NASA-STD-3001 Technical Brief

Spacesuits

OCHMO-TB-050

Executive Summary

Spacesuits are vital to provide a self-contained habitable atmosphere to sustain human life and meet crew health, safety, and performance needs throughout a suited mission. Suited activities are an essential part of human spaceflight, enabling astronauts to work in hazardous environments that are otherwise uninhabitable to humans. These include extravehicular (EVA), such as EVAs outside the International Space Station and planetary surface missions, and Launch, Entry, and Abort (LEA) or intravehicular (IVA) activities. Each type of activity requires a different level of support needs and performance functionality, providing the same life support functions as spacecrafts including oxygen and pressure, carbon dioxide removal, temperature and humidity control, food and water provisions, and the collection of human waste. Suited activities allow many aspects of mission science, exploration, and maintenance. Additionally, it is important for vehicle designers to understand and account for the interfaces between vehicle systems and spacesuits. These human system requirements should be reviewed for consideration of the suit-to-system interface.

Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev E

[V2 11001] Suited Donning and Doffing
[V2 11125] Suit Materials Compatibility
[V2 11126] Suit Materials Cleanability
[V2 11006] Suit Pressure Set-Points
[V2 11007] Suit Equilibrium Pressure
[V2 11009] Continuous Noise in Spacesuits
[V2 11010] EVA Suit Radiation Monitoring
[V2 11011] Suited Crewmember Heat Storage
[V2 11013] Suited Body Waste Management – Provision
[V2 11028] EVA Suit Urine Collection
[V2 11014] LEA Suit Urine Collection
[V2 11015] Suit Urine Collection per Day – Contingency
[V2 11016] Suit Feces Collection per Day – Contingency
[V2 11017] Suit Isolation of Vomitus
[V2 11018] Suited Field of Regard
[V2 11019] Suit Helmet Optical Quality
[V2 11020] Suit Helmet Luminance Shielding
[V2 11021] Suit Helmet Visual Distortions
[V2 11022] Suit Helmet Displays
[V2 11023] Suit Information Management
[V2 11100] Pressure Suits for Protection from Cabin Depressurization
[V2 11024] Ability to Work in Suits
[V2 11025] Suited Nutrition
[V2 11029] LEA Suited Hydration
[V2 11030] EVA Suited Hydration

Executive Summary (continued)

Spacesuits for Artemis: Moon Dust and Mobility
https://youtu.be/cLRaP4SVvCc

www.nasa.gov/SuitUp

Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev E

[V2 11027] Suited Medication Administration
[V2 11031] Suited Relative Humidity
[V2 11032] LEA Suited Decompression Sickness Prevention Capability
[V2 11033] Suited Thermal Control
[V2 11034] Suited Atmospheric Data Recording
[V2 11035] Suited Atmospheric Data Displaying
[V2 11036] Suited Atmospheric Monitoring and Alerting
[V2 11039] Nominal Spacesuit Carbon Dioxide Levels
[V2 11040] Contingency Spacesuit Carbon Dioxide Levels for Partial Gravity Scenarios
[V2 11037] EVA Suited Metabolic Rate Measurement
[V2 11038] EVA Suited Metabolic Data Display
[V2 11101] Incapacitated Crew Rescue (ICR)

Many other requirements in NASA-STD-3001 are also intended to be applicable to spacesuits; section 11 is a subset of requirements that are uniquely applicable to spacesuits and suited operations.

Background - History

Mercury Program (1958-63) The first NASA spacesuits were modified Navy high-altitude pressure suits, worn only inside the spacecraft.

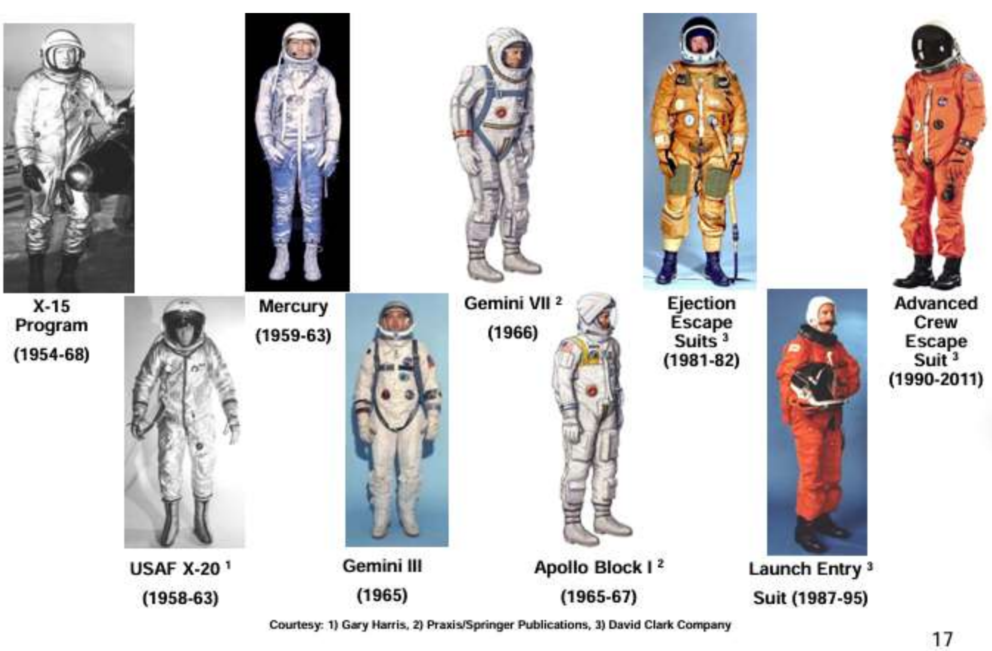
Gemini Program (1956-66) Gemini suits were more advanced, enabling astronauts to perform spacewalks. They were connected to the spacecraft's life support system via a tether (umbilical).

