS3 1.0 and 2.0 envelopes are based on data collected in the studies, whereas the HS3 2.5 envelope is predicted based 1.0 and 2.0 results/trends.

6.3.2 Characterization Test Data Comparison from HS3 1.0 and 2.0

Using the same test protocol and procedures between HS3 1.0 and 2.0 characterization studies, objective data (metabolic rate (MR), heart rate (HR), MST, and suit performance metrics) and subjective data (surveys, workload, suit experience) were characterized using the integrated sensor platform during 1-hour 28 minutes simulated suited EVAs in HS3 (~ 2-hr suit time). The HS3 2.0 engineering improvements resolved major system concerns from HS3 1.0 and incorporated feedback from experienced suited subjects. Major achievements are summarized below:

- Population subjective workload, objective workload, and suit performance were benchmarked.
- Engineering and operational performance envelopes for the suit were baselined.
- Potential suit injury and subjective suited experience characterized.
- Areas of system improvements identified (for HS3 2.5).

Table 6-6. HS3 Characterization Data Summary Inferred Based on Available Data Trends

	HS3 1.0	HS3 2.0	Comparison Summary
Physical Workload (%HR and MR)	40-75 %HR _{max} , 500 – 2000 BTU/hr	50 – 75 % HR _{max} , 670 – 2300 BTU/hr	Comparable w/ 2.0 trending slightly higher (non-statistically significant), due to increased system weight. 2.0 Subjects reported the same or lower subjective fatigue despite increased wt.
Cognitive Workload	Simulated EVA in did not negatively impact cognitive performance in complex scanning/visual tracking (DSST) or vigilant attention (PVT) domains, except for DSST Mean Reaction Time.		Comparable with slight improvement in 2.0 (less cognitive burden), except for one subject whose data were considered aberrations based on external factors. Cognitive performance results for HS3 were overall comparable to ARGOS with a few small exceptions.
Subjective Suit Experience	Suit-like but w/ neck load artifact	More suit-like HUT and ROM	More suit-like than 1.0 by subjects, 2.0 CG loading improved significantly.
Thermal Workload	MST: 29-31 °C LCG: short lived Subjective: Worse	MST: 28–32 °C LCG: Long lived Subjective: Better	Improved significantly in subject subjective comfort and MST regulation
Suit Metrics ²⁻⁶	B: 2-2.5 hr C: q 60 min W: 44+/- 2lb V: 30 L/min O: at least 5 min/hr (helmet break for neck) I: neck strain resolved afterward	B: 6-8 hr C: q 60-90 min W: 54+/- 2lb V: N/A O: at least 5 min/hr I: N/A	At least 5 min/hour “offloading” break is needed for a 6-hr long EVA.

1. Values presented in this table shows the 50% median value in the population.
2. C/Cooling life is measured by LCG hot swap frequency (q X minutes = every X minute).
3. B/Battery life: assuming LCG use on demand, actual battery time varies depending on usage.
4. W/loaded suit weight: median loaded suit weight on subject.
5. O/Offload breaks: mandatory offload breaks due to the suit weight.
6. I/Potential Injury Concerns: neck strain

6.3.2.1 System and Operational Performance

As shown in Table 6-7, HS3 2.0 is roughly 10 lbs heavier than 1.0 with a general increase in the %body weight (%bWt) column by 4-8% for loaded and total weight respectively. Typically, a loaded overnight backpack is recommended to weigh less than 10-20 %bWt (loaded on back) to prevent onset of injury [22, 23] [24] [23]. Based on military rucksack training, an absolute maximum of 40% is used but not recommended by the HS3 team [25] [26]. The increase in weight will impact subjects disproportionately particularly when focusing on smaller sized subjects experiencing higher loading; however, all subjects indicated that balance, loading, and thermal improvements are worth the tradeoff for increasing weight. **Despite the increase in weight, subjects reported same or lower physical exertion fatigue.** Subjects recommended that at least 5 min/hour be allocated to a hip “offloading” break from the PLSS to safely complete a 6-hour long EVA. The HS3 2.5 weight is measured on a different cohort of subjects (see Table 6-8), but the weight has successfully been reduced to be closer to the HS3 1.0 weight setpoint. As a result,

it is expected that the physical workload of HS3 2.5 will be enveloped by HS3 1.0 and 2.0 and being closer to HS3 1.0 values.

Table 6-7. Weight Comparison Between HS3 1.0 and 2.0. (red: > 20% Body Weight [23] [26])

Units (lbs)		HS3 1.0			HS3 2.0				
Subject	Body Wt	Loaded on back	Total System	%bWt Loaded	%bWt Total	Loaded on Back	Total System	%bWt Loaded	%bWt Total
A	181	34	44	19%	24%	43.8	55.2	24%	31%
B	240	34	44	14%	18%	42.4	53.6	18%	22%
C	134	34	44	25%	33%	43.6	54.2	33%	40%

(1) Loaded = loaded weight in lbs on back. Total = total weight including sensors and items worn by subjects.

(2) %bWt = percent body weight, i.e., divide loaded and total weight by subject's nude body weight.

Table 6-8. HS3 2.5 Weight Measurement. (red : > 20% Body Weight [23] [26])

Units (lbs)		HS3 2.5			
Subject	body Wt (bWt)	Loaded on Back	Total System	%bWt Loaded	%bWt Total
S1	157.25	34.55	46.55	22%	30%
S2	208.2	36.4	48.4	17%	23%
S3	198.7	33.7	45.7	17%	23%

Table 6-9. HS3 Weight Comparison

HS3 1.0				HS3 2.0				HS3 2.5			
Loaded (lbs)	Total (lbs)	%bWt Loaded	%bWt Total	Loaded (lbs)	Total (lbs)	%bWt Loaded	%bWt Total	Loaded (lbs)	Total (lbs)	%bWt Loaded	%bWt Total
34	44	14-25%	18-24%	42-44	53-55	18-33%	22-40%	33-36	45-48	17-22%	23-30%

(1) Loaded = loaded weight in lbs on back. Total = total weight including sensors and items worn by subjects.

(2) %bWt = percent body weight, i.e., divide loaded and total weight by subject's nude body weight.

Table 6-10 shows a comparison summary of HS3 system performance. From HS3 2.0 onwards, a centralized power system design has offered a more streamlined power management system as well as weight reduction. The centralized power bank can be easily hot swapped in case of hardware failure though it is expected to support a full 6 hr EVA simulation without the need of hot swap. The enhanced LCG capability in HS3 2.0 and 2.5 has reduced the hot swap frequency from every 60 to every 90 minutes according to subjective feedback and objective data shown by

both LCG and MST data during the 2.0 study. Per subject feedback, HS3 was switched to a full body LCG post 2.0 study; and the ventilation system was reduced to only a head fan since subjects reported not being able to feel the ventilation over the body when wearing a full body LCG garment.

Table 6-10. HS3 System Performance Summary

Specifications	HS3 1.0	HS3 2.0	HS3 2.5
Communication System	Range & Battery Life: <ul style="list-style-type: none"> 33 ft (COTS wireless earbuds, such as LG Tone 5) <ul style="list-style-type: none"> 10 hr (5 min charge time/1 hr life), 3000 ft (integrated motorcycle headset) <ul style="list-style-type: none"> 12 hr (2.5 hr charge to full) 		Range: 33' Bone conduction headphone (SHOKZ OpenRun) Battery Life: 8 hr (10 min charge time/1.5 hr life)
Electrical System	Multiple batteries: 1. DeWalt power source w/ Dewalt Battery x2 2. COMPCOOLER LCG battery x1 Output/Capacity: 1. Dewalt (8 Ah x2, 12-20V) 2. COMPCOOLER (2200mAh, 7.4V) Battery life: 2-2.5 hr (hot swap < 1 min)	Centralized power bank: EGRETECH Plume 300 Output/Capacity: 300W/260Wh Battery life: 8 – 10 hr	Centralized power bank: Anker SOLIX C200X Output/Capacity: 200W, 192Wh Battery life: 6-8 hr
	HS3 System Consumption < 30W including LCG pump, ventilation, Sensors. (Not currently powering wireless parts: comm headset, COSMED, light, camera, iButton)		
Ventilation Capability	Full body ventilation loop: 1.06 CFM (30 L/min)		USB Fan for Head Only: 36.2 CFM (max, 1025 L/min)
LCG Capability (bag size)	<ul style="list-style-type: none"> Capacity: 3L x1 Hot swap q 60 min (< 5 min hot swap) No surface supply option Half body LCG 	<ul style="list-style-type: none"> Capacity: 1.5L x2 Hot swap q 60-90 min (< 5 min hot swap) Surface supply available Half body LCG 	<ul style="list-style-type: none"> Capacity: 3.5L x1 Hot swap q 60-90 min (< 5 min hot swap) Surface supply available Full body LCG

Note: Wireless parts such as comm headset, COSMED, light, iButton, and camera uses built-in batteries and are not currently using the HS3 suit electrical system. However, it is possible to connect to the electrical system for charging.

6.3.2.2 Workload Characterization

6.3.2.2.1 Physical Workload of HS3

From Figure 6-12 and Figure 6-13, **mean physical workload (%HR and absolute MR) is comparable between HS3 1.0 and 2.0, with 2.0 trending slightly higher (non-statistically significant)**, likely due to increased system weight (~ +10lb from 1.0 to 2.0, see Table 6-9). Observations from subjective inputs and physical workload data indicate that the physical workload difference is minimal between HS3 1.0 and 2.0 despite the increased weight, likely due to better hip and shoulder loading in the 2.0 version. %HR shows more consistent variability across tasks than absolute MR (Figure 6-14 and Figure 6-15). %HR is similar overall between 1.0 and 2.0, whereas absolute MR shows a consistent offset. This is likely

impacted by subject's individual fitness level, body composition, body posture, thermal status, and similar physical traits. Like HS3 1.0 results, %HR and absolute MR responded differently in different EVA tasks. Absolute MR can be used to assess both physical workload and suit consumption. The original 1.0 results showed %MR is better at predicting for low workload tasks, whereas %HR is better for high workload tasks. To represent a direct comparison of normalized values, Figure 6-14 and Figure 6-15 show the %HR and %MR variability on tasks for individual subjects.

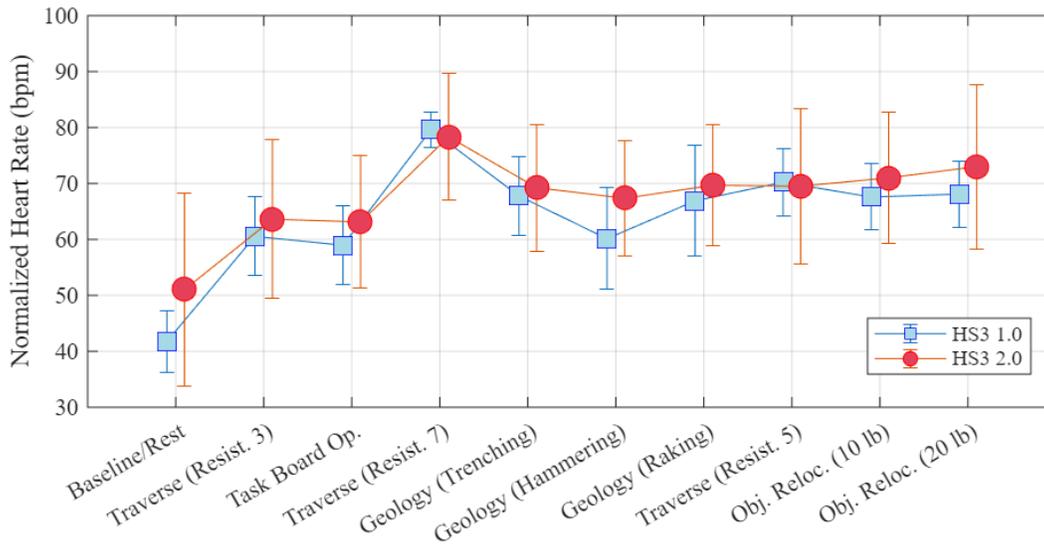


Figure 6-12. Physical Workload Comparison between tasks conducted in HS3 1.0 and 2.0 From LMM Results –Normalized Heart Rate (%HR) Prediction for the Population Mean.

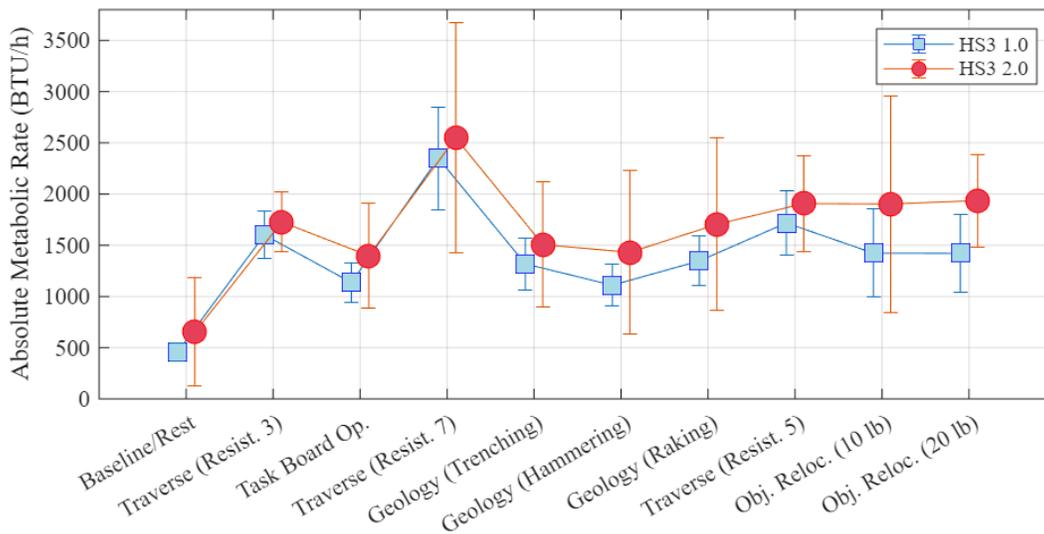


Figure 6-13. Physical Workload Comparison Between HS3 1.0 and 2.0 from LMM results – Absolute Metabolic Rate (MR) Prediction for the Population Mean.

It is expected that %HR is more sensitive than MR to individual fitness, meaning that increases for smaller subjects in 2.0 could mean smaller subjects endure a higher workload from the 2.0 weight increase versus larger subjects. Absolute MR shows a small increase of average workload given increased 2.0 weight gain as expected; however, %MR shows varying trends based on the variability of subject fitness, task execution, and thermal preferences. The 2.0 data set had larger uncertainty and variation due to the low population; however, the 2.0 and 1.0 results are consistent enough such that 1.0 data can be used to expand the 2.0 statistics (consider 1.0 and 2.0 physical workload equivalent) and thus used together for HS3 physical workload prediction.

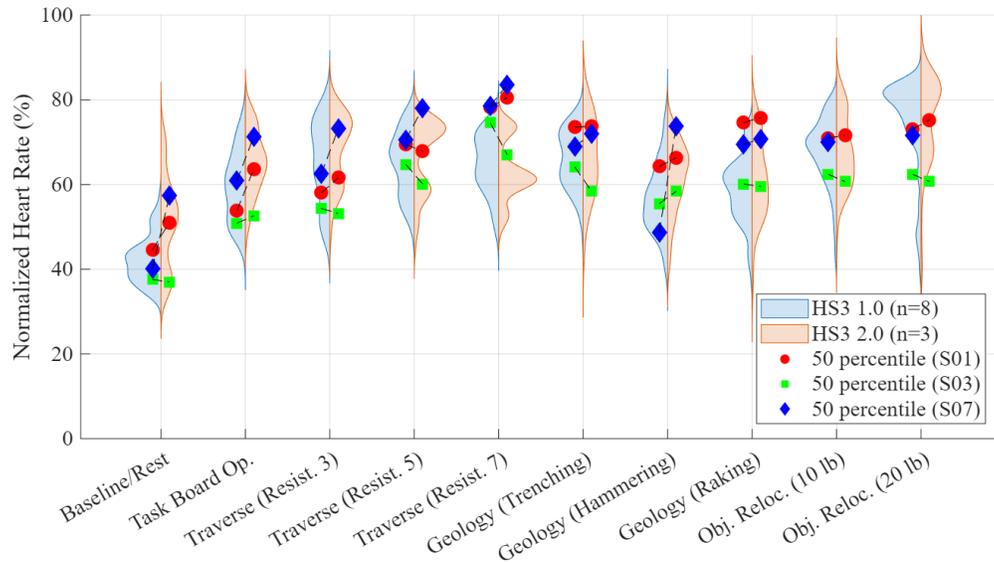


Figure 6-14. Subject Normalized HR (%HR) for Individual Subject Comparison in Physical Workload.

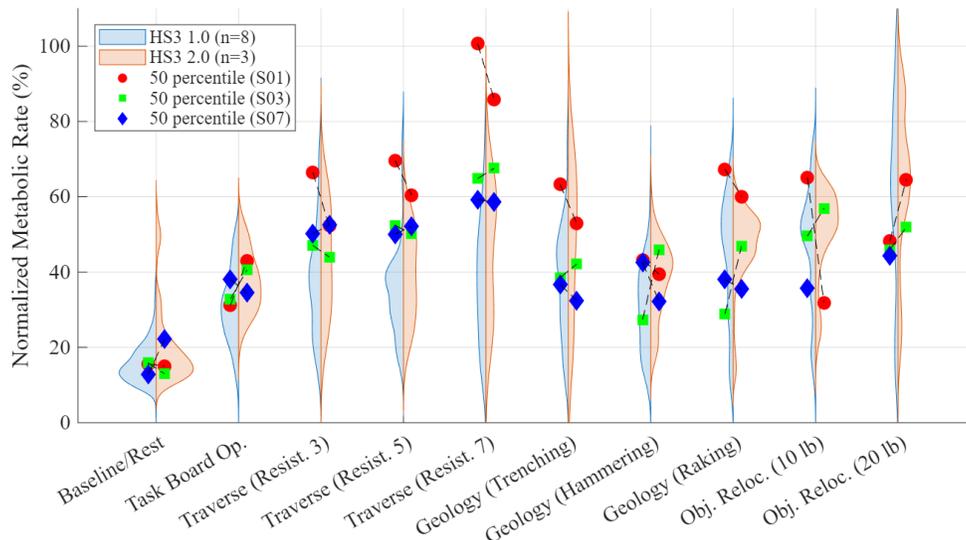


Figure 6-15. Subject Normalized MR (%MR) for Individual Subject Comparison in Physical Workload.

As illustrated in Figure 6-16 **Figure 6-16** and Figure 6-17**Figure 6-17**, the objective data (MR/HR) and subject survey data (fatigue/RPE) show similar trends in physical workload

response with subjective data showing less variation across tasks. Differences in both objective and subjective physical workload are minimal between HS3 1.0 and 2.0 despite the increased weight, likely due to the improved CG loading in the 2.0 version (which offsets the weight increase).