Apollo Program (1967-72) The Apollo suits were specifically designed for lunar surface activities. The Apollo suits were custom-tailored for each astronaut.

Space Shuttle Program (1972-2011): Astronauts wore both intravehicular suits (IVA) - launch and entry suits (often orange) and extravehicular activity (EVA) suits for spacewalks. The Extravehicular Mobility Unit (EMU) was the primary EVA suit used during this period.

International Space Station (Present): The EMU, developed during the Shuttle Program, continues to be used for spacewalks outside the ISS.

Launch, Entry, & Abort (LEA)/Intravehicular (IVA) Spacesuits
LEA (sometimes referred to as IVA) spacesuits are worn by crew during launch and reentry. They are part of an overall vehicle crew escape and survival system.



From: JSC/EC5 U.S. Spacesuit Knowledge Capture (KC) Series Synopsis – Launch, Entry, & Abort, Intravehicular Spacesuits (Kenneth S. Thomas, 2013)

Physiological Parameters for Suit Design

Oxygen

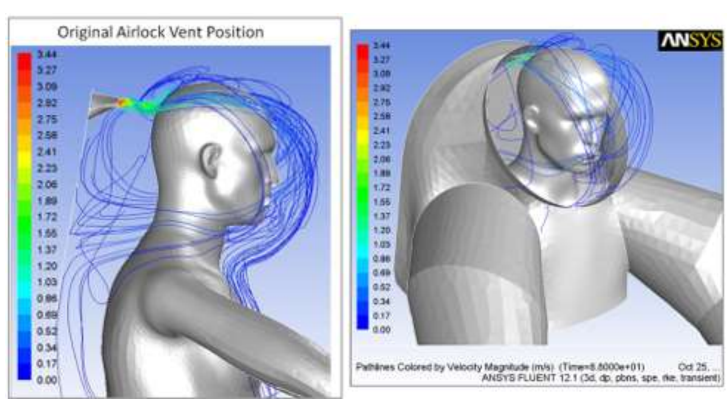
The partial pressure of oxygen (ppO_2) delivered to the lungs, must be sufficient to prevent hypoxia, yet must be low enough to prevent oxygen (O_2) toxicity. Suits are typically designed to operate with 100% O_2, both to reduce Decompression Sickness (DCS) risk and because low total suit pressure is near the limit for ppO_2.

Inspired O_2 partial pressure $P_IO_2 = (PB - 47) * F_IO_2$				
	Normoxia Target Range	Indefinite Hyperoxia Upper Limit	Short-Term Hyperoxia Upper Limit	Mild Hypoxia Lower Limit
P_IO_2 (mmHg)	145-155	356	791	127****
P_IO_2 (psia)	2.80-3.00	6.89	15.30***	2.46****
Acceptable Duration	Indefinite	Indefinite	6-9 Hours*	Indefinite with monitoring**
Examples	Habitat and Spacesuit Minimum	EVA and Cabin Depress In-Suit Survival	O_2 Prebreathe for EVA Preparation	EVA Preparation (ISS Campout, Shuttle 10.2, Exploration Atmosphere of 8.2 psia and 34% O_2)

PB – Ambient Barometric Pressure (mmHg)
F_I – Fractional concentration of inspired oxygen
F_IO_2 – The dry-gas decimal fraction of ambient O_2
**From Johnson Procedural Requirements (JPR) 1830.6 (Requirements Applicable to Personnel Participating in Diving, Hyper/Hypobaric Chambers, and Pressurized Suit Operations). Page 15, subsection 4.2: Limitations during Oxygen Breathing," shows the limits for prebreathe in a spacesuit. The limit is nine hours when that is the only exposure to enriched O_2 in a 48-hour period. The limit is six hours when it is the only exposure to enriched O_2 in a 24-hour period and also states that consecutive daily exposures are not to exceed five consecutive days.*
***There is no opportunity to collect data in microgravity with P_IO_2 of 127 mmHg to cover the durations of Exploration Class missions, so a health monitoring and mitigation plan are required to implement this condition*
****This P_IO_2 may be exceeded during DCS treatment.*
***** 1-hour time-weighted average with an absolute lower limit for the minimum hypoxia range of 122 mmHg/2.36 psia*

Carbon Dioxide

While the limits for carbon dioxide (CO_2) are the same for a pressure suit as they are for a vehicle, the ability to monitor and remove it in a suit is different. Since CO_2 is produced upon exhalation, it tends to be localized in the helmet. Without adequate airflow to recycle the air, CO_2 tends to build up around the face. The flow of air into the helmet must be sufficient to remove CO_2 and replenish O_2 throughout the range of expected activity and respiration rates. See [Nominal Spacesuit Carbon Dioxide Levels Standard Technical Bulletin] for additional information.