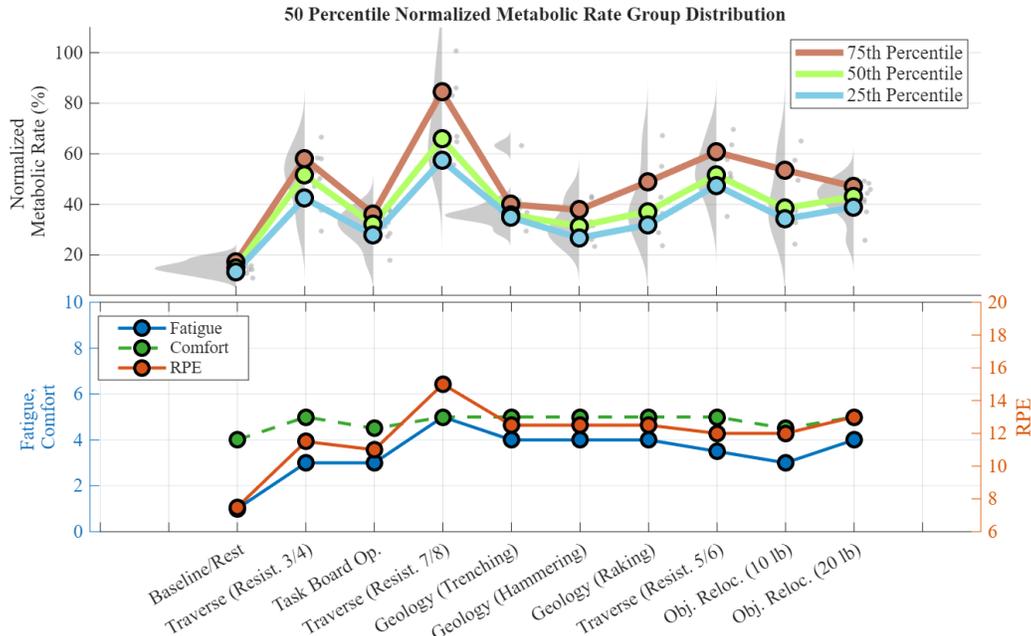


Figure 6-16. HS3 1.0 Objective and Subjective Physical Workload Comparison (Entire Population).

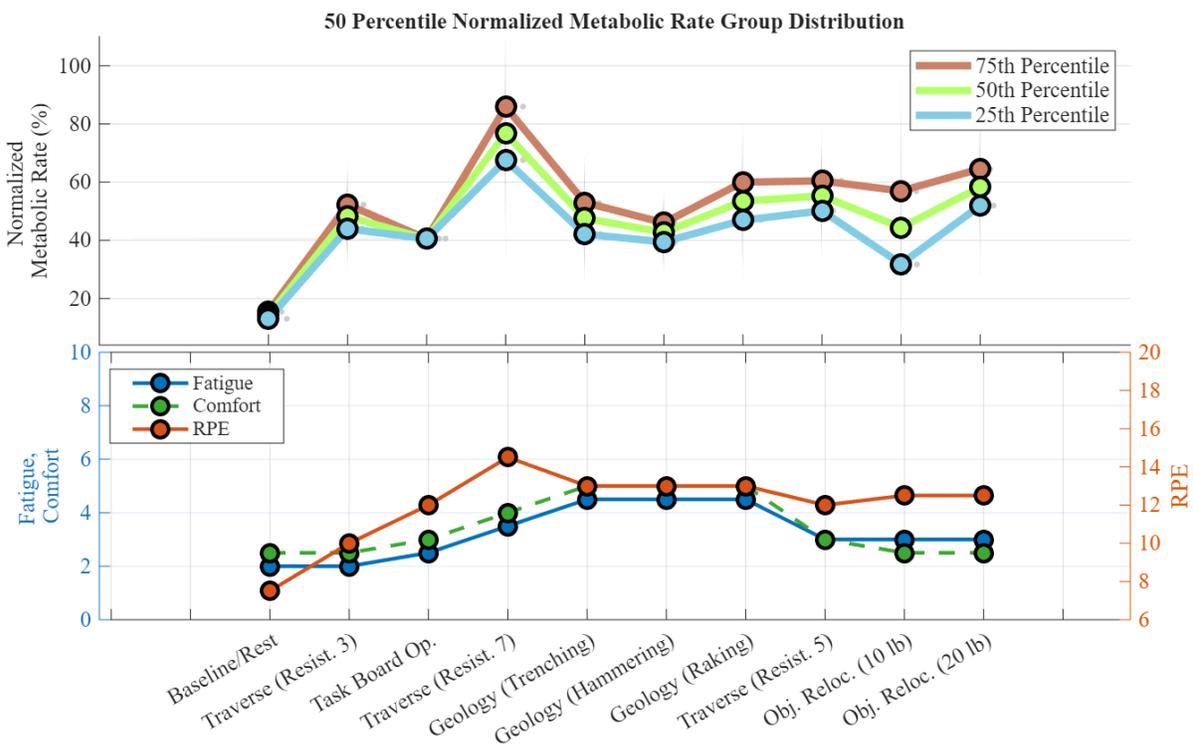


Figure 6-17. HS3 2.0 Objective and Subjective Physical Workload Comparison (Entire Population).

6.3.2.2.2 Cognitive Performance of HS3

Cognitive performance as measured by the Cognition Test Battery Digit-Symbol Substitution Test (DSST) and Psychomotor Vigilance Test (PVT) was largely similar between HS3 1.0 and 2.0 Test Series, with slight improvement in the 2.0 Test Series possibly due to a reduction in cognitive burden associated with the suit. Combining results from 1.0 and 2.0 test series revealed generally stable accuracy between pre-EVA and post-EVA sessions, and slightly worse speed between pre-EVA and post-EVA sessions on both DSST and PVT. Speed and accuracy results are shown in Figure 6-18. See Appendix E: Additional Cognitive Performance Results from HS3. 2.0 Study for other parameters.

- DSST mean RT and proportion correct improved from Pre-EVA to Post-EVA in HS3 2.0 Test Series. In contrast, DSST outcomes in HS3 1.0 worsened from Pre-EVA to Post-EVA (Figure 6-18 (a) (b)).
- PVT mean RT and accuracy outcomes were slightly worse post-EVA in the 2.0 compared to 1.0 Test Series. Decrements in PVT performance in the 2.0 test series may have been largely driven by a single subject. Several hardware issues during this subject's test session, in addition to earlier start to subject's day due to unexpected work obligations, may have increased this subject's fatigue and negatively impacted their cognitive performance in the 2.0 compared to 1.0 Test Series; however, given that this subject's results were within nominal ranges of prior subject testing, no retest was recommended (Figure 6-18 (c) and (d)).

Cognitive performance results suggest that the HS3 suit changes in the 2.0 Test Series may have had opposing impacts on cognitive performance. Better loading in line with subjects' center of gravity in 2.0 likely resulted in less cognitive workload needed to adjust body position, while reduced waist range of motion (ROM) and higher suit weight in 2.0 may have resulted in increased cognitive workload.

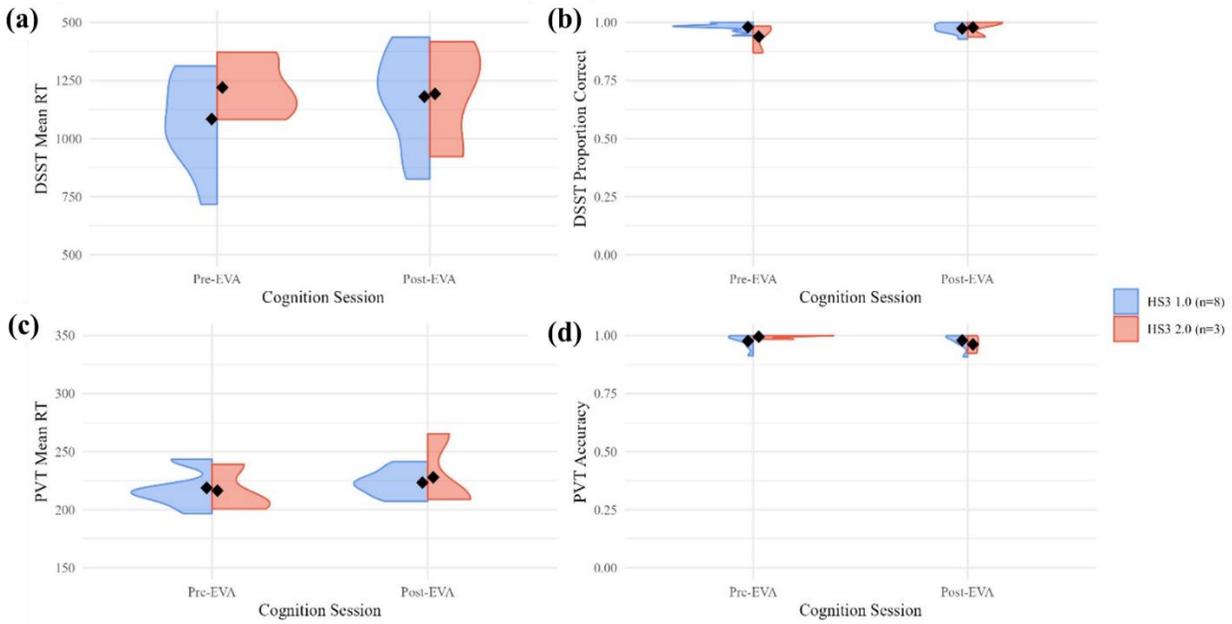
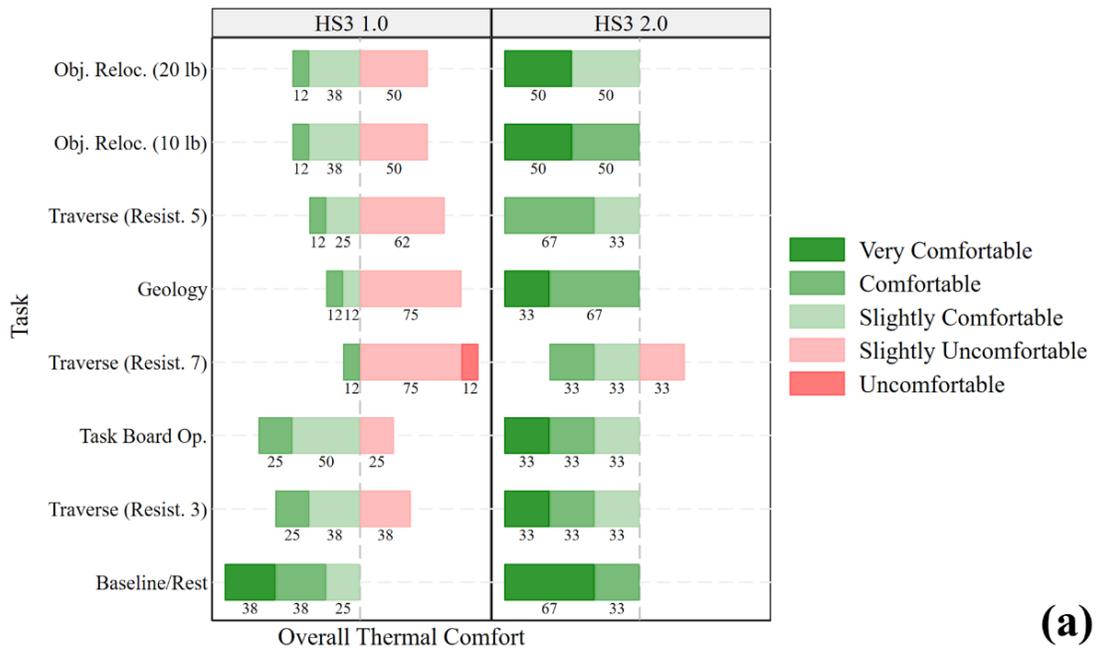


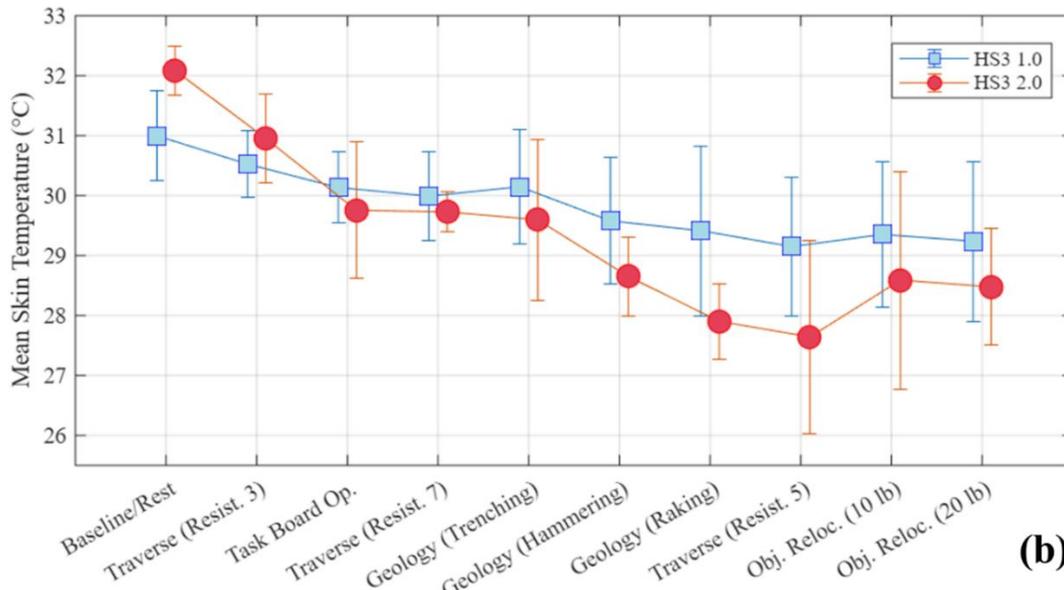
Figure 6-18. Cognition Test Battery Digit-Symbol Substitution Test (DSST) and Psychomotor Vigilance Test (PVT) Mean Reaction Time (RT) and accuracy results shown for HS3 1.0 vs. 2.0.

6.3.2.2.3 Thermal Characteristics of HS3

Both the subjective and objective thermal data are consistent with the improvement from 1.0 in cooling capability (lower temperature, faster and longer-lasting cooling). Subjective overall thermal comfort improved across the spectrum (shifted to more green areas) as shown in Figure 6-19 (a). In Figure 6-19 (b), MST shows similar trends across EVA timeline between 1.0 and 2.0. Initial MST is higher in 2.0, but 2.0 quickly out-performs 1.0 thermal system and resulted in lower MST. LCG hot swap usually occurs between the resistance 7 traverse and geology task, and significant MST dropping in 2.0 can be seen in Figure 6-19(b) with the superior full body LCG system. The thermal environment remains stable (Figure 6-19) despite of the higher absolute MR (i.e., increase heat storage) response observed in HS3 2.0 (Figure 6-13). This illustrates HS3 2.0 LCG’s superior capability in handling the increased heat.



(a)



(b)

Figure 6-19. Thermal Workload Results:
(a) Subjective thermal comfort scale; (b) Mean Skin Temperature (MST) population mean from LMM.

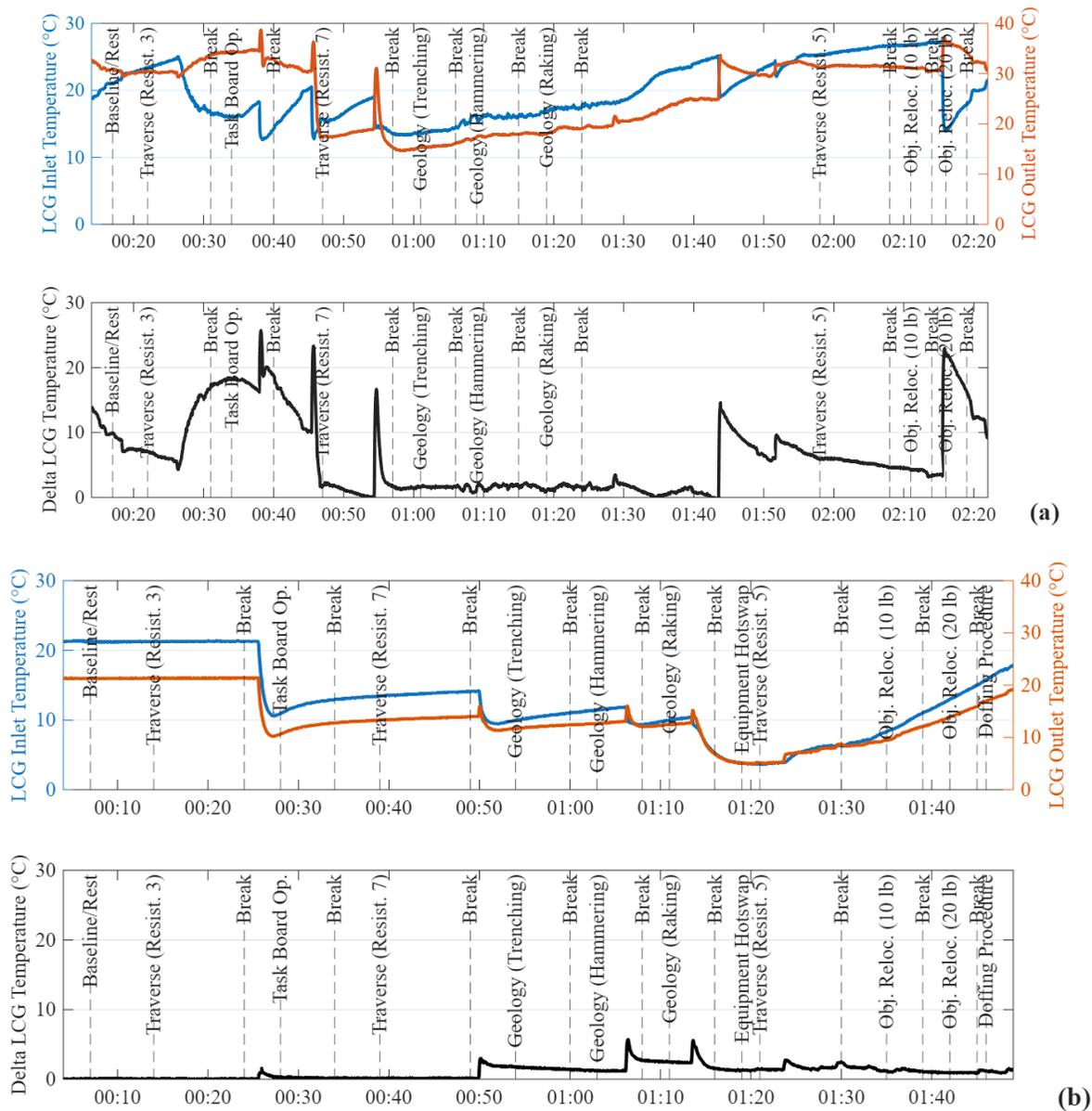


Figure 6-20. LCG Performance Benchmark Comparison between HS3 1.0 and 2.0.
(a) HS3 1.0 Example Subject Data (note there is a trouble shooting event took place around 1:20 -1:55 due to heart rate sensor problem), (b) HS3 2.0 Example Subject Data.