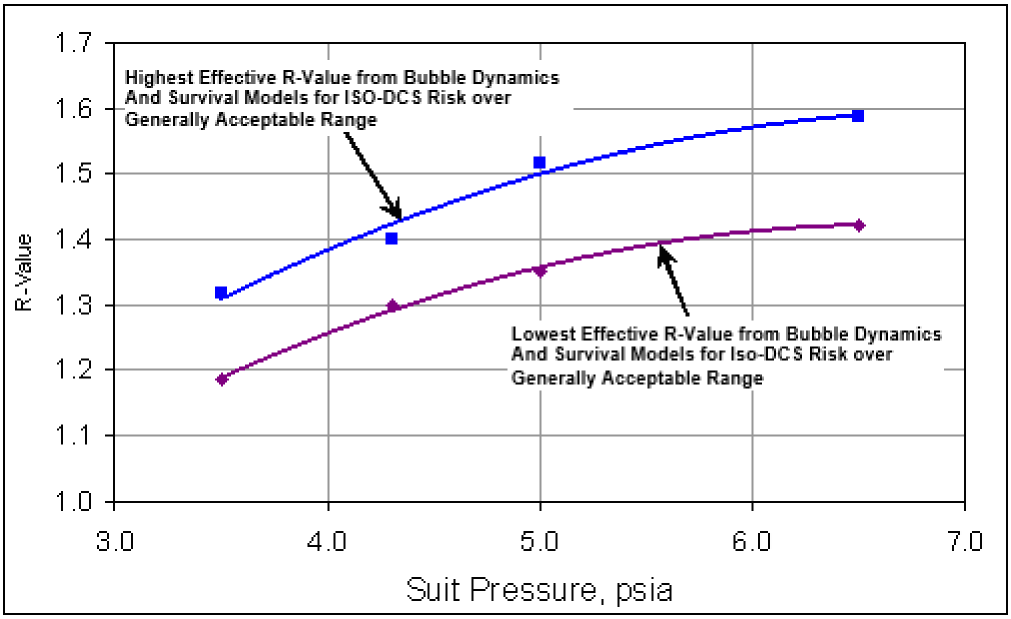


Computational Fluid Dynamics (CFD) flow patterns from suit evaluation. Source: Maintaining Adequate Carbon Dioxide Washout for an Advanced Extravehicular Mobility Unit, Chullen et al. (2013)

Physiological Parameters for Suit Design

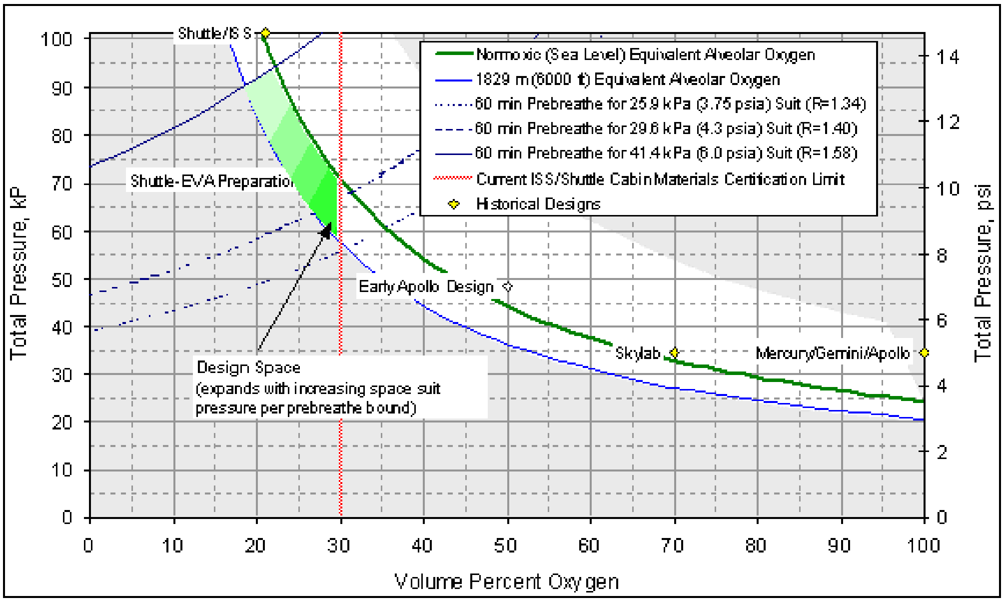
Total Pressure
The graph to the right describes options for habitat and suit pressures for given DCS risks. The "design space" is bounded by sea level and 1829-m (6000-ft) equivalent alveolar oxygen levels, the Shuttle materials certification limit, and the chosen R-value for a given suit pressure.

Maintaining a constant pressure level after a set point has been reached is important to protect the crew from discomfort in body cavities and sinuses, especially in the ear. Excess fluctuations in suit pressure will cause pressurized suited crewmembers to constantly re-equilibrate pressure in body cavities and sinuses, increasing the likelihood of pressure-induced discomfort in these areas. The suit must maintain each individual suit pressure to within 0.1 psi after that suit has achieved an equilibrium pressure for a set point. Another important consideration for pressure inside the suit is minimizing the rate of pressure change to prevent discomfort and barotrauma.



Cabin suit pressure combinations related by R-values

The tissue ratio (R-Value) is an index of the true decompression dose ratio-value used by NASA and is function of suit pressure. TR is the decompression dose, which approximates the potential volume at an ambient pressure of N_2 evolved in a unit volume of tissue given that all the available N_2 at P2 has transformed from the dissolved state to the evolved state (Conkin 1994, Conkin et al. 1998).



Options for vehicle and suit pressures within an acceptable range of decompression sickness risk, R=1.34 to 1.58.

Physiological Parameters for Suit Design

Temperature

Data from military aircrew protective ensembles have found that body temperature increases more rapidly over time in pressure suits than in a shirt-sleeve environment. Excess heat load and accumulation may quickly reach human tolerance limits and may impair performance and health. Impairment begins when skin temperature increases greater than 1.4ºC (2.5ºF -17) (0.6ºC [1ºF -17.4]) core or if pulse is greater than 140 bpm). Keeping the heat storage value below the performance impairment line allows the crewmember the ability to conduct complex tasks without heat-induced degradation. If the crewmember is in a suit, the heat load may increase rapidly.

[V2 11011] Suited Crewmember Heat Storage The system shall prevent the energy stored by each crewmember during nominal suited operations from exceeding the limits defined by the range 3.0 kJ/kg (1.3 Btu/lb) > ΔQ stored > -1.9 kJ/kg (-0.8 Btu/lb), where ΔQ stored is calculated using the 41 Node Man or Wissler model. *From: NASA-STD-3001 Volume 2*

Relative Humidity

Average suited humidity is to be maintained using the following guidelines: ≤5% up to 1 hour, 5% to ≤15% up to 2 hours, 15% to ≤25% up to 8 hours, and 25% to ≤75% (nominal range) indefinitely. These limits ensure the environment is not too dry for the nominal functioning of mucous membranes, and maintained below the upper limits for crew comfort to allow for effective evaporation and to limit the formation of condensation.

Suited Metabolic Rate

Suited operations encompass a diverse set of activities that result in varied metabolic rates. The suit must accommodate the expected range of activities by providing adequate consumables such as oxygen, water, and food, and by removing generated heat, humidity, carbon dioxide, and bodily waste. The suit and supporting systems must accommodate contingency operations, including additional consumables and loads on the suit environmental control system. ***See OCHMO-TB-047 Crew Survivability for more details***.

The *41-Node Man Program* is a Fortran-based thermal model that simulates the human body with 10 body compartments or “segments” representing the torso, arms, legs, hands, feet, and head of a person. The model simulates heat transfer and heat generation within the body. Heat generation comes from the basal metabolism, work, and shivering. Heat transfer between segments occurs from conduction and blood flow (advection). Heat is transferred between the skin and the suit or environment by conduction, sweating, convection, and radiation. Heat loss from the body also occurs due to respiration. The table below contains ranges of metabolic rates expected during suited operations and will evolve as the operations concept matures.

Crewmember Metabolic Rates for Suited Operations, kJ/h (Btu/h)

Data Source	Minimum	Average	Maximum[1]
µ Gravity EVA (ISS and STS)	575 (545)[2]	950 (900)[3]	2320 (2200)
Apollo Lunar Surface EVA	517 (490)[2]	1030 (980)	2607 (2471)
Advanced Walkback Test[4]	1767 (1675)[1]	2505 (2374)	3167 (3002)

[1] Transient condition less than 15 min in duration, individual instance
[2] Minimum for low-activity EVA durations
[3] Includes Orlan ISS EVAs, which trend to slightly higher metabolic rates
[4] Simulated 10-km (6.2-mile) lunar surface walk requiring 1 to 2 hours to complete, in case of rover failure, n = 6

Physiological Parameters for Suit Design

Waste Management

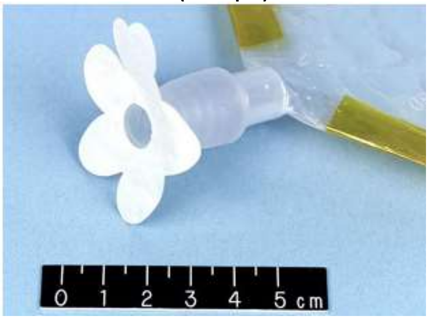
Both LEA and EVA suits are required to be capable of collecting a quantity of urine throughout suited operations utilizing the following equation: $0.5 + 2t/24$ liters, where t is suited duration in hours. This quantity allows crewmembers to eliminate liquid waste at their discretion without affecting work efficiency during suited operations.

Depending on diet and health, a crewmember may need to defecate while wearing an EVA suit. However, astronauts tend to wait to defecate until they can use the vehicle's waste management system after the EVA. In a contingency event, crewmembers may have to remain suited for several days without having the capability to access the fecal and urine collection system. The system must collect and contain 75 g (2.6 oz) (by mass) and 75 ml (2.5 oz) (by volume) of fecal matter per crewmember per day during an unrecoverable vehicle pressure failure. For the suit to contain feces, the fecal output during suited operations should be reduced with a low residue diet, to not exceed the maximum containment of the suit's waste collection garment.

The EMU includes a diaper-like maximum absorbency garment for urine and feces collection during EVAs. In the event of an unrecoverable vehicle pressure failure, crewmembers may have to remain suited for several days without having the capability to access the fecal and urine collection system. The suit must be able to collect and contain 1 L (1.1 qt) per crewmember per day of urine during such an event; this amount reflects the altered water and nutrition supplied during contingency suited operations.

Space motion sickness, which often includes vomiting, usually affects crewmembers in the first 72 hours of flight. Because of this, EVAs are not planned for the first 72 hours of flight. However, if an unplanned EVA takes place earlier than 72 hours or a crewmember continues to have space motion sickness symptoms after that time, vomiting in the suit may occur. On the lunar surface, a high-magnitude solar particle event could result in radiation exposures that produce nausea and vomiting. If vomitus enters the internal suit environment, it must be kept away from the suited crewmember's nose to prevent inhalation, which could cause asphyxiation. In 0g, directing airflow to move vomitus out of the helmet, or providing a pouch with a valve to contain the vomitus may be considered. In a gravity environment, the ability for vomitus to drain downward from the helmet should be provided. The suit should provide for isolation of the crewmember from vomiting events of 0.5 L (1.1 pt) each.

Urine Collection Device (female)



Urine Collection Device (male)

OCHMO-TB-040 EVA Mishaps describes lessons learned during EVA suited activities.