Despite an LCG sensor malfunction during the study, Figure 6-20 shows example subject data from HS3 1.0 and 2.0 studies. HS3 2.0 shows superior cooling capability over HS3 1.0 with stable $\Delta LCG = 1.5\text{-}2.5 \text{ deg } ^\circ\text{C}$ offloading between inlet and outlet throughout entire EVA. LCG hot swap (during equipment hot swap) refreshes the offload capability by increasing ΔLCG in HS3 1.0, and effectively extended LCG endurance. It was noted that in HS3 2.0, due to the superior LCG capacity, the ΔLCG remains stable across hot swap showing that the life of LCG is longer than the hot swap interval.

6.3.2.3 Subjective Suited Experience

In Figure 6-21, the Likert plot shows that HS3 2.0 is more suit-like than 1.0 given all suited experience area scores are shifted to the right (i.e. more blue) on the 0 to 10 subjective scale. The most prominent improvements were seen in motion, ROM, field of view (FOV), communication, EVA immersion, and physical workload. All other suited experience areas show relatively consistent distribution. Subjects recommended adding additional hip ROM restrictions to the 2.0 suit to make walking more “difficult” and suit-like.

One astronaut subject reflected on HS3 experience and said “Overall [HS3] feels very similar to xEMU, but the individual body part contribution is different (xEMU contributed more from lower body, NBL/POGO has water drag, limb 1G loading effect in ARGOS). It is a great tool for simulation and training in 1G.” Although none of the suit simulation analogs are perfect, data shown in this section supports that HS3 is better than shirtsleeve (0) in terms of suit-likeness (10 – pressure suit) with reasonably good simulation quality in most EVA tasks. The strengths and weaknesses of HS3 in 1G EVA simulation can be roughly summarized as below:

- **Strongest** simulation areas: thermal environment, visibility (FOV restriction), communication
- **Good** simulation areas: Cognitive/physical workload, restricted dexterity, overall EVA immersion, ROM, motion
- **Weakest** simulation areas (still with mostly > 5 score) : balance and overall comfort à **key difference from suited experience**

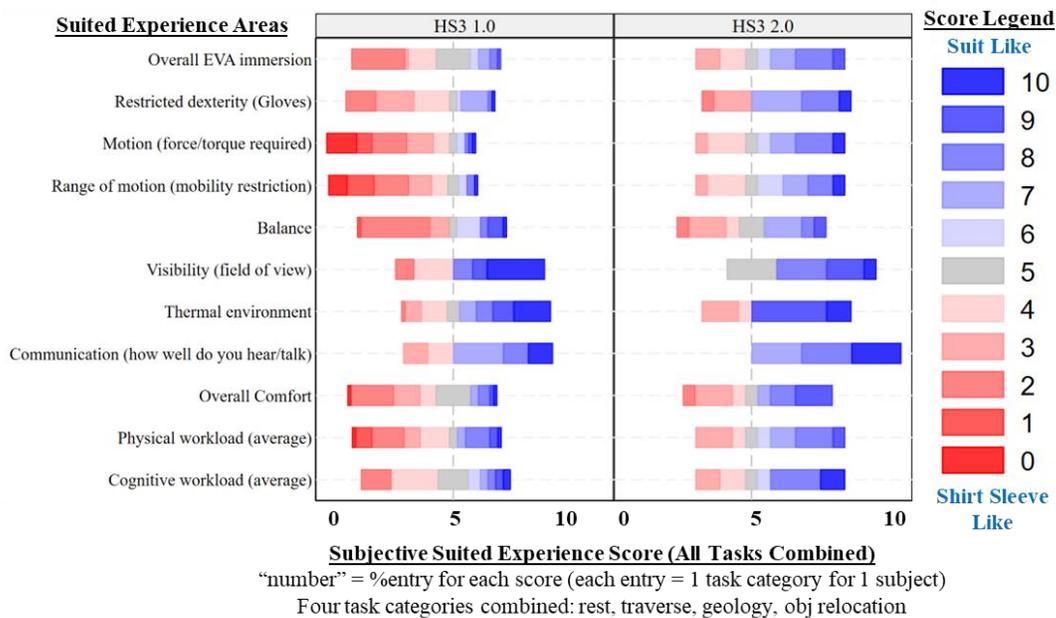


Figure 6-21. Likert Chart for Subjective Suited Experience Score with all Tasks Combined (entire EVA).

The scale ranks from 0 to 10, with 10 being the most suit-like. Note: HS3 1.0 shows n=8, while HS3 2.0 shows n =3.

Figure 6-22 through Figure 6-25 show the Likert plots for individual task categories, i.e., baseline/rest, geology, object relocation, and traverse. All task categories saw improvement of

subjective suited experience with updated suit designs, with geology and object relocation seeing the most drastic improvements (more drastic blue shift).

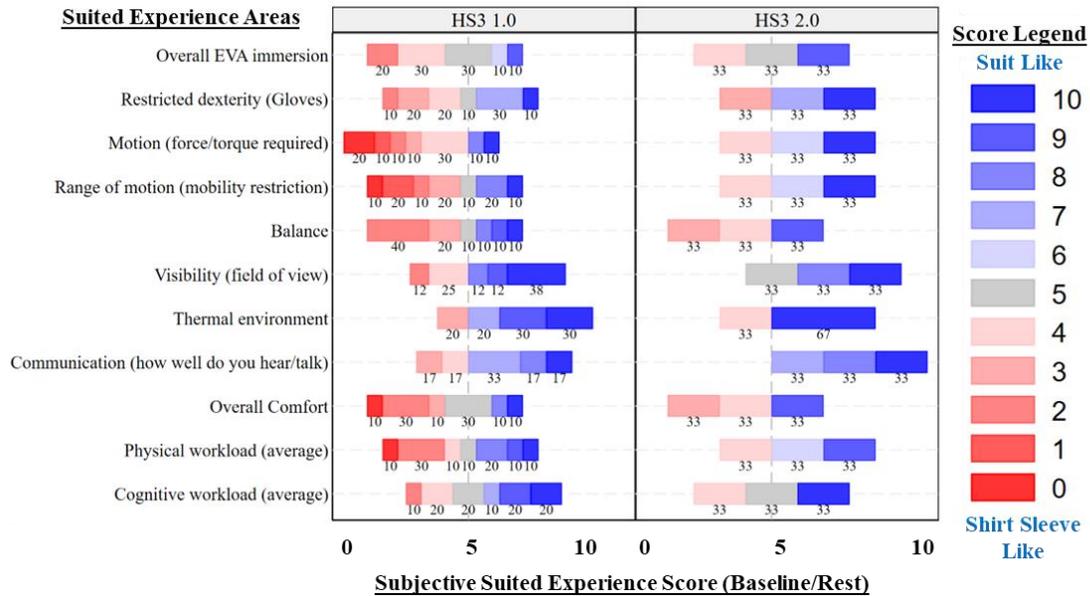


Figure 6-22. Likert chart for Subjective Suited Experience Score for Baseline/Rest Task. The scale ranks from 0 to 10, with 10 being the most suit-like. Note: HS3 1.0 shows n=8, while HS3 2.0 shows n =3. Individual numbers under the color bar show %entry for each score (each entry = 1 subject).

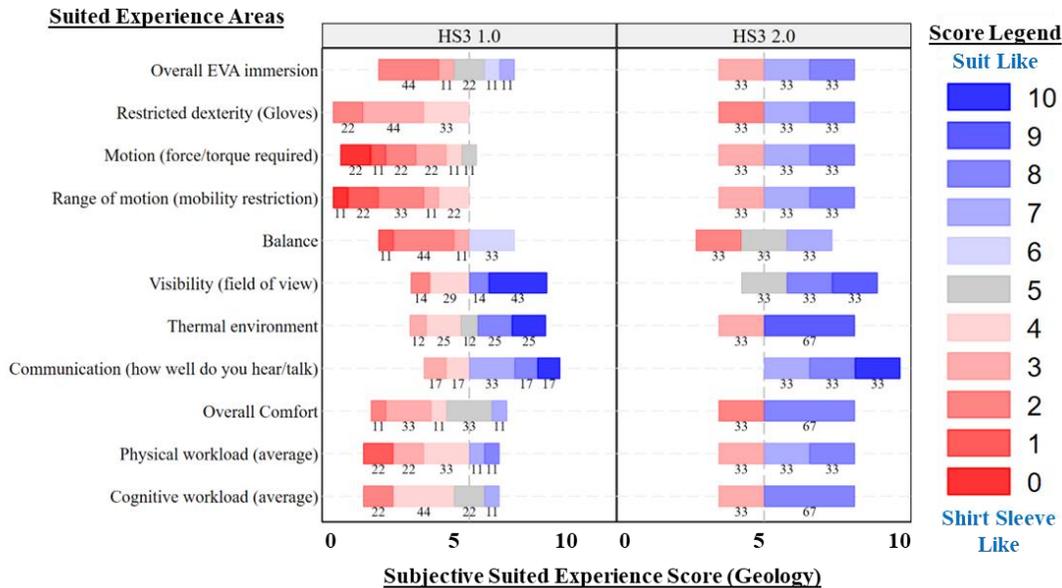


Figure 6-23. Likert chart for Subjective Suited Experience Score for Geology Tasks. The scale ranks from 0 to 10, with 10 being the most suit-like. Note: HS3 1.0 shows n=8, while HS3 2.0 shows n =3. Individual numbers under the color bar show %entry for each score (each entry = 1 subject).

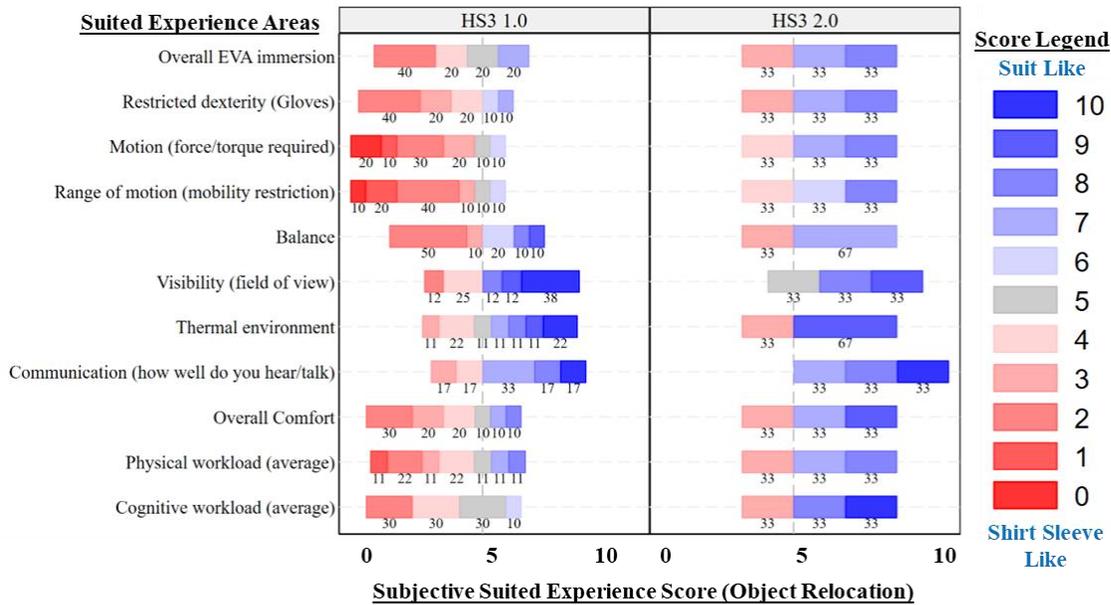


Figure 6-24. Likert chart for Subjective Suited Experience Score for Object Relocation Tasks.

The scale ranks from 0 to 10, with 10 being the most suit-like. Note: HS3 1.0 shows n=8, while HS3 2.0 shows n =3. Individual numbers under the color bar show %entry for each score (each entry = 1 subject).

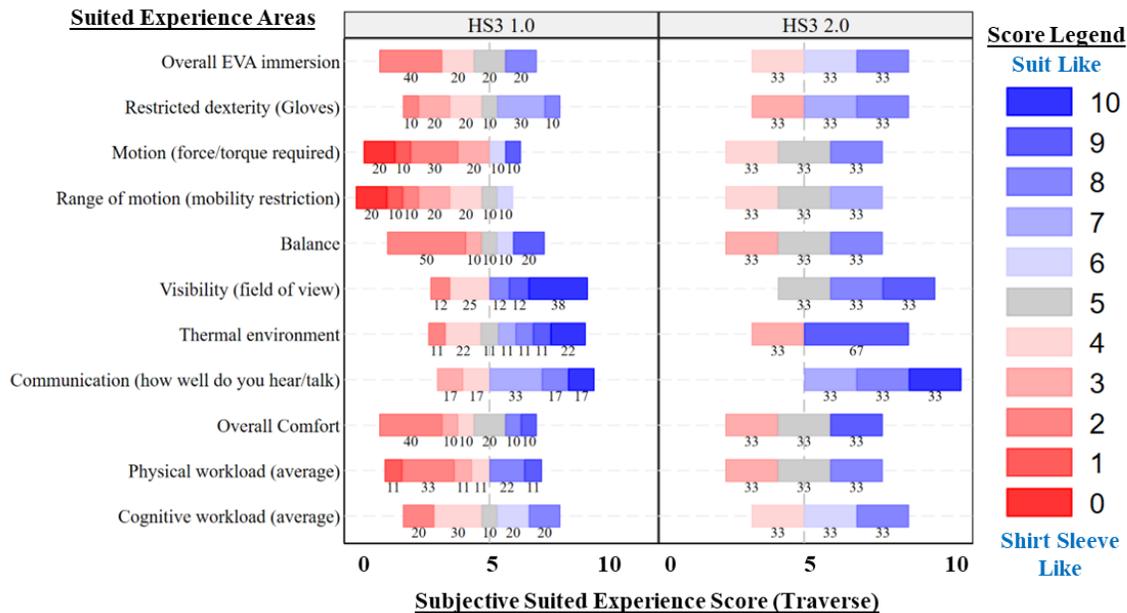


Figure 6-25. Likert chart for Subjective Suited Experience Score for Traverse Tasks. The scale ranks from 0 to 10, with 10 being the most suit-like. Note: HS3 1.0 shows n=8, while HS3 2.0 shows n =3. Individual numbers under the color bar show %entry for each score (each entry = 1 subject).

The Bedford and NASA Task Load Index (TLX) are benched marked with population mean values in Table 6-11. These subjective workload scale benchmark values can be used to plan future

HS3 applications. The subjective workload is roughly comparable between HS3 1.0 and 2.0. As a result, the HS3 2.5 is expected to be comparable with HS3 1.0 and 2.0 data. From Table 6-11, subjective physical workload is slightly higher in 2.0 (consistent with the objective measurement), and subjective cognitive workload is roughly the same between 1.0 and 2.0. However, these variations are small, and the subjective workload is considered comparable between 1.0, 2.0, and 2.5.

Table 6-11. Subjective Workload Scale Benchmark Results for HS3 1.0 and 2.0. (Legend based on relative scale, i.e., max value in table = high, and min = low)

		HS3 1.0				HS3 2.0			
Population Mean		Task Board	Geology	Obj Relocation		Task Board	Geology	Obj Relocation	
				10 lbs	20 lbs			10 lbs	20 lbs
Bedford		3	3	3	3	3	3	3	3
TLX	Mental	25	13	30	18	37	20	20	23
	Physical	28	50	40	33	40	47	45	55
	Temporal	13	10	18	10	27	20	15	15
	Performance	18	20	10	15	17	10	15	15
	Effort	23	45	30	33	43	43	40	50
	Frustration	28	25	15	13	37	30	20	20
Legend		High	Med/High	Medium	Low	Lowest			

7 Future Work

HS3 has been iteratively developed over the course of several years to serve as a physical and cognitive workload approximation tool focused on usage for simulated EVA analog research. Through the development process, physical, cognitive, and hardware capability bands have been applied to the suit simulator to aid in pre-defining workloads attributed to targeted research studies. These workload bands have been focused particularly on 1G analog environments using objective and subjective feedback from pressure suited experienced subjects. The released designs of HS3 provide a detailed construction and usage procedures to implement suit like workloads as part of 1G assumptions.

Forward work for HS3 development includes a larger in-depth analysis of the workload simulator capability bands when compared to current EVA task analogs (e.g., the Active Response Gravity Offload System (ARGOS), Neutral Buoyancy Laboratory, field-based analogs). Extensive simulated EVA research has been conducted in these NASA testbeds to characterize exploration task paradigms and associated workloads experienced by test subjects and crewmembers alike. The tasks associated with the HS3 characterization studies were selected to mirror EVA tasks at these gravity offload facilities. An in-depth analysis will be conducted to compare the HS3 physical workloads to the gravity offload facilities to determine the relevancy of the ground-based suit simulator to other suit analogs. This data output will enable workload factors to that can be applied to the HS3 data to associate to gravity offload counterpart research. Additionally, as HS3 is used in the community, parallel recommendations and updates to the HS3 designs are expected to be populated and refined to aid in future exploration EVA research. The hope is that external space/EVA researchers can use HS3 in their testing to allow for more repeatable, comparable outcomes between tests at disparate locations and with varying objectives

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9 Appendix

9.1 Appendix A: Soft Suit Pattern

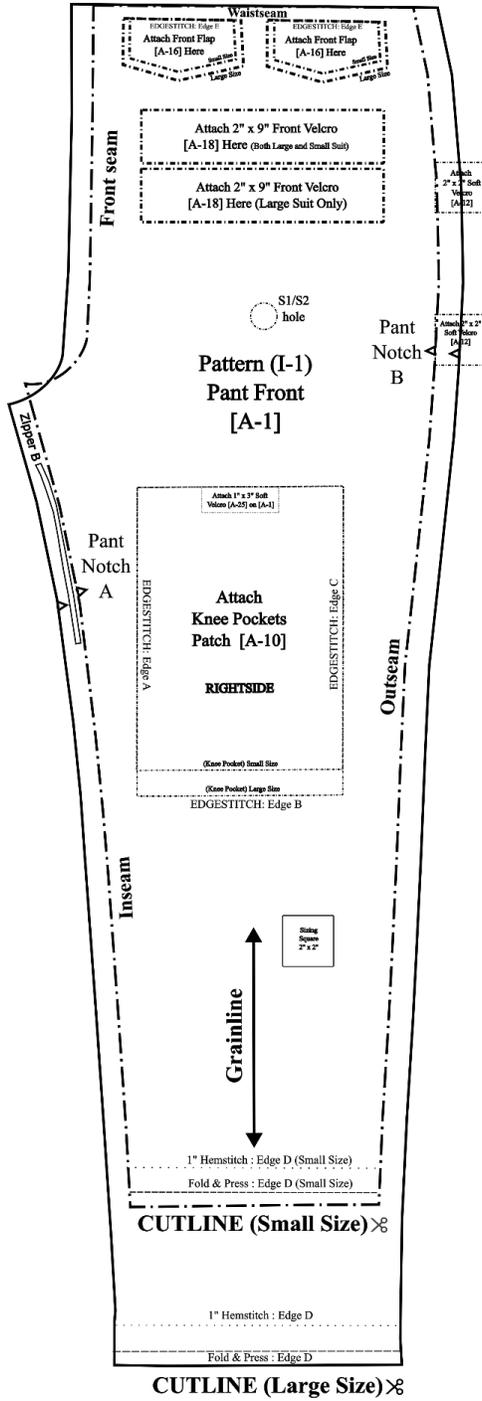


Figure 9-1. Pant Front [A-1]
 (Printable version of Pattern (I-1) for printable version: 1_PantFront.png).