Physiological Parameters for Suit Design

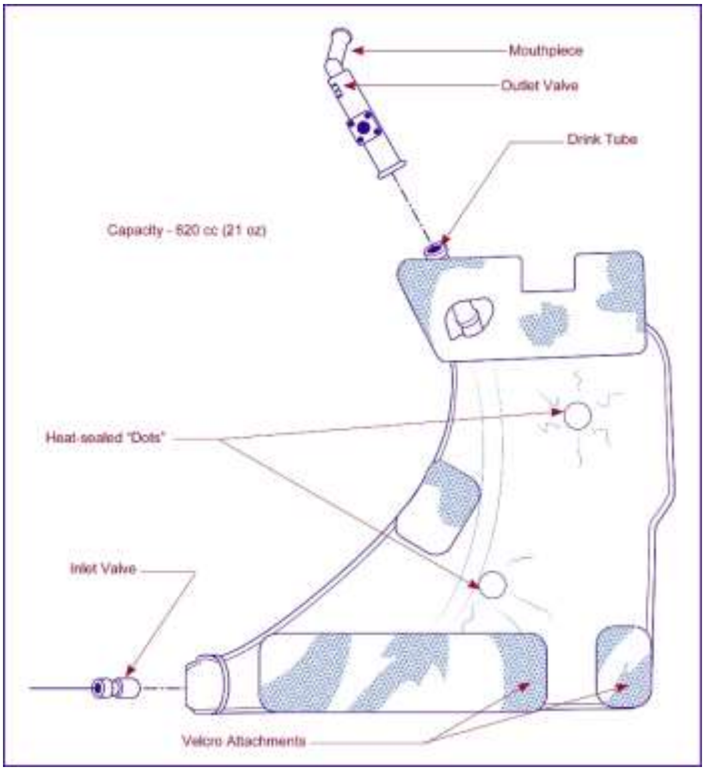
Nutrition and Hydration

EVA energy expenditure will usually be high enough to demand additional caloric energy. The type and amount of food to be provided on an EVA will depend on the gravity environment, EVA duration, expected tasks, and estimated energy expenditure. ISS EVAs typically last 6 to 8 hours, plus 2 to 3 hours inside the suit during EVA preparation, airlock depressurization, and re-pressurization. EVA duration is typically limited by suit consumables, such as O_2, as well as the duration of EVA preparation and post-EVA cleanup. The duration of surface (i.e., lunar, Mars) EVAs may be similar to those at 0g in terms of consumables, but activities will likely require much greater energy expenditure than a 0g EVA. Therefore, additional calories will need to be provided to EVA crewmembers to maintain high performance levels during surface EVAs. During suited operations longer than 12 hours, the crew will need to consume nutrition in excess of what is likely available inside the suit. The suit should allow for the delivery of nutrition to the pressurized suited crew to occur during extended contingency use of pressure suits. The nutrition in contingency cases such as unplanned cabin depressurization could be delivered via a hydration drink port, similar to that used on Apollo missions, and may consist of a low-residue substance.

Potable water is needed during suited operations to prevent dehydration due to insensible water loss and to improve crew comfort. The amount of water necessary depends on the EVA duration and tasks, and on the expected energy expenditure and resulting dehydration.

During long-duration suited operations, such as an unplanned pressure reduction scenario, the crew will need to consume additional water in excess of what is likely available inside the suit, to prevent crew performance degradation associated with dehydration. For both nominal and contingency scenarios, one solution is to have the potable water system be rechargeable from an external source, as long as the internal suit reservoir has sufficient capacity to allow ready access to water without affecting work efficiency.

NASA-STD-3001 [V2 11029] LEA Suited Hydration requires a minimum of 2L (67.6oz) per 24 hours of LEA suited activity. [V2 11030] EVA Suited Hydration requires a minimum quantity of 240mL (8.1oz) per hour for EVA suited operations.



Shuttle EMU in-suit drink bag

Physiological Parameters for Suit Design

Suited Strength Performance

Strength capabilities of an EVA crewmember are influenced by the pressure suit design as well as the positioning and restraint of the crewmember at the worksite location.

Strength data collected from minimally clothed humans should be used as guidelines only, as this data indicates trends and orders of magnitude of force output. It is important to verify that the full range of potential EVA crewmembers can perform the physical tasks required by the hardware design and situational configuration.

Because of the pressurization of the gloves, concerted effort is required to move the arms, hands, and fingers, and repetitive motion can cause hand fatigue and discomfort. This can be minimized with glove design, or with an object's glove interface design, to reduce the need for repetitive finger and hand motion. Tasks such as the manual removal or replacement of threaded fasteners, continuous force-torque application, and extended gripping functions should be minimized in hardware designed for EVA servicing. If such equipment designs are necessary, hardware suppliers need to provide power tools to assist the EVA crewmember. Gloves should also allow firm retention of items to be grasped, such as handholds, switches, and tools, for short periods of time without hand fatigue.

Overcoming pressure moment and friction forces inherent in the mobility joints of the EMU requires application of force by the crewmember. The joints are designed to approximate neutral stability throughout the full range of motion when pressurized to 4.3 psid (29.6 kPa). The EMU suit-joint neutral stability feature helps to alleviate the requirement to apply a significant counteracting force to maintain a desired position

Reference OCHMO-TB-031 Exercise Overview for additional information on muscle strength requirements.

Astronauts must maintain their strength capabilities while in microgravity for an extended period of time, such as exercising with the Advanced Resistive Exercise Device (ARED – left) so that they are capable of performing suited activities on planetary surfaces.

Suit Design Considerations

Atmosphere and Physiological Parameters Display and Alerting

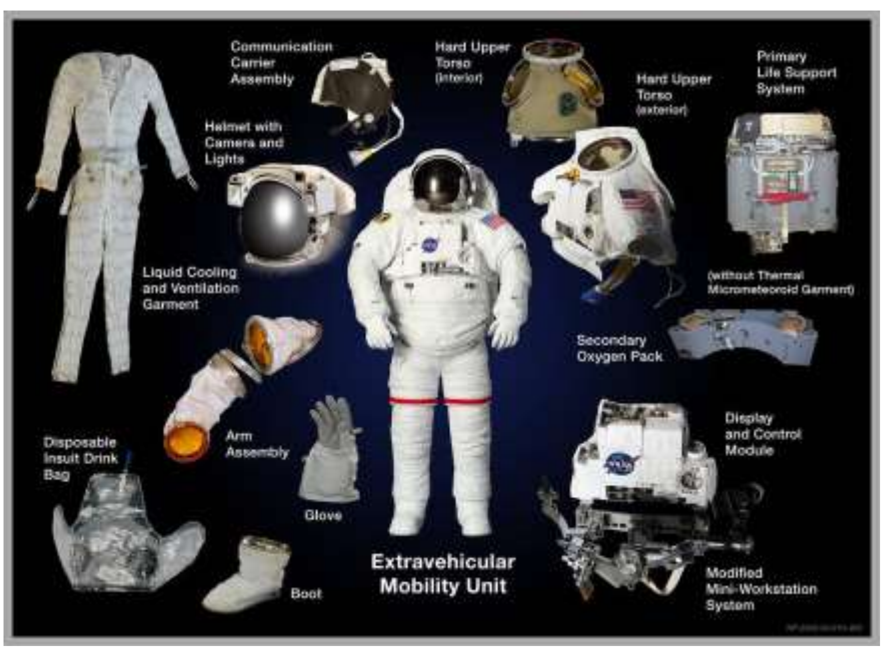
Feedback of relevant suit atmospheric and physiologic information to the crew allows better consumable management, improved optimization of EVA task performance, and reduces risk of physiologic stress and injury. Atmospheric parameters that must be displayed to the EVA crew are total pressure, ppO_2, and $ppCO_2$. Suit consumables, such as power, O_2, and water, must also be measured and relayed to the crewmember. In addition, having insight into trends in physiologic parameters and life-sustaining consumables will allow the crew to act prospectively in preventing unsafe operating conditions, or responding to off-nominal scenarios.