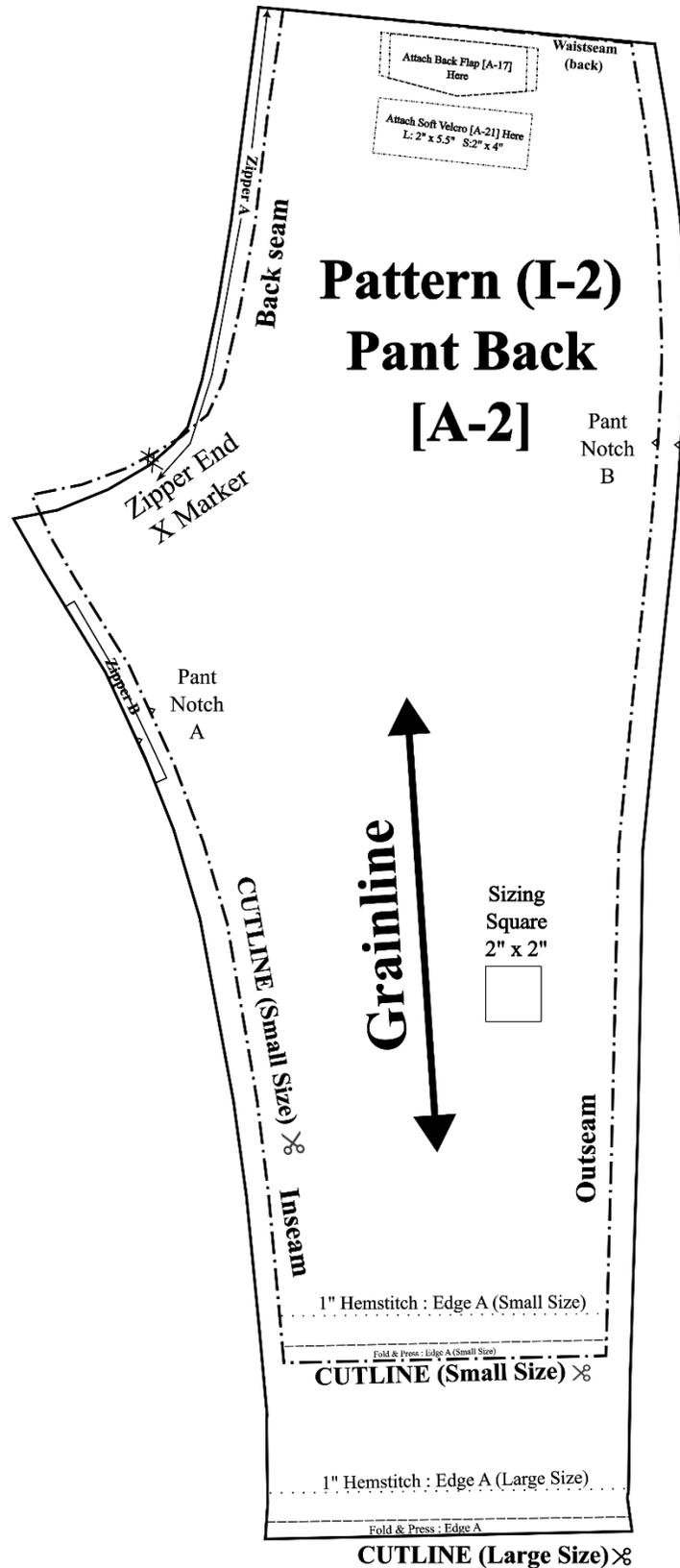


Figure 9-2. Pant Back [A-2]

(Printable version of Pattern (I-2) for printable version: 2_PantBack.png).

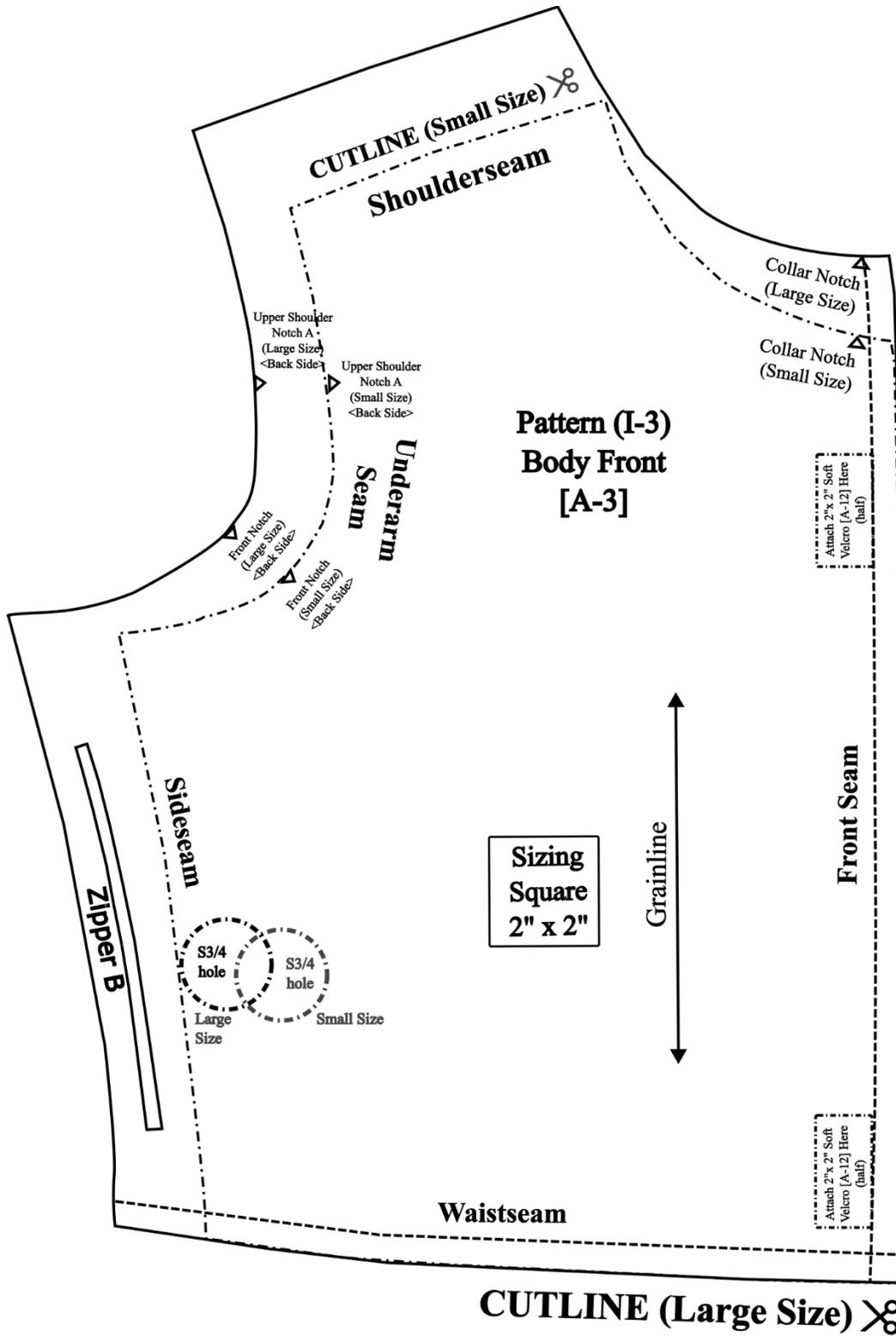


Figure 9-3. Body Front [A-3]
 (Printable version of Pattern (I-3) for printable version: 3_BodyFront.png).

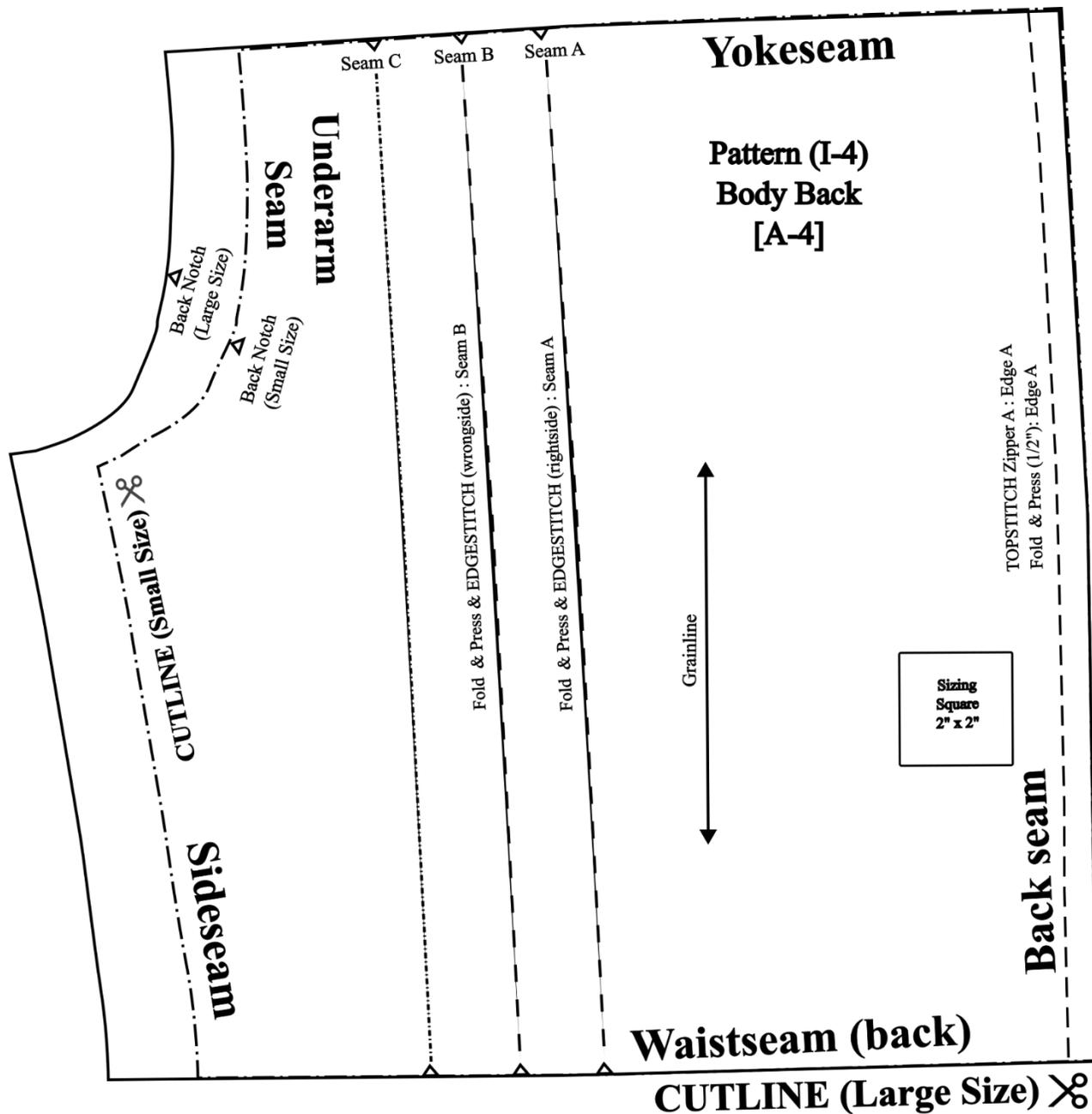


Figure 9-4. Body Back [A-4]
 (Printable version of Pattern (I-4) for printable version: 4_BodyBack.png).

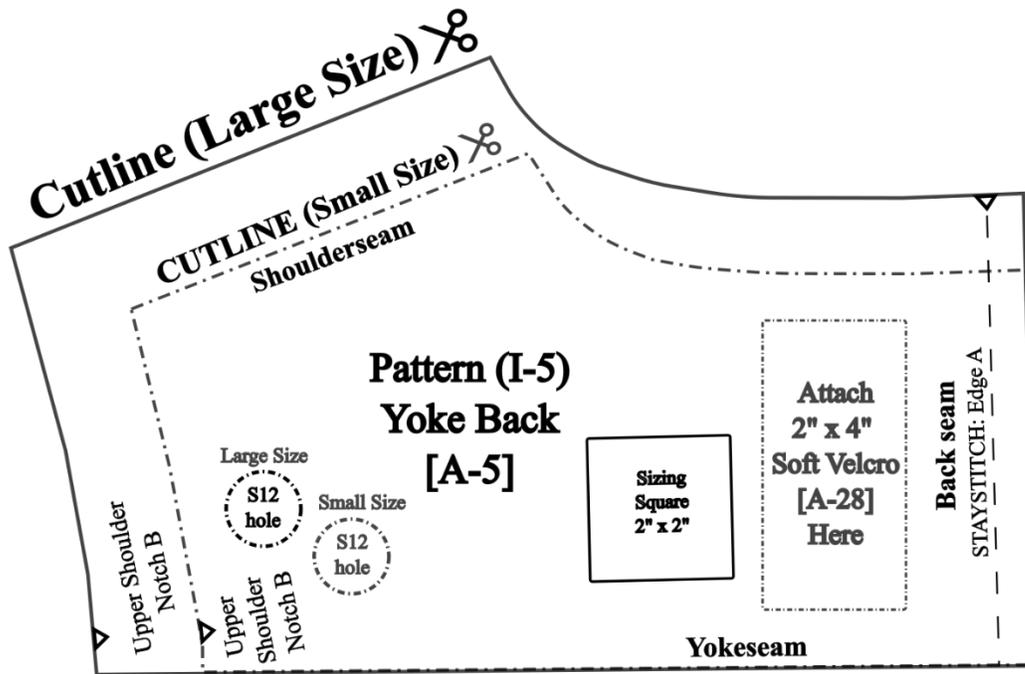
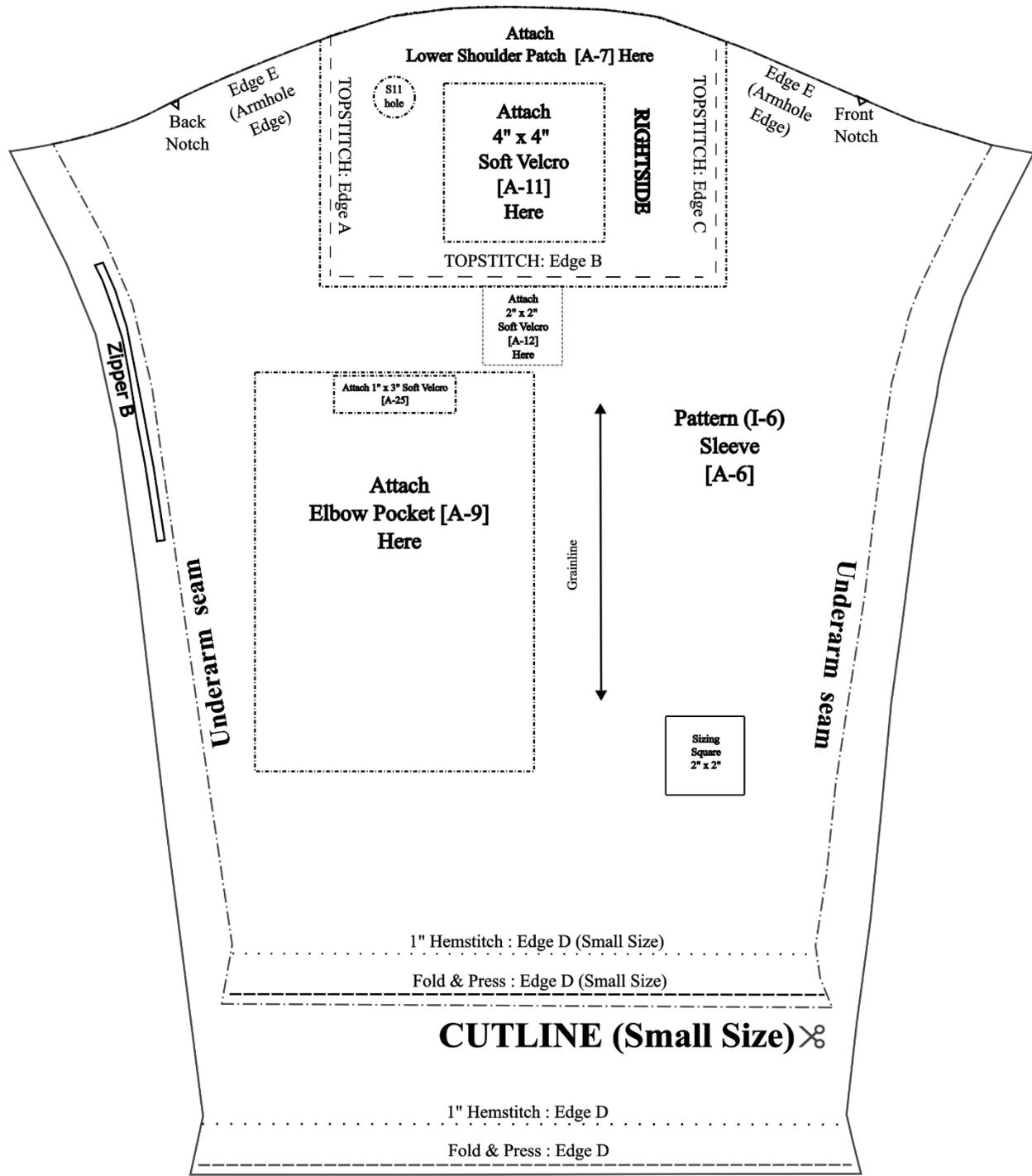


Figure 9-5. Yoke Back [A-5]
 (Printable version of Pattern (I-5) for printable version: 5_YokeBack.png).



Cutline (Large Size) ✂

Figure 9-6. Sleeve [A-6]

(Printable version of Pattern (I-6) for printable version: 6_Sleeve.png).

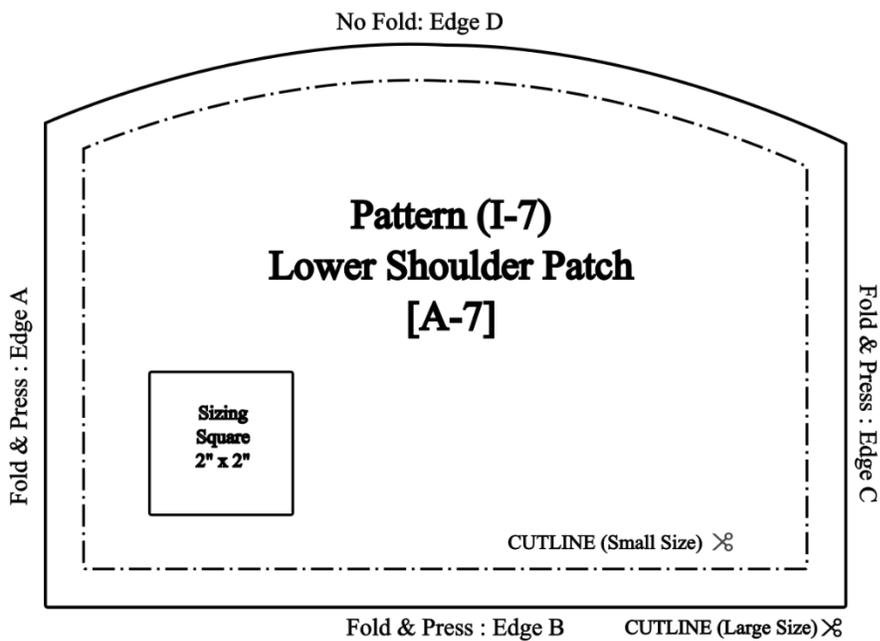


Figure 9-7. Lower Shoulder Patch [A-7]
 (Printable version of Pattern (I-7) for printable version: 7_LowerShoulderPatch.png).

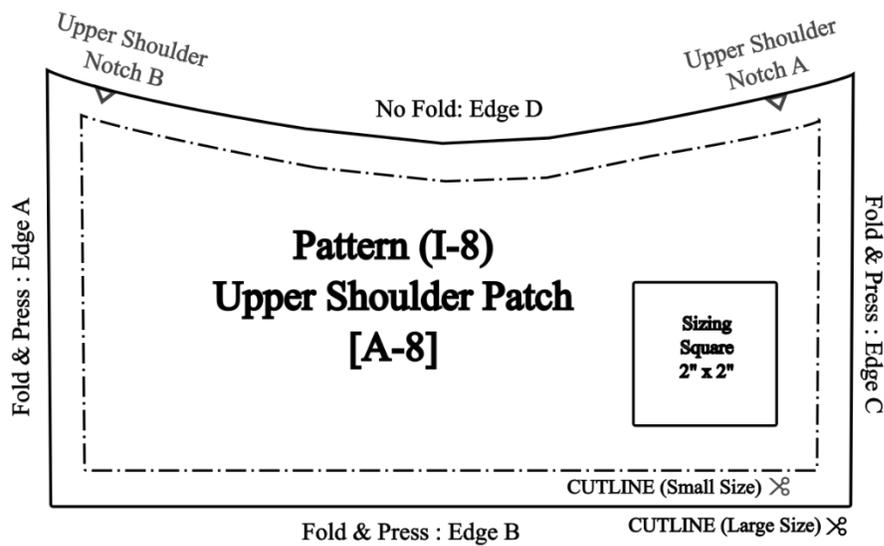


Figure 9-8. Upper Shoulder Patch [A-8]
 (Printable version of Pattern (I-8) for printable version: 8_UpperShoulderPatch.png).

Cut line ✂

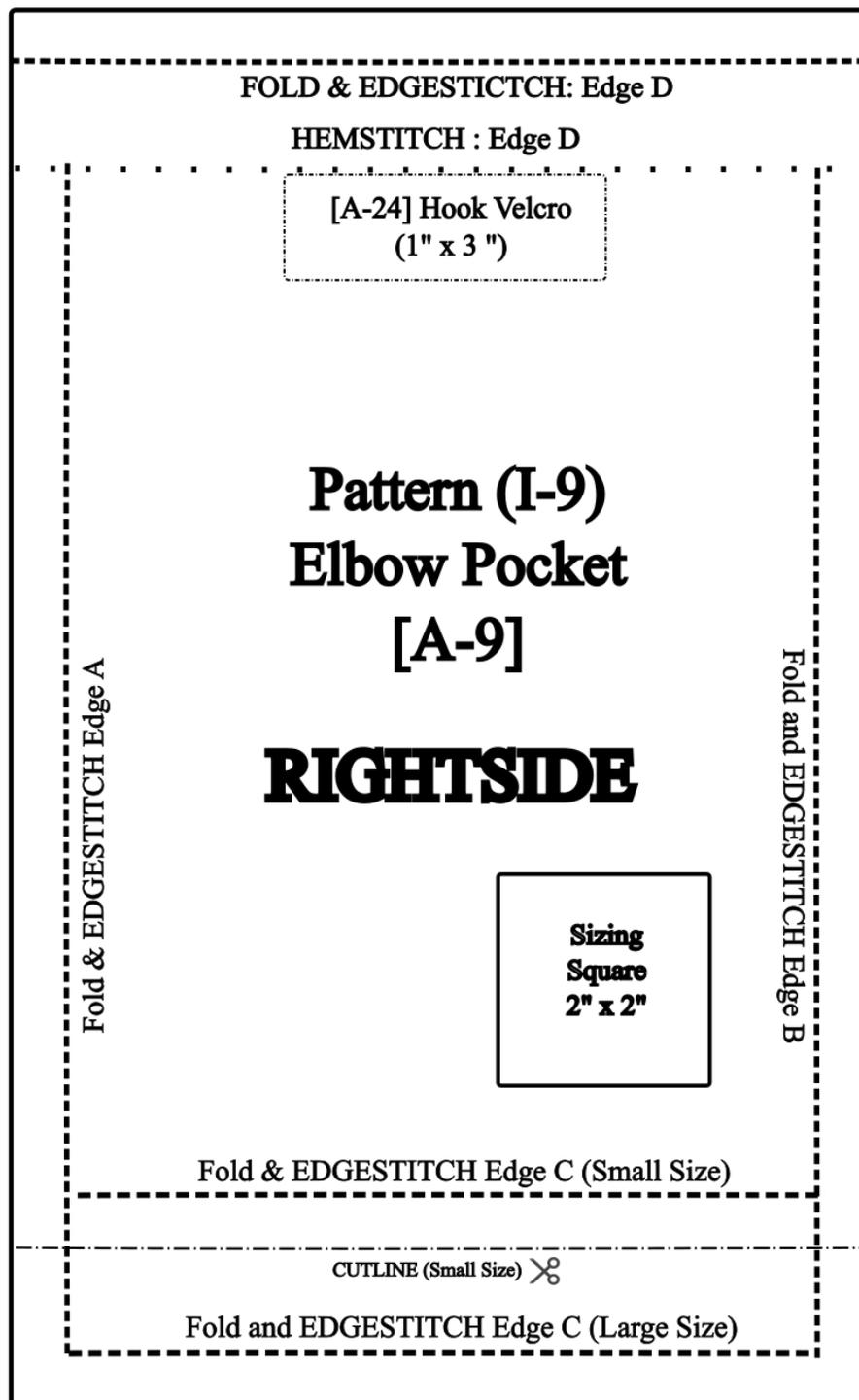


Figure 9-9. Elbow Pockets [A-9]
(Printable version of Pattern (I-9) for printable version: 9_ElbowPocket.png).

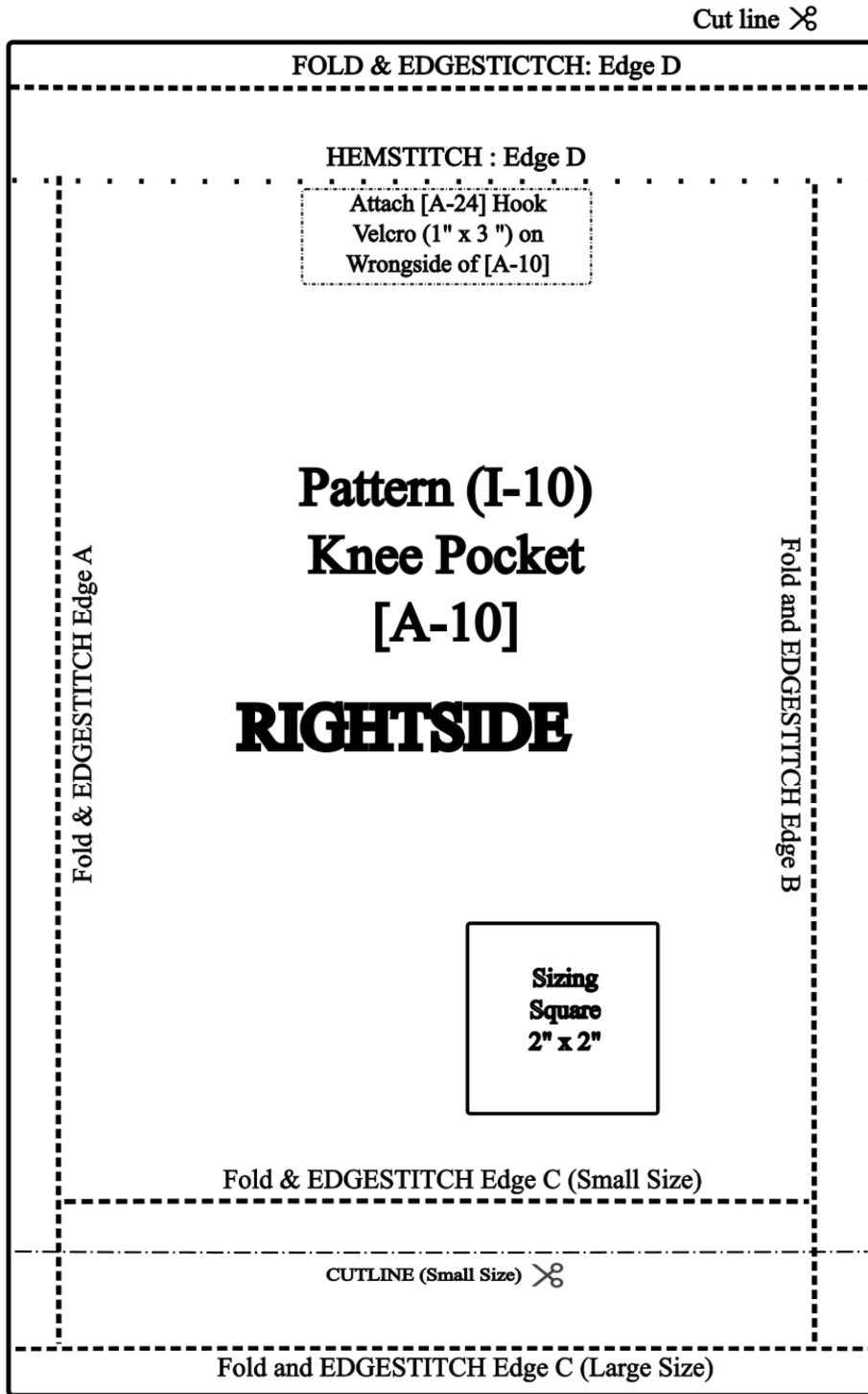


Figure 9-10. Knee Pockets [A-10]
(Printable version of Pattern (I-10) for printable version: 10_KneePocket.png).

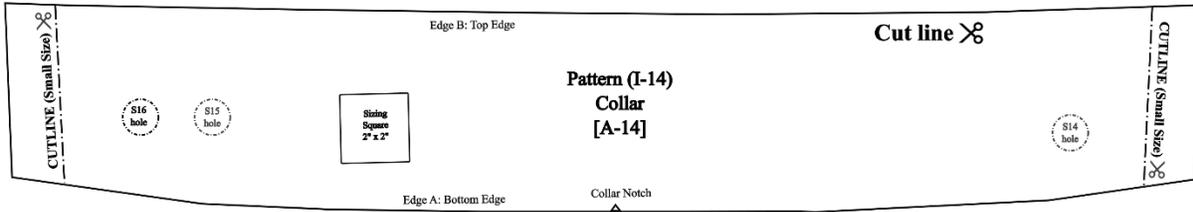


Figure 9-11. Collar [A-14]
 (Printable version of Pattern (I-14) for printable version: 14_Collar.png).

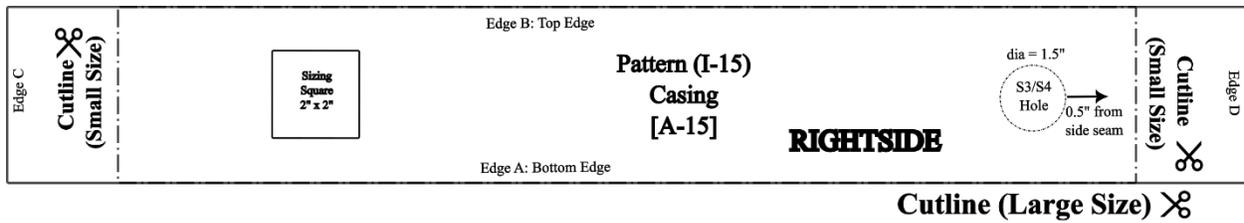


Figure 9-12. Casing [A-15]
 (Printable version of Pattern (I-15) for printable version: 15_Casing.png).

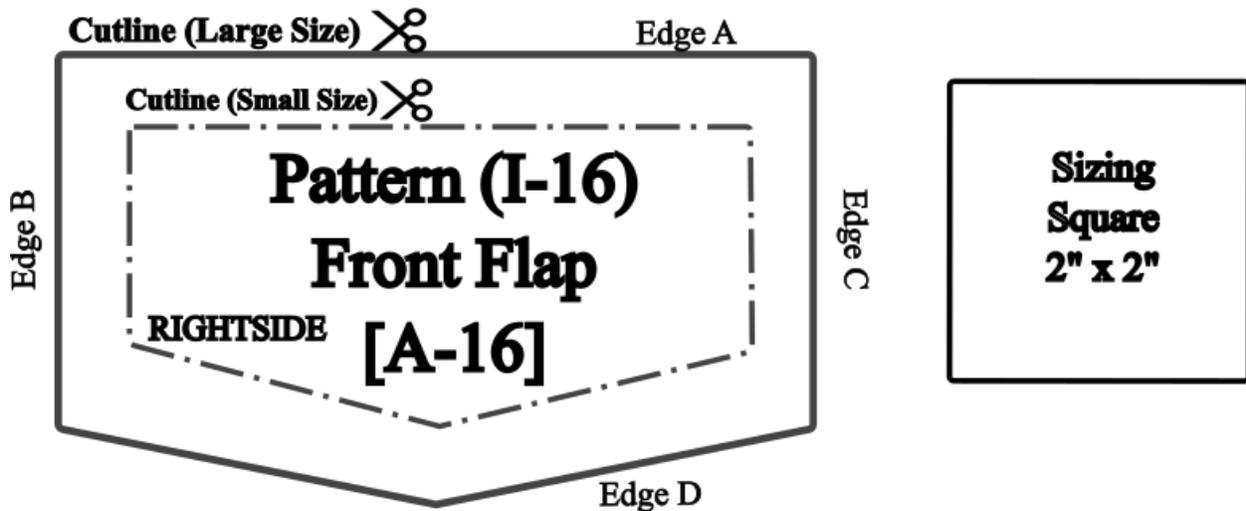


Figure 9-13. Front Flap [A-16]
 (Printable version of Pattern (I-16) for printable version: 16_FrontFlap.png).

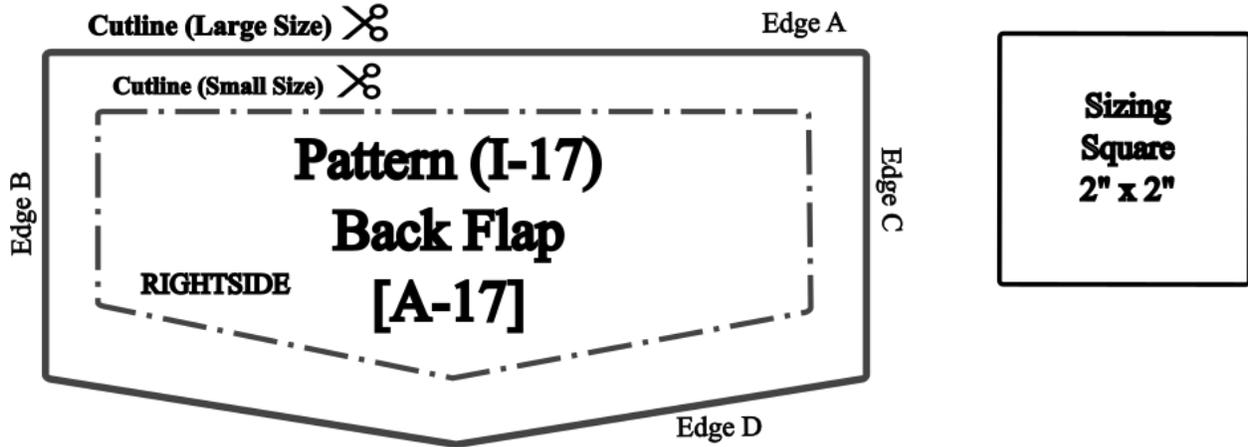


Figure 9-14. Back Flap [A-17]
 (Printable version of Pattern (I-17) for printable version: 17_BackFlap.png).

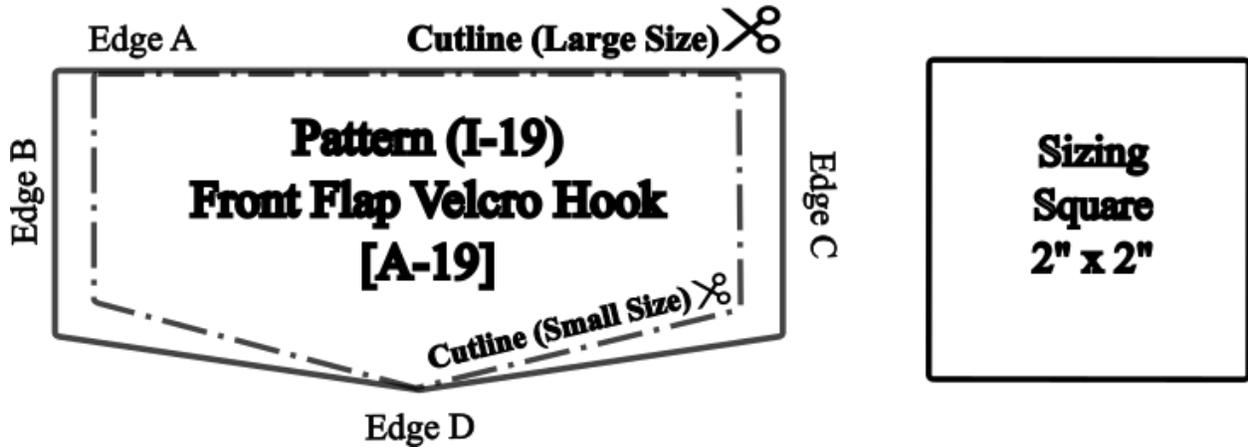


Figure 9-15. Front Flap Velcro Hook [A-19]
 (Printable version of Pattern (I-19) for printable version: 19_FrontFlapVelcroHook.png).

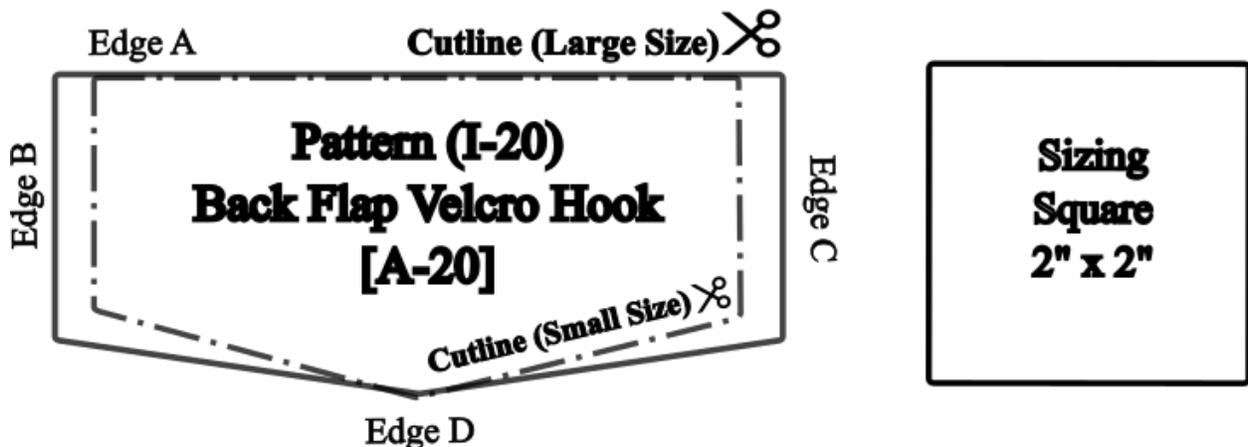


Figure 9-16. Back Flap Velcro Hook [A-20]
 (Printable version of Pattern (I-20) for printable version: 20_BackFlapVelcroHook.png).