Measurement of physiologic parameters, such as heart rate, ECG, and body temperature, during contingency and mission-preserving EVA, as well as during unrecoverable vehicle pressure loss, is necessary to ensure the health and safety of the crewmember(s). The intent is to obtain biomedical data during suited operations, with minimal crew time or effort required to don and doff the measurement hardware while maintaining crew comfort.

Alerting the crew as soon as relevant suit atmospheric and physiologic parameters move into the off-nominal range will allow the crew to appropriately react to off-nominal scenarios, before unsafe operations develop. Automated suit algorithms, rather than ground medical support, may be the primary method of monitoring, especially on long-distance missions, such as Mars missions, where near-real-time communication with Earth is not possible.

Atmosphere Parameter Control

The ability of the crew to adjust their suit pressure is an important design consideration. For efficient workload, the crew needs to be able to select a minimum operating pressure. In the case of an unrecoverable vehicle pressure failure where the crew is not able to prebreathe before operating in a pressurized suit, the crew will need to be able to select a higher pressure to mitigate the risk of DCS, followed by the ability to select a midrange suit operating pressure to allow more mobility to operate the vehicle. Some tasks may require periods of high and low physical exertion, and variable exposure to the Sun, which will affect body heat and moisture content. The ability to adjust temperature and humidity is important to maintain comfort in the suit.



Extravehicular Mobility Unit (EMU)

Page 18 of OCHMO-TB-002 Environmental Control and Life Support System (ECLSS): Human Centered Approach describes the EMU Portable Life Support System (PLSS).