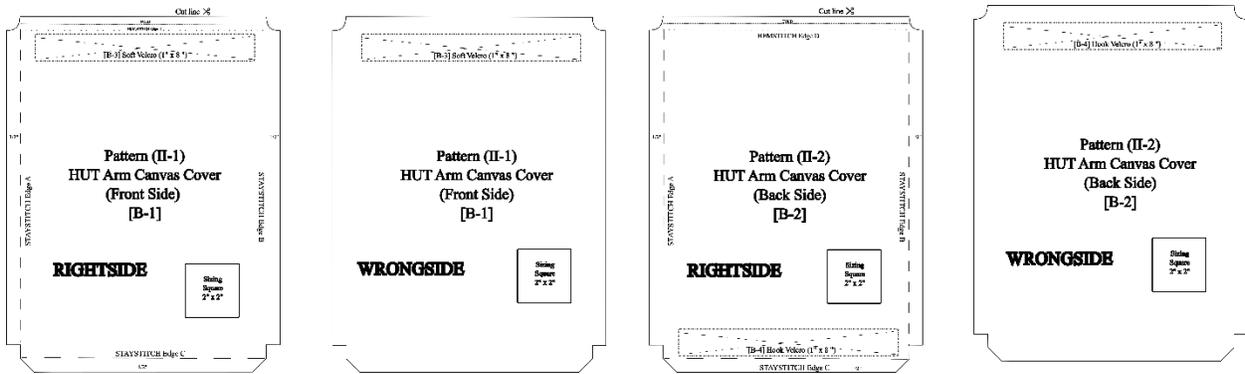


Figure 9-17. HUT Arm Canvas Cover (Front/Back) [B-1 and B-2]
 (Printable version of Pattern (II-1 to II-2) for printable version: II-1_HUTArmCover.png).

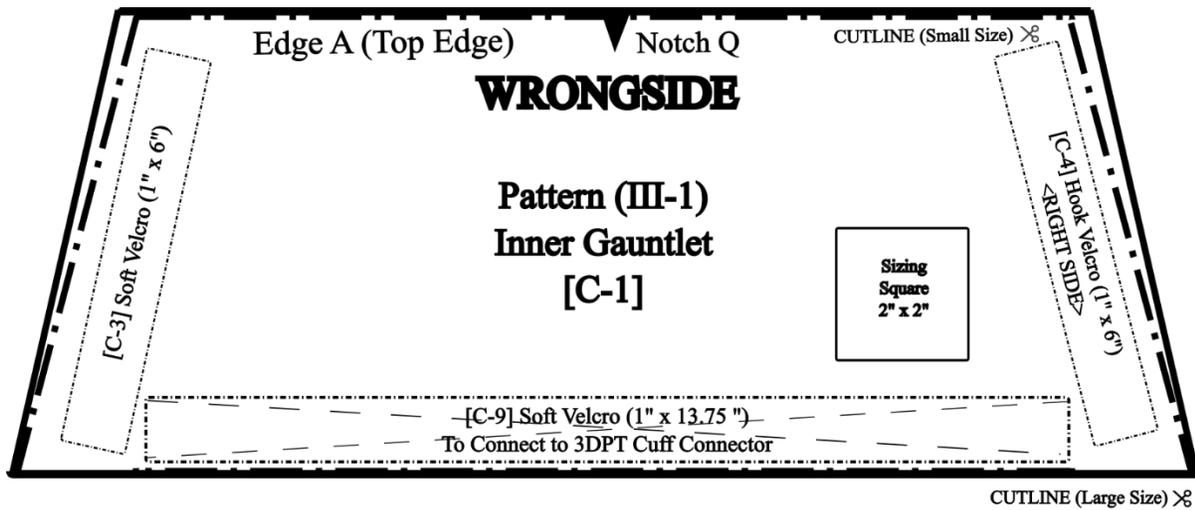


Figure 9-18. Inner Gauntlet [C-1]
 (Printable version of Pattern (III-1) for printable version: III-1_InnerGauntlet.png).

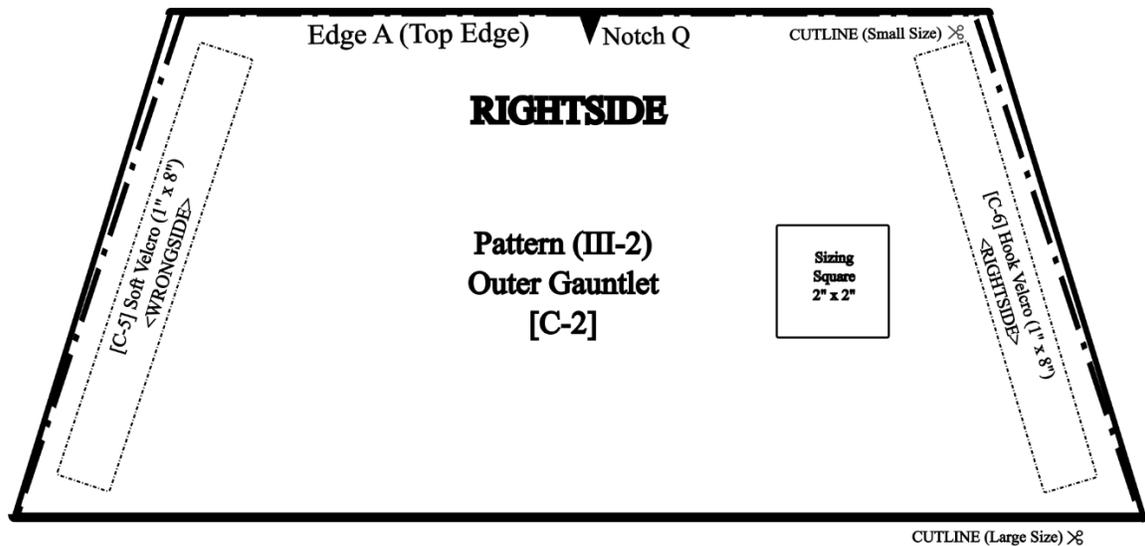


Figure 9-19. Outer Gauntlet [C-2]
 (Printable version of Pattern (III-2) for printable version: III-2_OuterGauntlet.png).

9.2 Appendix B: Emergency Egress Procedures

Table 9-1. Example Emergency Egress Procedures of HS3

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
Location: Treadmill				
		B.1	Perform study specific emergency calls.	
		B.2	Set treadmill resistance to '10' by pushing the brake forward. (if passive treadmill) or press emergency stop on motorized treadmill.	
		B.3	Detach the helmet ventilation fan's electrical cable from PLSS	Support the PLSS before detaching/cutting.
		B.4	Detach/remove the HUT by disconnecting the (x4) pip pins at the HUT's mounts then sliding the HUT past the subject(s) arms.	
		B.5	Detach (x2) LCG hoses on left side of subject(s).	These are concurrent steps.
		B.6	Detach/cut the (x2) shoulder, (x1) chest, and (x1) waist belt straps.	
		B.7	Remove the PLSS from the emergency area and set aside.	
		B.8	Slowly lower the subject(s) to a seated position on the base of the treadmill using the harness system.	These are subsequent steps.
		B.9	Support the subject(s) body weight and head/neck before cutting the safety harness.	
		B.10	Detach/cut the harness off the subject(s).	
		B.11	Slowly support subject(s) body and head weight and transition them off treadmill onto a flat, open space on the floor.	
		B.12	Slowly position/roll subject(s) to back.	
		B.13	Cut soft suit garment off subject(s).	
		B.14	Unzip LCG garment from subject(s) to expose chest/abdomen.	
		B.15	Inspect the area safely and begin to perform CPR if no pulse/respirations.	
Location: Open Space				
		B.1	Perform study specific emergency calls.	
		B.2	Detach the helmet ventilation fan cable from PLSS.	Support the PLSS before detaching/cutting.
		B.3	Gently lowered subject to a sitting position with one operator supporting head/neck from the front.	
		B.4	Detach/remove the HUT by disconnecting the (x4) pip pins at the HUT's mounts then sliding the HUT past the subject(s) arms.	These are concurrent steps.
		B.5	Detach (x2) LCG hoses on left side of subject(s).	
		B.6	Detach/cut the (x2) shoulder, (x1) chest, and (x1) waist belt straps.	
		B.7	Lean the subject(s) forward then remove the PLSS from the emergency area and gently set aside.	These are subsequent steps.
		B.8	Support the subject(s)'s body weight and head/neck and lay them down.	
		B.9	Detach/cut the harness off the subject(s).	
		B.10	Slowly support subject(s) body and head weight and transition them out of the sandbox onto a flat, open space on the floor.	

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
		B.11	Slowly position/roll subject(s) to back.	
		B.12	Cut soft suit garment off subject(s) and waist inhibitor.	
		B.13	Unzip LCG garment from subject(s) to expose chest/abdomen.	
		B.14	Inspect the area safely and begin to perform CPR if no pulse/respirations.	
Location: Donning Stand				
		B.1	Perform study specific emergency calls.	These are concurrent steps.
		B.2	Detach the helmet ventilation fan cable from PLSS.	
		B.3	Detach/remove the HUT by disconnecting the (x4) pip pins at the HUT's mounts then sliding the HUT past the subject(s) arms.	
		B.4	Detach (x2) LCG hoses on left side of subject(s).	
		B.5	Support subject head/neck/weight before detach/cut the (x2) shoulder, (x1) chest, and (x1) waist belt straps.	These are subsequent steps.
		B.6	Lean the subject(s) out of the donning stand	
		B.7	Support the subject(s) body weight and head/neck and lay them down.	
		B.8	Detach/cut the harness off the subject(s).	
		B.9	Slowly support subject(s) body and head weight and transition them onto a flat, open space on the floor.	
		B.10	Slowly position/roll subject(s) to back.	
		B.11	Cut soft suit garment off subject(s) and cut the waist inhibitor	
		B.12	Unzip LCG garment from subject(s) to expose chest/abdomen.	
		B.13	Inspect the area safely and begin to perform CPR if no pulse/respirations.	

9.3 Appendix C: Suit Sizing Steps

Table 9-2. Recommended HS3 System Sizing Procedures

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
TCU Sizing				
		C.1	<ul style="list-style-type: none"> <input type="checkbox"/> Use TCU (thin) tops and bottoms using regular subject clothing sizes. <input type="checkbox"/> Ask the subject(s) to change into the clothes in the locker room. <input type="checkbox"/> Show and walk the subject(s) to the locker rooms/ bathrooms. 	<i>Record the sizing information in the FAM Test Checklist</i>
Soft Suit and LCG Sizing				
		C.2	<p>LCG Sizing</p> <ul style="list-style-type: none"> <input type="checkbox"/> Start with subjects' general clothing size. <input type="checkbox"/> Have the subject(s) try on the LCG garments and confirm their sizing. <p>Note: M/L garment fits like a S to L, XL/2XL garment fits like a L to XL.</p> <p>Soft Suit Sizing</p> <ul style="list-style-type: none"> <input type="checkbox"/> Measure subject(s) height against the wall with tape measurer <ul style="list-style-type: none"> ○ Subject(s) < 6 feet: have them try on the size SMALL ○ Subject(s) >= 6 feet: size them to size LARGE <input type="checkbox"/> Confirm suit sizing: suit legs should hang past ankles so they can be tucked into boots. Zipper should be able to zip up fully. <input type="checkbox"/> <u>Soft suit can shorten the length with vertical Velcro waist constraints. Record the waist Velcro configuration.</u> 	<i>Record the sizing in TCL</i>
Boot Sizing				
		C.3	<ul style="list-style-type: none"> <input type="checkbox"/> Start with subject(s) shoe size and try on the closest boot size. <input type="checkbox"/> Ensure that they can tuck the soft suit into the boots. <input type="checkbox"/> Lean ankle back to tighten BOA strap as tight as they can. <input type="checkbox"/> <u>If needed, provide subject(s) with sole inserts to test boot fitting.</u> 	<i>Record the sizing in TCL</i>
Glove Sizing				

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS																
		C.4	Have subject(s) try on the S/M gloves. Ensure they can fully insert their hands/fingers and snap into the wrist bearings. If unsuccessful, try on the L gloves.	<i>Record the sizing in TCL</i>																
Waist inhibitor and Range of Motion Inhibitor Sizing																				
		C.5	<p>Have subject(s) try on 15 in Waist Inhibitor as default. Ensure pool noodle protrusion is 4 inches in both the front and back of the subject. (Refer to Figure E-3)</p> <ul style="list-style-type: none"> <input type="checkbox"/> If exceeding protrusion, size down to 10 in Waist Inhibitor. <input type="checkbox"/> If not protruding enough, size up to 18 in Waist Inhibitor. <p>NOTE: 15+ inch Waist Inhibitor does not fit within S/M Soft Suit, size inhibitor down or size up soft suit for optimized sizing.</p>	<i>Record the sizing in TCL</i>																
Spine Sizing and Shoulder/Lumbar Padding Placement																				
		C.7	<p>Spine Sizing</p> <ul style="list-style-type: none"> <input type="checkbox"/> Torso Length: Measure from the C7 vertebrae to the iliac crest (top of hip bones) using a soft tailor's tape. Record in TCL. <input type="checkbox"/> Replace the spine frame to match the torso height or subject height per table below. <p style="text-align: center;">Table 9-3. Spine/Frame Sizing Chart</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th></th> <th style="text-align: center;">Spine Size (in)</th> <th style="text-align: center;">Torso Length (in)</th> <th style="text-align: center;">Height (in)</th> </tr> </thead> <tbody> <tr> <td>Regular</td> <td style="text-align: center;">22</td> <td style="text-align: center;">< 17</td> <td style="text-align: center;"><5'10"</td> </tr> <tr> <td>Tall</td> <td style="text-align: center;">24</td> <td style="text-align: center;">17 – 19</td> <td style="text-align: center;">5'10" – 6'1"</td> </tr> <tr> <td>X-Tall</td> <td style="text-align: center;">26</td> <td style="text-align: center;">>= 19</td> <td style="text-align: center;">>= 6'1"</td> </tr> </tbody> </table>		Spine Size (in)	Torso Length (in)	Height (in)	Regular	22	< 17	<5'10"	Tall	24	17 – 19	5'10" – 6'1"	X-Tall	26	>= 19	>= 6'1"	<p><i>Record the sizing in TCL</i></p> <p>Spine Removal: Loosen/remove the (x6) screws holding the spine to the backplate.</p>
	Spine Size (in)	Torso Length (in)	Height (in)																	
Regular	22	< 17	<5'10"																	
Tall	24	17 – 19	5'10" – 6'1"																	
X-Tall	26	>= 19	>= 6'1"																	
		C.8	<p>Shoulder and Lumbar Padding Placement</p> <ul style="list-style-type: none"> <input type="checkbox"/> Subject(s) ingress into the HS3 softgoods. <input type="checkbox"/> Clip-in and tighten shoulder straps, waistbelt and chest strap <input type="checkbox"/> Shoulder Padding Adjustment <ul style="list-style-type: none"> o Shift down: If gap (>= 1-2") between shoulders and the padding. o Shift up: If the shoulder padding straps is too close to the clavicle/neck (i.e., most padding not sitting on top of shoulder). <p><u>Note: you can get away with not having to move the shoulder padding (if small gaps are present) by tightening the shoulder straps down more, but make sure it does not make the subject(s) uncomfortable/too tight.</u></p> <ul style="list-style-type: none"> <input type="checkbox"/> Verify/adjust lumbar pad is positioned on hips and lower back/on butt. 	<p>Shoulder Pad:</p> <ol style="list-style-type: none"> 1. Detach Velcro shoulder blade. 2. Slide/tilt shoulder padding to desired location by using the grooved channels built into the spine, then reseat the Velcro padding. 																
Spine Padded Harness Sizing																				

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS								
		C.9	<p>Spine Padded Harness Sizing</p> <ul style="list-style-type: none"> <input type="checkbox"/> Waist Circumference: Measure the subject's waist slightly above the waistline on hips using a soft tailor's tape. Record in TCL. <input type="checkbox"/> Install the harness system to match the waist size of the subject per the table below. <ul style="list-style-type: none"> ○ To replace the harness system, remove lower lumber padding Velcro to access the spine. Remove vertical Velcro to release padding and replace harness system with correct size by adhering Velcro. <p>Table 9-4. Spine Padded Harness Sizing Chart</p> <table border="1"> <thead> <tr> <th></th> <th>S/M (qty – 2)</th> <th>L/XL (qty – 2)</th> <th>Women's (qty – 1)</th> </tr> </thead> <tbody> <tr> <td>Waist Size:</td> <td>25-34</td> <td>34-52</td> <td>25-44</td> </tr> </tbody> </table>		S/M (qty – 2)	L/XL (qty – 2)	Women's (qty – 1)	Waist Size:	25-34	34-52	25-44	<i>Record the sizing in TCL</i>
	S/M (qty – 2)	L/XL (qty – 2)	Women's (qty – 1)									
Waist Size:	25-34	34-52	25-44									

9.4 Appendix D: Safety Harness Creation/Donning

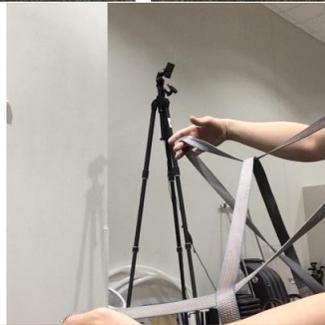
Table 9-5. HS3 Safety/Treadmill Positioning Harness Procedure

Intl. FAM	Intl. TEST	SEQ	OPERATION	REMARKS
		D.1	Prepare a water knot to make a giant loop of the safety tether	
		D.2	<p>Subject(s) gets in position for the safety harness. Harness should run from behind the neck to front of each shoulder.</p> <p>Note: make sure equal length on each side</p> <p>Note: water knot is behind the neck.</p> 	
		D.3	<p>Grab the bottom section and pull forward between legs to form a loop.</p> <p>Note: make sure the straps loop behind the heels.</p> <p>Note: black arrows points to the shoulder straps.</p> 	

Grab onto “shoulder straps” (run from heels to shoulder). Pull the shoulder straps INWARD through the loop made in last step (see blue markings). Then, drop the two shoulders straps outward/down to the waist. Grab onto the “shoulder strap” section when finished.



D.4



Pull the “shoulder strap” outward and then to the sides to tighten by pulling to the left and right.