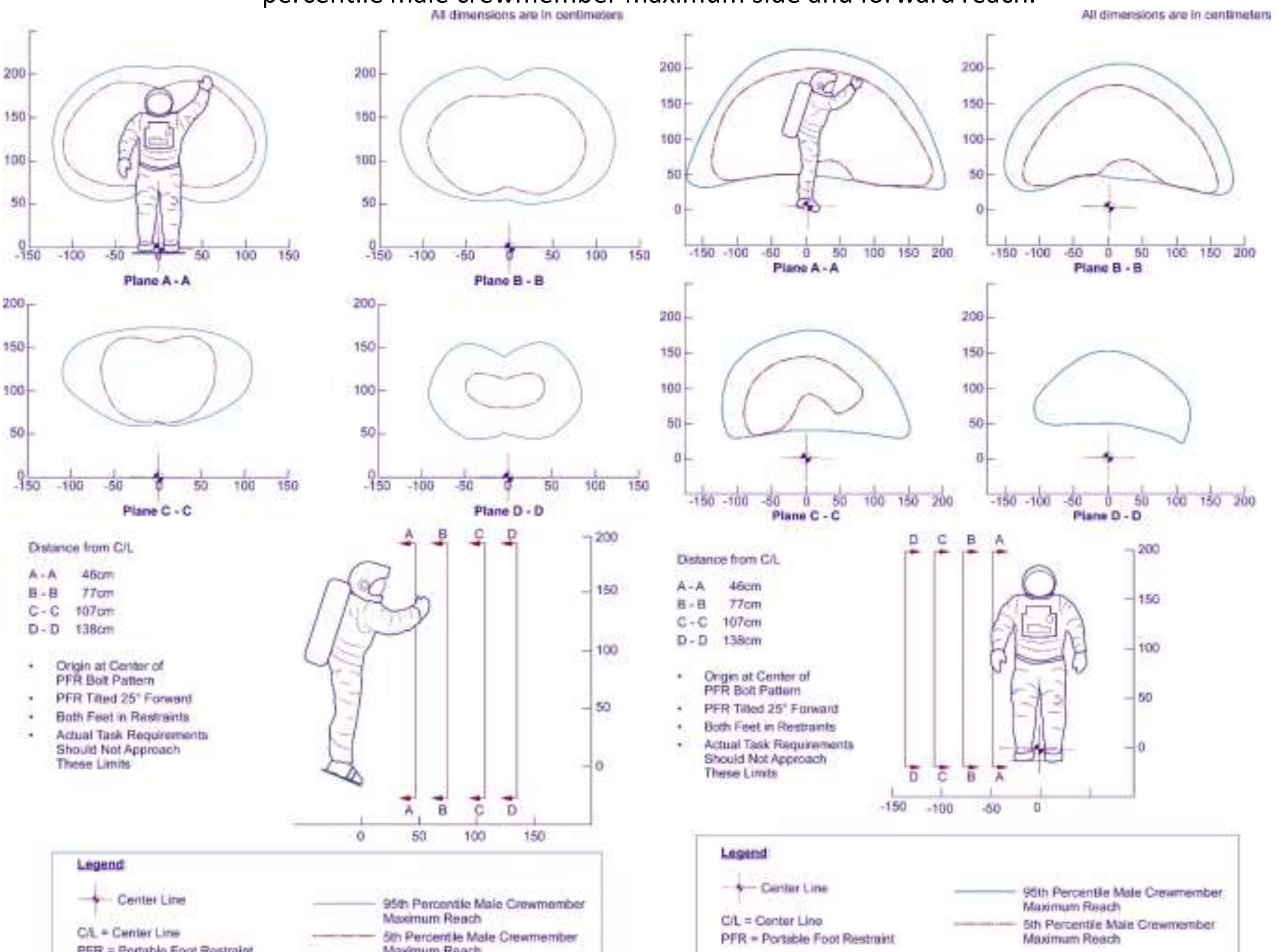
Suit Design Considerations

Suited Anthropometry, Reach and Range of Motion

The EMU suit is designed to provide bending and centers of rotation of the mobility joints to approximate the natural body joint movements. The EMU includes mobility joints in the shoulder, elbow, wrist, finger, thumb, waist, hip, knee, and ankle areas, which allow the crewmember freedom of movement in both the pressurized and unpressurized modes. Spacesuit gloves degrade hand and finger range of motion, tactile feedback, and proficiency compared to bare-hand operations. Depending on the design, dexterity can generally be compared to that with heavy work gloves. Controls that will be operated by a pressure-suited crewmember must accommodate limited finger and hand range of motion and dexterity. Glove design should provide gloved-hand dexterity as close to bare-hand dexterity as possible.

Reference OCHMO-TB-049 Anthropometrics and Crew Physical Characteristics for additional information and tables of anthropometric values.

The figures depict the Shuttle EMU work envelope as defined by the 5th- and 95th - percentile male crewmember maximum side and forward reach.



Suit Design Considerations

Shoulder Injury Prevention

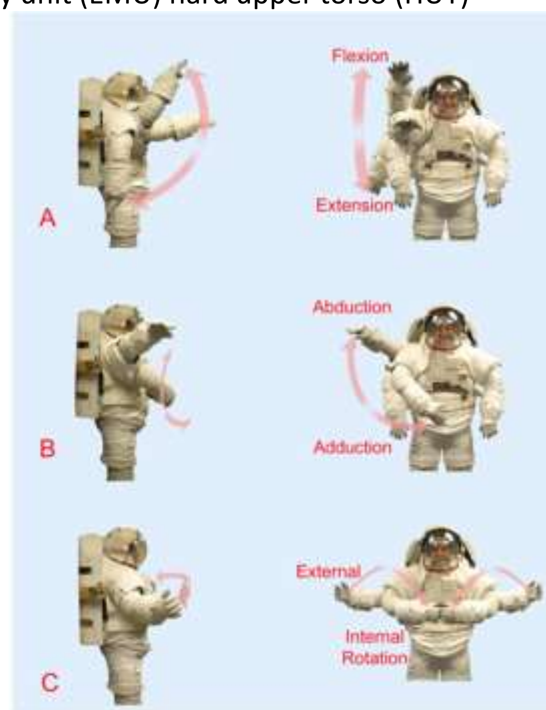
Being the joint with the greatest range of motion, the shoulder often compromises stability for mobility and relies heavily on ligaments and muscles for steadiness and proper function. A combination of the robust physical training regimen that NASA astronauts follow, the potential cumulative musculoskeletal deconditioning effects of long-duration spaceflight missions, and certain design elements of spacesuits emphasizes the importance of monitoring and treating shoulder pain and injuries swiftly and appropriately.

During the Shuttle-era in the early 2000s, a growing concern was expressed about the risk of shoulder injury associated with EVA training at the Neutral Buoyance Laboratory (NBL). A list of contributing factors to the observed minor shoulder injuries included:

- Limitations to shoulder mobility in the extravehicular mobility unit (EMU) hard upper torso (HUT)
- Performing overhead tasks
- Repetitive motion
- Heavy tools
- Performing tasks in inverted body positions
- Suboptimal suit fit
- Frequency of NBL training runs

The design of the planar HUT shoulder joint is a significant factor contributing to the risk of injury during EVA training. An integrated approach to mitigating the risk of shoulder injury requires a combination of reducing the number and frequency of high-risk tasks with redesigning the planar HUT shoulder joint.

The primary range of shoulder motion required to work within the envelope of the EMU is a combination of internal/external rotation, flexion/extension and abduction/adduction for the majority of EVA tasks. Lateral and overhead motion during EVA training is of greatest interest in the context of EVA training-related shoulder injuries.



Subject demonstrating suited shoulder movements.
From: *EMU Shoulder Injury Tiger Team Report (2003)*

Spacesuit design considerations must account for proper movement and function of the shoulder joint to minimize the risk of shoulder injuries. The goal should be to design the suit to allow freedom of movement throughout the body's range of motion and when pressurized, not compromise or restrict the ability to move naturally. In addition, the suit design needs to incorporate ease of donning and doffing and not require the user to flex to extremes of their range of motion. Finally, the inclusion of experts knowledgeable on human anatomy, anthropometrics, and kinesiology in the development of future spacesuits will allow engineers to design a suit that is optimal for human performance.

Reference OCHMO-MTB-006 Shoulder Injury Overview & Treatment Guidance for additional information.

Suit Design Considerations

Suited Maneuverability, Crew Restraints, Mobility Aids, Translation Paths, and Work Efficiency

To ensure proper design of the hardware to be used by the crew, current human factors evaluations collect various types of objective and subjective data to determine the usability of the hardware. Objective data have been used to quantify the mobility of space suits; however, these do not cover all aspects of maneuverability. Comments during evaluations support the need to gather subjective data in addition to objective data since they can provide a different point of view on maneuverability. However, none of the existing subjective scales used during these evaluations provide a clear subjective measurement of the ease of movement while executing tasks. A maneuverability scale was developed and modified that can be used to evaluate maneuverability in space suits and confined spaces such as crew quarters (Archer, Sandor, & Holden, 2009). The Maneuverability Assessment Scale (MAS) is a 5-point scale from 1 – very poor to 5 – excellent. Maneuverability is defined as the "ability to move in any direction with the desired pace and accuracy".