D.5

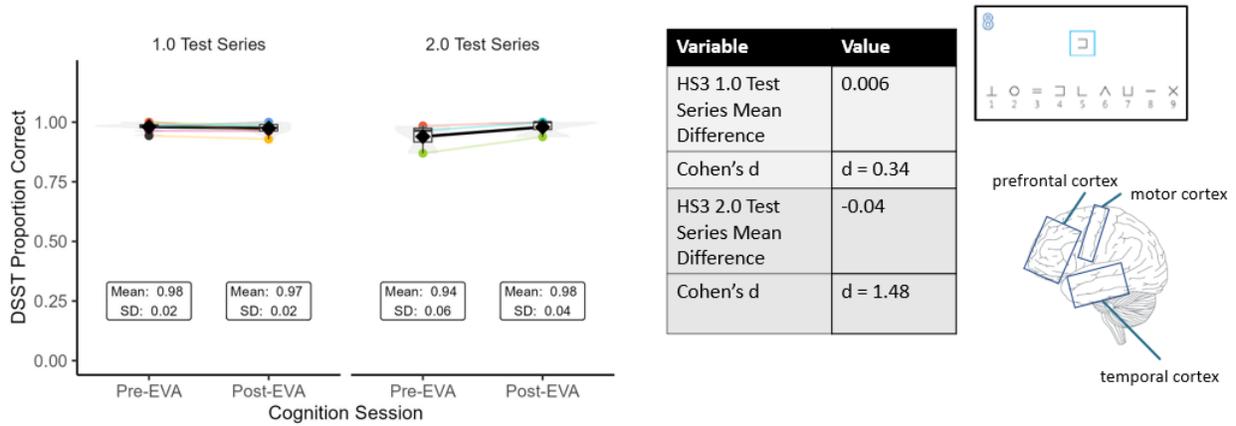


Pull shoulder straps upward

D.6



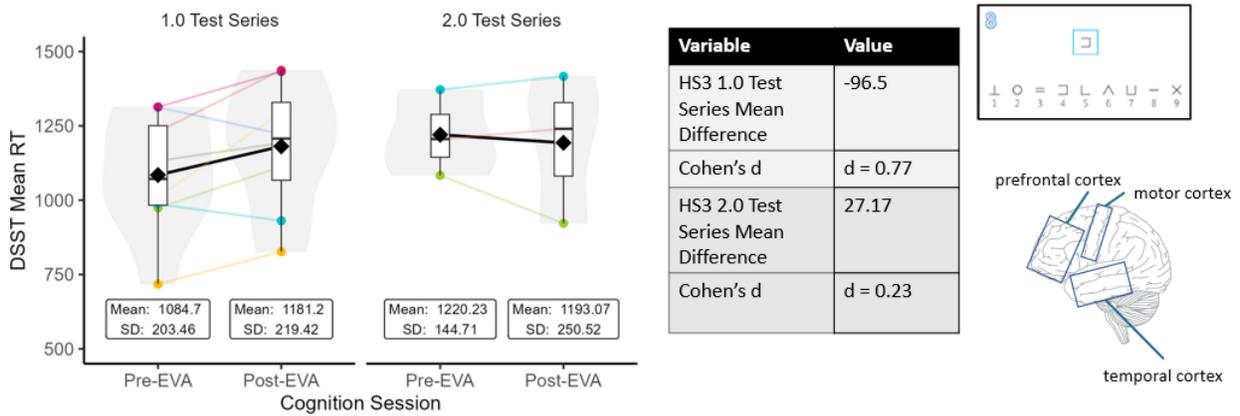
9.5 Appendix E: Additional Cognitive Performance Results from HS3. 2.0 Study



Lower values = **worse** performance

Worse pre-EVA performance in 2.0 compared to 1.0 Test Series, but similar post-mission performance

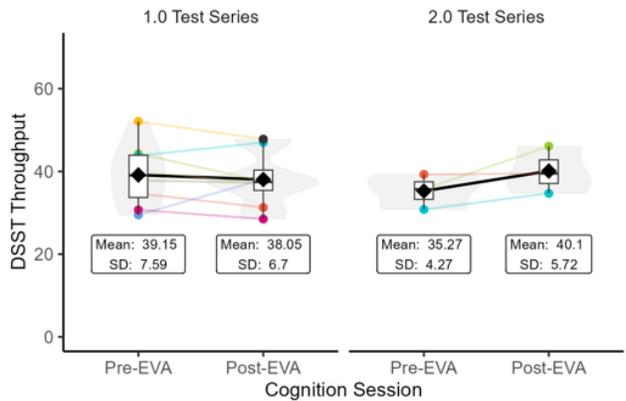
Figure 9-20. Digit-Symbol Substitution Test (DSST) Proportion Correct Shown for HS3 1.0 vs. 2.0.



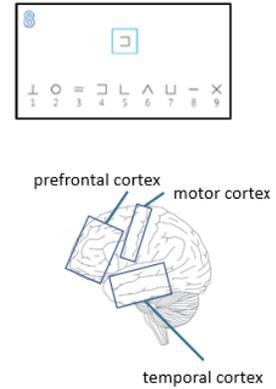
Higher values = **worse** performance

Improved post-EVA performance in 2.0, unlike 1.0 Test

Figure 9-21. Digit-Symbol Substitution Test (DSST) Mean Reaction Time (RT) shown for HS3 1.0 vs. 2.0.



Variable	Value
HS3 1.0 Test Series Mean Difference	1.1
Cohen's d	d = 0.23
HS3 2.0 Test Series Mean Difference	-4.83
Cohen's d	d = 0.94

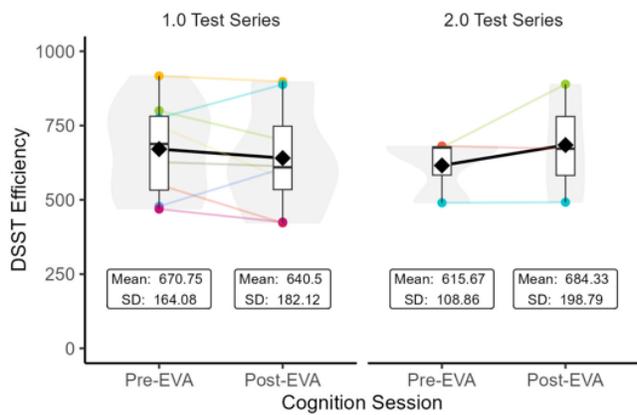


Lower values = **worse** performance

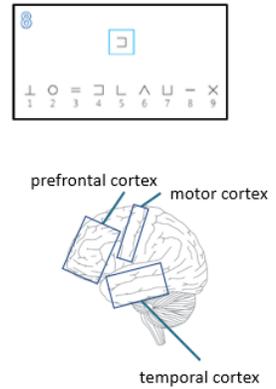
Throughput = Number of correct responses per minute

Improved post-EVA performance in 2.0, unlike 1.0 Test

Figure 9-22. Digit-Symbol Substitution Test (DSST) Throughput (Number of correct responses per minute) shown for HS3 1.0 vs. 2.0.



Variable	Value
HS3 1.0 Test Series Mean Difference	30.25
Cohen's d	d = 0.28
HS3 2.0 Test Series Mean Difference	-68.67
Cohen's d	d = 0.55

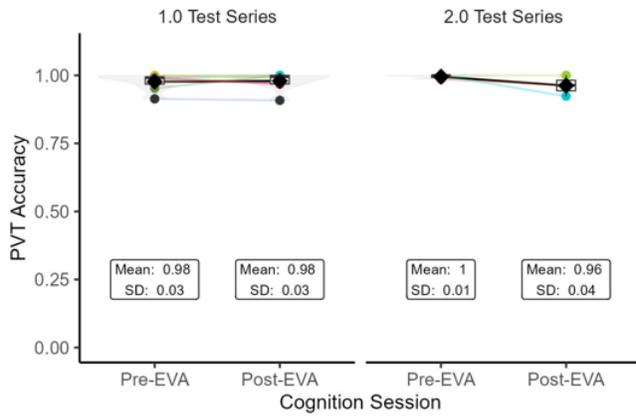


Lower values = **worse** performance

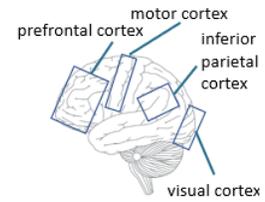
Efficiency = Based on deductions for false starts and long responses

Improved post-EVA performance in 2.0, unlike 1.0 Test

Figure 9-23. Digit-Symbol Substitution Test (DSST) Efficiency (Based on deductions for false starts and long responses) shown for HS3 1.0 vs. 2.0.



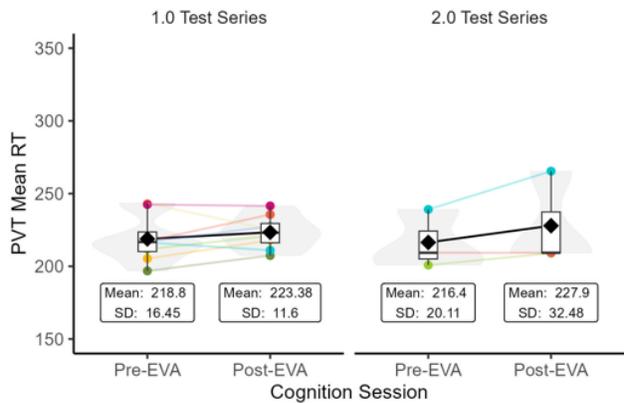
Variable	Value
HS3 1.0 Test Series Mean Difference	-0.003
Cohen's d	d = 0.11
HS3 2.0 Test Series Mean Difference	0.03
Cohen's d	d = 0.83



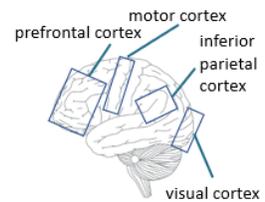
↓ Lower values = **worse** performance

Worse post-EVA performance in 2.0 compared to 1.0 Test Series

Figure 9-24. Psychomotor Vigilance Test (PVT) Accuracy shown for HS3 1.0 vs. 2.0.



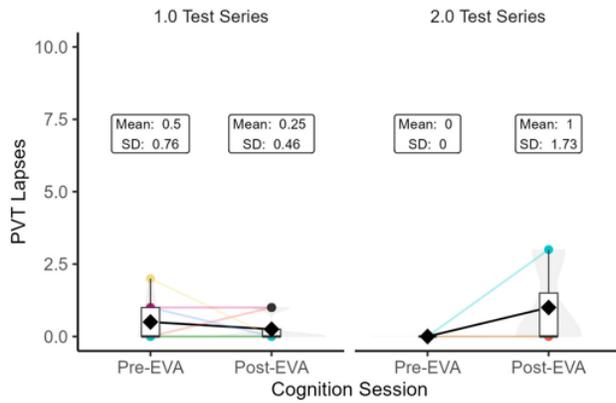
Variable	Value
HS3 1.0 Test Series Mean Difference	-4.58
Cohen's d	d = 0.38
HS3 2.0 Test Series Mean Difference	-11.5
Cohen's d	d = 0.85



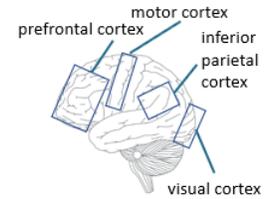
↑ Higher values = **worse** performance

Worse post-EVA performance in 2.0 compared to 1.0 Test Series

Figure 9-25. Psychomotor Vigilance Test (PVT) Mean Reaction Time (RT) shown for HS3 1.0 vs. 2.0.



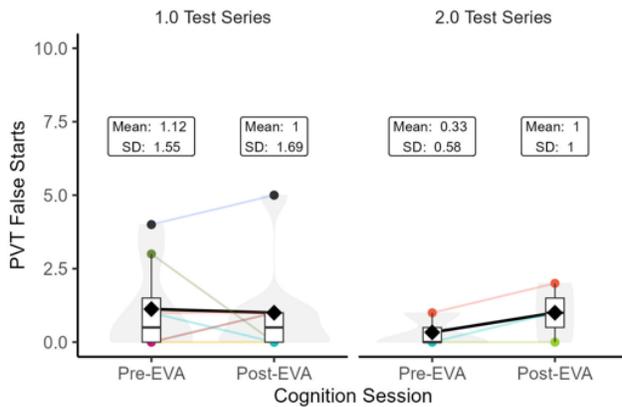
Variable	Value
HS3 1.0 Test Series Mean Difference	0.25
Cohen's d	d = 0.28
HS3 2.0 Test Series Mean Difference	-1
Cohen's d	d = 0.58



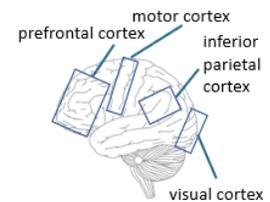
↑ Higher values = **worse** performance **Lapse** = Response time > 355 ms

Worse post-EVA performance in 2.0 compared to 1.0 Test Series

Figure 9-26. Psychomotor Vigilance Test (PVT) Lapses (lapse = response time > 355 ms) shown for HS3 1.0 vs. 2.0.
 (Cognition session 1 = Pre-EVA; Cognition session 2 = Post-EVA). Worse post-EVA performance in 2.0 compared to 1.0 Test Series.



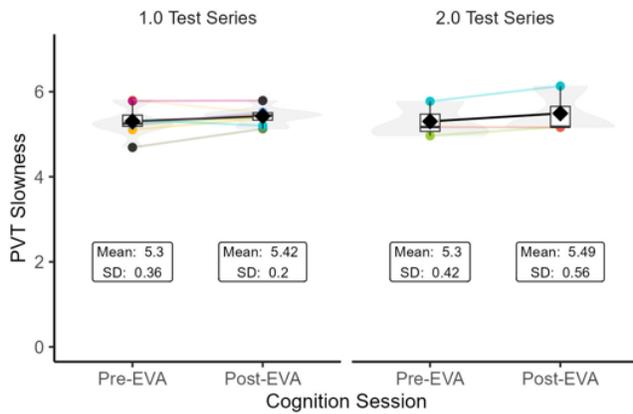
Variable	Value
HS3 1.0 Test Series Mean Difference	0.13
Cohen's d	d = 0.09
HS3 2.0 Test Series Mean Difference	-0.67
Cohen's d	d = 1.15



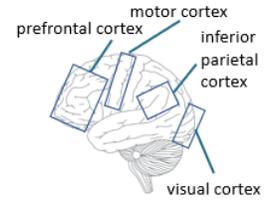
↑ Higher values = **worse** performance **False Start** = Responding before counter appears on screen

Worse post-EVA performance in 2.0 compared to 1.0 Test Series

Figure 9-27. Psychomotor Vigilance Test (PVT) False Starts (responding before counter appears on screen) shown for HS3 1.0 vs. 2.0.



Variable	Value
HS3 1.0 Test Series Mean Difference	0.13
Cohen's d	d = 0.49
HS3 2.0 Test Series Mean Difference	-0.19
Cohen's d	d = 1.00

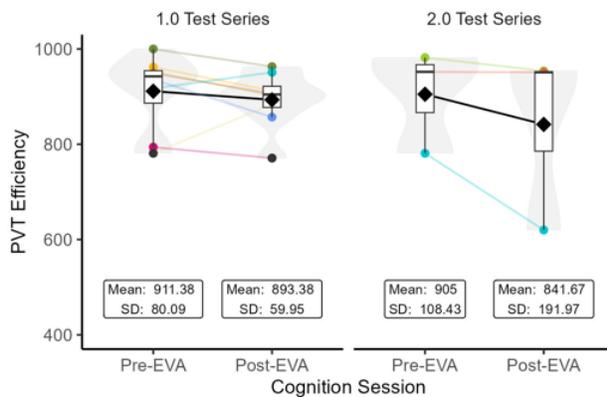


↑ Higher values = **worse** performance

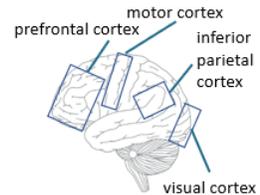
Slowness = 10 – Mean reciprocal of reaction time

Worse post-EVA performance in 2.0, similar to 1.0 Test Series

Figure 9-28. Psychomotor Vigilance Test (PVT) Slowness (10 – Mean reciprocal of reaction time) shown for HS3 1.0 vs. 2.0.



Variable	Value
HS3 1.0 Test Series Mean Difference	18
Cohen's d	d = 0.31
HS3 2.0 Test Series Mean Difference	63.3
Cohen's d	d = 0.74



↓ Lower values = **worse** performance

Efficiency = Based on deductions for false starts and long responses

Worse post-EVA performance in 2.0, similar to 1.0 Test Series

Figure 9-29. Psychomotor Vigilance Test (PVT) Efficiency (Based on deductions for false starts and long responses) shown for HS3 1.0 vs. 2.0.

9.6 Appendix F: HS3 Hazards and Controls for Reference

Table 9-6. HS3 Hazards and Controls

Hazardous Condition	Cause	Effect	Control(s)	Control Verification
Electrical	Inadequate power supply, improper installation of instrument, power cords frayed, poor ground, improper operation or maintenance of instrument, exposure to energized parts. Facility: Electrical-faulty breakers, improper grounding.	Personal injury or hardware damage	1. Operation and suit setup will follow procedures. 2. All cables will be properly insulated. 3. Consolidated battery pack used during suited operation. 4. Liquid coolant feedwater capped and sealed.	1. Pre-test inspection of cables and hardware per HS3 pre-test checklist. 2. Liquid coolant feedwater checklist. 3. Liquid coolant feedwater pre-test leak check.
Emergency Egress	Inability to remove a subject from the suit simulator	Personal Injury	1. A spotter will aid as required to the subject during suited activities. 2. Operators trained in emergency egress procedures. 3. Facility emergency evacuation training.	1. Operator Training 2. Emergency egress procedure checklist
Falls on the same level	Falling during suited operations	Personal Injury	1. A spotter will aid as required to the subject	1. Pre-test inspection per

			<p>during suited activities.</p> <ol style="list-style-type: none"> The subject will wear a positioning harness to provide stability during treadmill activities. Operators trained in harness adjustment. Pre-test inspection of work area to verify trip hazards are removed. 	<p>HS3 pre-test checklist.</p> <ol style="list-style-type: none"> Operator training Verify appropriate boot tread is installed per pre-test checklist.
Sharp edges/pinch points/ contact with rotating components/ contact with donning stand	Inadvertent contact with sharp edges, pinch points, and/or corners.	Personal Injury	<ol style="list-style-type: none"> Sharp edges are mitigated during suit design. Pinch Points and rotating parts are covered internally and externally. Suited subject wears a layer of clothing while in HS3 to add a layer of protection. Pinch points on donning stand are covered and sharp edges are mitigated during donning stand design. 	<ol style="list-style-type: none"> Pre-study Inspection for sharp edges per checklist. Pre-study Checklist verifies tape or padding in place. Operator training
Musculoskeletal (MSK) Injury	Inadequate warm-up,	Personal Injury	1. Operators will be present	Operator will give subject time to

	stretching, or Hydration. High exertion on the treadmill. Weight loading from the suit.		during all testing to monitor the subject. 2. Subject will be provided with water should they desire it. 3. Subject to have availability to sit and offload the suit during task breaks.	stretch, pause, or offload the suit if desired. Survey will be used to capture any injuries/hotspots that occur. Padding/adjustments can be made as requested by subject or solution to potential hotspot.
Delayed onset muscle soreness	Performing walking tasks.	Personal Injury	1. Test personnel will be present during all exercise sessions to monitor the subject.	Operators will recommend stretching exercises after the test. Subject will be encouraged to report discomfort.
Cardiovascular Event	Cardiovascular disease, arrhythmia, or another physiological anomaly.	Serious cardiovascular injury and/or death.	1. Subjects shall be pre-screened for history of cardiovascular disease and must have successfully completed medical examination within the last 12 months. 2. All operators to be BLS trained. 3. Automated External Defibrillator (AED) in the vicinity of the test area.	Subjects will be requested and cleared per study qualifications.
Pressure Points	Improper suit fit or restraint	Personal Injury	1. Subjects instructed to inform the	1. Pre-test donning checklists 2. Operator training

	systems on equipment		operators of suit discomfort. 2. Add or adjust padding 3. Operators assist in adjustment of suit.	
Skin Irritation	Rubbing of weighted suit at specific pressure points during ambulation.	Personal Injury	1. Subject required to wear athletic clothing under suit. 2. Mole skin available as necessary. 3. Subject can terminate test at any time.	1. Pre-test donning checklists
Hygiene	Multiple users contaminate the equipment or garments with sweat, etc.	Personal Injury or Illness	Following operations, operator will wipe down the suit or any other components that may encounter sweat or other bodily fluids with Clorox wipes and Clorox fabric spray.	Reference operations procedure which shows instructions for the technician to clean the device where necessary after each use.
Glasses Fogging	Inability to see through safety glasses	Personal injury or loss of field of view	1. Operator will ensure proper fit. 2. Air flow into helmet over face and glasses 3. Air flow in helmet set to 29-30 L/min	1. Pre-test checklist 2. Pre-equipment verification 3. Operator certification
Restricted Breathing	Improper fit of COSMED Metabolic Analyzer	Personal Injury	1. Operators trained on COSMED mask fit and	1. Pre-test checklist 2. Donning checklist 3. Pre-equipment

			<ul style="list-style-type: none"> operation. 2. Follow COSMED setup-checklist 3. Operator to perform fit check and breath check. 	<ul style="list-style-type: none"> verification 4. Operator training
Face and Nose Irritation	Improper fit of COSMED mask	Skin irritation may cause discomfort	<ul style="list-style-type: none"> 1. Mole skin or bandage available prior to mask donning to prevent skin rubbing. 2. Operators trained to perform proper mask fit check. 	<ul style="list-style-type: none"> 1. Pre-test checklist 2. Operator training

9.7 Appendix G: List of files included in NASA Release

The following directories of files will be included as part of the open-source report release:

1. **CAD Files/:** include all CAD files (assembly and part) for HS3 and donning stand.
 - Please review README file in the directory
 - **Donning stand files/:** contain donning stand 3D CAD files.
 - **HS3V2.5 Files/:** contain main HS3 assembly in .step and .stl format.
 - **STEP FILES/:**
 - [HS3V2.5 PLSS and HUT \(assembly file\).step](#)
This is the main assembly file of HS3. It was exported as a single assembly in .step format.
 - [HS3V2.5 PLSS and HUT.zip](#)
This is the main assembly file exported in .zip format. Each part file within the assembly is exported as individual .step file. These files can be imported into various CAD software to see/edit the assembly file and all its individual parts. This exported assembly is based on the Large-XL sized HUT and Rail Struts.
 - [AdditionalConfigurationOption](#): includes additional sizes and/or hardware options that can be used for different configuration selection, such as the 300W egretech power bank shelf, Volumetric power bank .zip file, Carriage Rail Struts (S-M size), and the Small HUT.
Since there were very few parts that differed from the Large-XL and Small-M HS3 assemblies, the Small HUT and S-M Rail Struts were exported separately instead of making another entire assembly file.
 - **STL FILES:** similar content but in .stl format
 - **Printable Files folder/:** contains the .stl files for all parts (HS3 assembly and Donning Stand) that were 3D printed.
2. **Softgoods Pattern Files/:** include all soft goods pattern files (Pattern I-1 to I-20, II-1 to II-2, and III-1 to III-2 per Table 4-25).
 - **PDF_PRINTABLE_VERSION:** contains PDF versions of pattern files. The 100% size should matches the actual print size. Users might need to print it on a plotter, e.g., at FedEx. Or can print it on multiple pieces of letter size paper.
 - **svg:** .svg editable files for users to update their design as needed
3. **Bill of Materials:** Excel version of bill of materials. Mapping to Section 4.6 for Bill of Materials. (File name: EEPL_HS3v2.5_HI_BOM_verA_externalReleases.xlsx)

9.8 Appendix H: 3D Printing and Slicer Settings

For the 3D printed components, our team used two different 3D printers that are commercial equipment: a Gigabot 4 XL (Re:3D, Houston, TX USA) and an Ultimaker S5 (Ultimaker, Netherlands, EU). The Gigabot 4 is an enclosed printer offering a very large print volume of 600 x 600 x 590mm length-width-height, allowing us to print larger components with ABS, such as our PLSS walls, backplate, and our HUT. The Ultimaker S5 is not an enclosed printer but allows us to print smaller components in tough PLA, such as our donning stand components, lever handles, and so forth. In terms of material choice, we chose ABS as our primary material for the PLSS and HUT components due to the impact-resistant, chemical-resistant, and flexible yet strong characteristics that ABS is widely known for. Since our PLSS and HUT are supporting weight of limbs and HS3 hardware as well as has a mounted backpacking frame and harness that is constantly flexing when the wearer bends over, ABS was the best, cheapest, most widely available material for our specific application.

For the slicer software, our team is using Ultimaker Cura v5.9.0 to prepare our files for 3D printing. While the Gigabot 4 is not natively used with Cura – rather, Simplify3D – our team followed the simple steps on Re:3D’s website to be able to use Cura instead of Simplify3D for preparing GCODE files that are compatible with the Gigabot’s hardware and Klipper and Moonraker interfaces.

For our print material, we used IC3D ABS and Ultimaker Tough PLA (H-26, H-27 in BOM) due to their costs, low lead times, and reliability in prints/print success rates.

We recommend you reach out to Re:3D (if you are using a Gigabot printer) or your manufacturer of your 3D printer for any assistance and troubleshooting you may run into or need. Acknowledging Re:3D for their constant support, real-time team calls, and for helping swap/replace some hardware as well as give great feedback and troubleshooting tips when we needed it most.

In the BOM, we specify printer settings A, B, and C for our parts printed in ABS and Tough PLA. In the lists below, we outline all settings that were adjusted/your team would need to know or have for printing any of the components on a Gigabot or Ultimaker printer. While these settings may not fit your application or hardware, these settings – primarily the settings for the Gigabot – were tweaked significantly to give the best possible prints with our equipment and within our work environment. Note that our print settings only use one extruder and use the print material as the support material, too. If any print settings are not specified, assume the default material settings and ‘0.2mm normal’ profile were used for those settings or the slicing software automatically calculate the setting numbers.

Print Settings A (ABS – default for larger, longer prints):

```
[general]
version = 4
name = ABS v7
definition = fdmprinter
```

```
[metadata]
type = quality_changes
quality_type = normal
intent_category = default
position = 0
setting_version = 24
material_bed_temperature = 110
```

```
[values]
bottom_layers = =999999 if infill_sparse_density == 100 and not magic_spiralize else
math.ceil(round(bottom_thickness / resolveOrValue('layer_height'), 4))
brim_gap = 0.03
brim_line_count = 30
brim_width = 15
cool_fan_enabled = True
cool_fan_speed = 0
cool_min_layer_time = 10
infill_overlap = 22
infill_pattern = gyroid
infill_sparse_density = 25
initial_layer_line_width_factor = 120
material_final_print_temperature = 240
material_flow_layer_0 = 107
material_initial_print_temperature = 210
material_print_temperature = 260
material_print_temperature_layer_0 = 240
optimize_wall_printing_order = True
raft_airgap = 0.2
raft_interface_speed = 65
raft_speed = 65
raft_surface_layers = 3
raft_surface_speed = 65
roofing_layer_count = 1
skirt_brim_speed = =speed_layer_0
skirt_gap = 15
speed_infill = 50
speed_layer_0 = =speed_print * 30 / 60
speed_print = 100
speed_roofing = =speed_topbottom
speed_support = 60
speed_support_infill = =speed_support
speed_support_interface = =speed_support / 1.5
speed_topbottom = =speed_print / 2
speed_wall = =speed_print / 2
speed_wall_0_roofing = =speed_wall_0
```

```
speed_wall_x = 50
speed_wall_x_roofing = 50
support_angle = 47
support_bottom_density = 35
support_bottom_enable = True
support_brim_enable = True
support_brim_line_count = 40
support_fan_enable = True
support_infill_rate = 15
support_interface_density = 50
support_interface_enable = True
support_interface_height = 0.4
support_interface_pattern = grid
support_line_width = =line_width
support_offset = 0.9
support_pattern = triangles
support_roof_density = 35
support_roof_enable = True
support_supported_skin_fan_speed = 0
support_tree_max_diameter = 75
support_z_distance = 0.155
top_bottom_thickness = 0.75
top_layers = =0 if infill_sparse_density == 100 else math.ceil(round(top_thickness /
resolveOrValue('layer_height'), 4))
wall_line_count = =1 if magic_spiralize else max(1, round((wall_thickness - wall_line_width_0)
/ wall_line_width_x) + 1) if wall_thickness != 0 else 0
wall_thickness = =wall_line_width_0 if magic_spiralize else 0.8
xy_offset = -0.02
```

Print Settings B (ABS – smaller prints):

```
[general]
version = 4
name = ABS v6
definition = fdmprinter

[metadata]
type = quality_changes
quality_type = normal
intent_category = default
position = 0
setting_version = 24
material_bed_temperature = 110

[values]
bottom_layers = 3
```

brim_gap = 0.2
brim_line_count = 35
brim_width = 15
cool_fan_enabled = False
infill_overlap = 22
infill_pattern = trihexagon
infill_sparse_density = 20
initial_layer_line_width_factor = 120
material_final_print_temperature = 210
material_initial_print_temperature = 210
material_print_temperature = 265
optimize_wall_printing_order = True
raft_airgap = 0.2
raft_interface_speed = 65
raft_speed = 65
raft_surface_layers = 3
raft_surface_speed = 65
roofing_layer_count = 1
skirt_brim_speed = 40
skirt_gap = 15
speed_print = 140
speed_topbottom = 40
speed_wall = 80
support_angle = 55
support_bottom_density = 40
support_brim_line_count = 35
support_infill_rate = 30
support_interface_density = 40
support_interface_enable = True
support_interface_pattern = grid
support_offset = 0.2
support_pattern = grid
support_z_distance = 0.25
top_bottom_thickness = 0.75
top_layers = 3
wall_line_count = 3
wall_thickness = 0.4

Print Settings C* (Tough PLA – smaller prints/Donning stand prints):

**Note: this is almost identical to the 'balanced – Normal' print settings profile for Ultimaker White Tough PLA in Cura v5.9.0.*

Global Settings:

[general]

```
version = 4
name = Normal (25% Infill, tPLA, Ultimaker S5)
definition = ultimaker_s5
```

```
[metadata]
type = quality_changes
quality_type = fast
intent_category = default
position = 0
setting_version = 24
```

```
[values]
infill_pattern = trihexagon
infill_sparse_density = 25
support_brim_line_count = 10
support_interface_enable = False
support_offset = 0.4
support_pattern = grid
support_z_distance = 0.15
```

Print Settings:

```
[general]
version = 4
name = Normal (25% Infill, tPLA, Ultimaker S5)
definition = ultimaker_s5
```

```
[metadata]
type = quality_changes
quality_type = fast
setting_version = 24
```

```
[values]
support_enable = True
support_structure = normal
```

9.9 Appendix I: HS3 Optional configurations and Use Case Examples

Example 1. Contingency CO₂ Walk Back Study at NASA Johnson Space Center (JSC)

- Purpose: The CO₂ Walk Back study was conducted in a ground-based setting at NASA JSC using a customized version of HS3 to examine the physiological and cognitive responses and performance limits to elevated levels of inspired CO₂ (0, 5, 10, 15, 20, 25, 30 mmHg) during a high-fidelity simulated 1-hour EVA walk back in virtual reality on the lunar surface [27].
- HS3 Configuration: HS3 1.0 configuration was modified into an adjustable HUT integrated sensor platform without the PLSS to simulate suit-like restrictions to respiration depending on subject and suit sizing. An HTC VIVE Virtual Reality (VR) headset, treadmill overhead positioning system, COSMED K5, heart rate (HR) sensor, and custom CO₂ breathing system were integrated into this configuration. See Figure 9-30 for HS3 configuration design features.

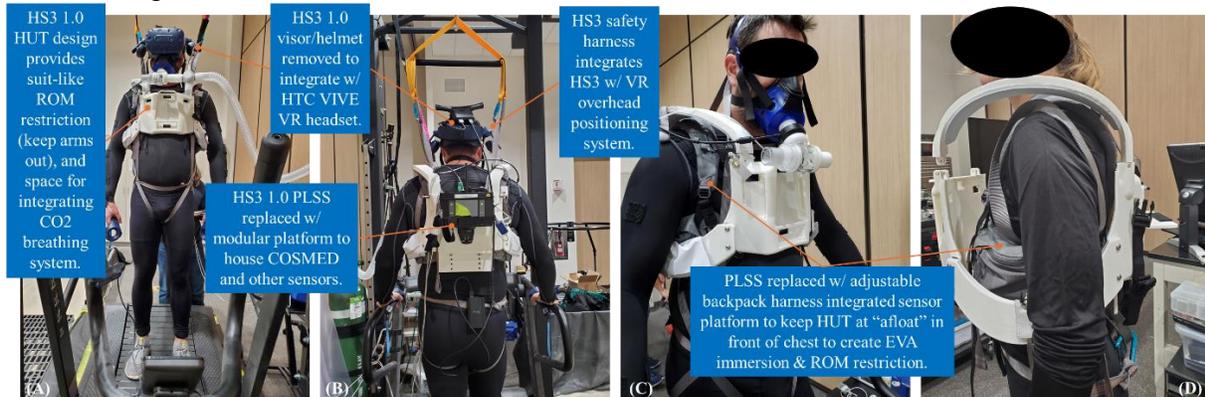


Figure 9-30. Design Features of a Modified HS3 Configuration in the Contingency CO₂ Walk Back Study.

(A) Subject Wearing HS3 on Treadmill, (B) Back View, (C) Close in View Showing Backpack Harness, (D) Side View of HUT and Backpack Harness Integration

Example 2. Crew State Risk Modeling (CSRM) Fatigue and Traverse (F&T) Study at JSC

- Purpose: The CSRM F&T study has been conducted in a ground-based setting at NASA JSC using a customized version of HS3 to enhance EVA simulation in VR environment and add on physical weight burden to define the accuracy bounds of the model in an analog suit to develop a “true model baseline” as a phased precursor step toward validation of the Fatigue and Traverse models in a pressurized suit.
- Protocol: A high-fidelity simulated EVA (1 hr low intensity treadmill traverse, open floor geology – 30 min, and high intensity treadmill travers 45 min or till exhaustion in virtual reality on the moon.

HS3 Configuration: HS3 2.0 and 2.5 with helmet/visor removed (take off the 4 screws attaching visors to HUT) to accommodate the Meta Quest 3 virtual reality headset & treadmill overhead system, COSMED K5, HR/thermal/inertial measurement unit (IMU) sensors. See Figure 9-31 for HS3 configuration design features.

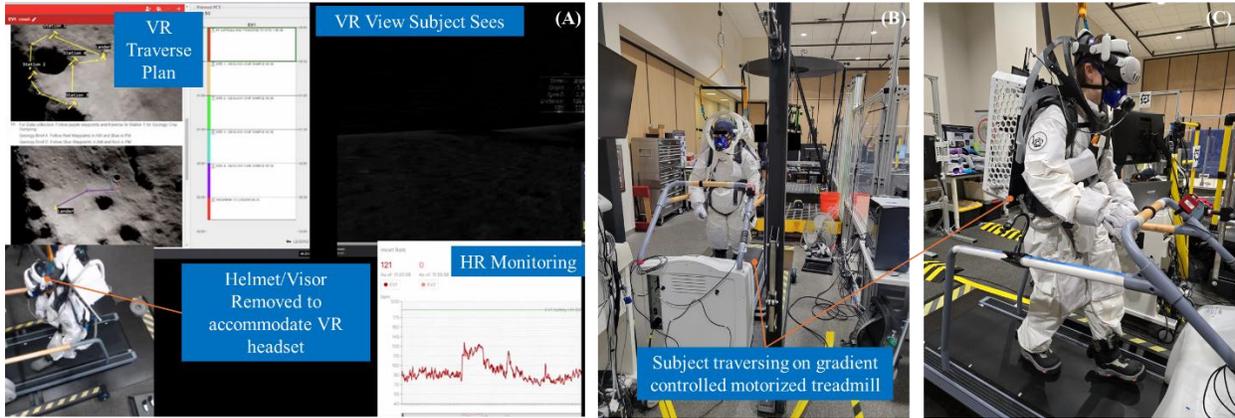


Figure 9-31. Design Features of a Modified HS3 2.0/2.5 Configuration in the CSRM F&T Study.

(A) Test Monitoring Display, (B) Subject Wearing HS3 on Treadmill Modified for VR Usage, (C) Subject Using HS3 2.5 in VR Configuration.

Example 3. Other application of HS3 optional configurations at JSC

- HS3 is extremely versatile in adapting new Human Health and Performance (HH&P) sensors as well as EVA simulation tools/environments
 - Figure 9-32(A) and (B): HS3 provides numerous built-in sensor attachment points on soft suit and in PLSS/HUT which makes sensor integration extremely convenient.
 - Figure 9-32(C): HS3 can be used without PLSS (cooling can be switched to surface supply cooling unit). HS3 is used with VR on a 6 degree-of-freedom (DOF) motion platform.
 - Figure 9-32(D): HS3 has a customized PLSS or backpack adapter that allows seamless integration with other treadmills such as the Infinadeck Omnidirectional treadmill.
 - Other possible optional configurations include but are not limited to:
 - **Surface supply LCG cooling (“umbilical” tethering):** use surface supply LCG cooling to enhance cooling capability during high workload events. The current PLSS has built in connector to support this option.
 - **HS3 with weighted suit:** adding weighted suit under the HS3 soft suit to increase workload
 - **HS3 with other sensors:** HS3 has a 200W power bank (a 300W option is possible and listed in the BOM as an option) that can provide auxiliary power to power other possible sensors.
 - **HS3 in outdoor environment:** HS3 can be used in outdoor environment.
 - **HS3 with lighting:** Several HUT multi-purpose adapters where flashlight or head lamps can be attached. Attachment option is also available on belt.
 - **HS3 & camera:** Several HUT multi-purpose adapters where camera (forward facing or self-facing) can be attached with or without extensions.



Figure 9-32. Other Modified HS3 Configurations.

(A, B) Adapt Sensors Easily via Suit Velcro Attachment, (C) HS3 on 6DOF Motion Platform for VR Rover Operations, and (D) HS3 on Omnidirectional Treadmill for VR Traverse Operations.