Maneuverability Assessment Scale Questionnaire

My ability to move in any direction with the desired pace & accuracy is				
Excellent Not affected	**Good** Slightly affected	**Fair** Moderately affected	**Poor** Significantly affected	**Very Poor** Severely affected
1	**2**	**3**	**4**	**5**

Proper restraint of the EVA crewmember at the workstation is essential for successful 0g EVA operations. Failure to provide adequate restraint can be the single most limiting factor of all EVA design elements. Inadequate restraint induces unnecessarily high workloads and may lead to crew fatigue, overloading of the life-support system, and premature termination of the EVA.

Force application and fine motor skill capability are related to the restraint available at the worksite. There are basically three levels of restraint:

a. free float, which is unrestrained except with flexible tether(s) and use of hands
b. restrained with a rigid tether
c. restrained in a foot restraint

Inadequate restraint also increases the potential for equipment damage during EVA operations. An unrestrained, or free-floating restrained, crewmember can effectively perform only low-force, short-time operations such as actuation of toggle and rotary switches, surveillance of controls and displays, and visual inspections.

To exert impulse-type loads, one hand is needed to hold on and one hand to apply the load. Use of a rigid tether allows a crewmember to perform two-handed tasks and relatively low-force activities but with greater control than is possible while free-floating. Very high loads can be applied, similar to shirtsleeve capability, using the foot restraint. These forces are reduced significantly when the point of force application is moved near the top of the crewmember's reach envelope. This necessitates providing adequate restraint and proper body orientation to the EVA crewmember to optimize force output. Foot restraints have proven to be the most effective means of stabilizing crewmembers and maximizing their capabilities.

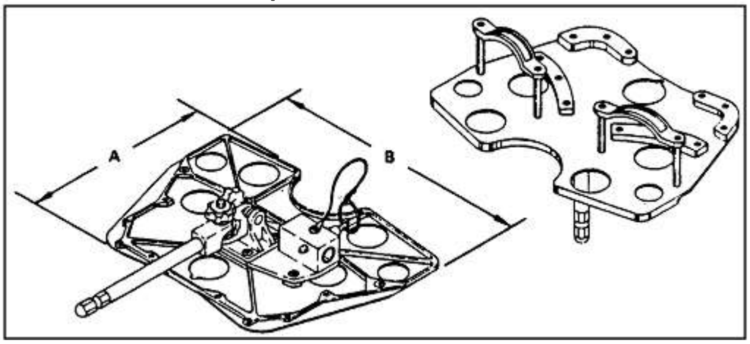
Reference OCHMO-TB-005 Usability, Workload, & Error for additional information on designing systems for crew performance.

Suit Design Considerations

Suited Maneuverability, Crew Restraints, Mobility Aids, Translation Paths, and Work Efficiency
Even while using foot restraints, a crewmember may use a handrail or other aid at the worksite to provide additional stabilization, additional force application, and restraint while getting into or out of the foot restraint. The loads that foot restraints can take are limited. The robotic arm (both Shuttle and ISS) will move out of position under high loads. For hard-mounted foot restraints on the ISS, load alleviators protect structures from induced loads, but can also move the crewmember out of position if too much force is applied. Restraints for each workstation should be selected on the basis of the task to be performed. Tethers and handholds may be adequate for short-term tasks such as inspection and monitoring, but foot restraints should be provided for tasks requiring moderate-to-heavy force application and long-term positioning. The EMU includes two 61-cm (24-in.) waist-safety tethers and a self-retracting 11-m (35-ft) safety tether for translation along the Shuttle payload-bay slide wire.
To reduce EVA workload, preinstalled handholds and handrails should be used when possible. Crew-attached or portable handrails, handholds, and foot restraints should be considered only for non-routine or unplanned EVA workstations. Handholds should also be provided for ingress and egress of foot restraints. Foot restraints must be adjustable to ensure the optimum reach and work envelope of the suited crewmember. On the Shuttle a primary means of restraint is a portable-foot restraint that consists of a foot-restraint platform with position adjustment capability, and an extension arm and a foot-restraint socket that locks into the extension arm.

Besides workstation restraint, tethers are used as a safety device during 0g operations, preventing the EVA crewmember from floating away from the spacecraft during translation and working, and should be two-fault tolerant. To prevent inadvertent unlatching, tethers should include latch locks that indicate whether or not they are engaged. There should also be a contingency method for removal of a snagged tether or release of a crewmember from a tether hook. Safety tether attachments should be removable and attachable by one-handed operation.
Restraint design and position should be such that the least number of engagements and disengagements are needed to minimize the risk of failure to attach in 0g. Restraints should be positioned so that a crewmember is restrained or tethered at all times. Consideration should be given to minimizing the crew time required to establish the restraint and to confirm complete engagement.

Shuttle portable foot restraint



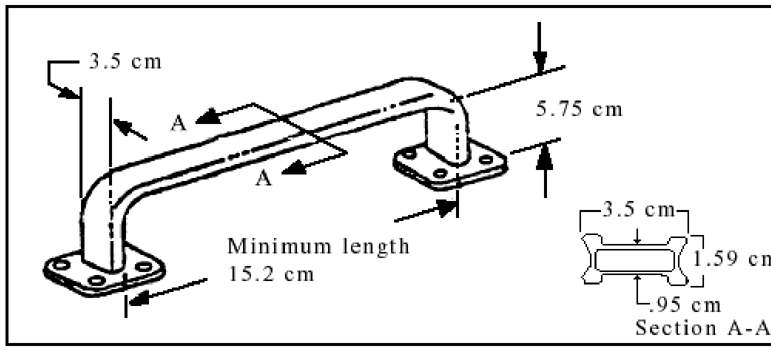
On a planetary surface, crew restraints should be provided for operations that involve the risk of falling from height, such as from a vehicle platform or ladder.

Suit Design Considerations

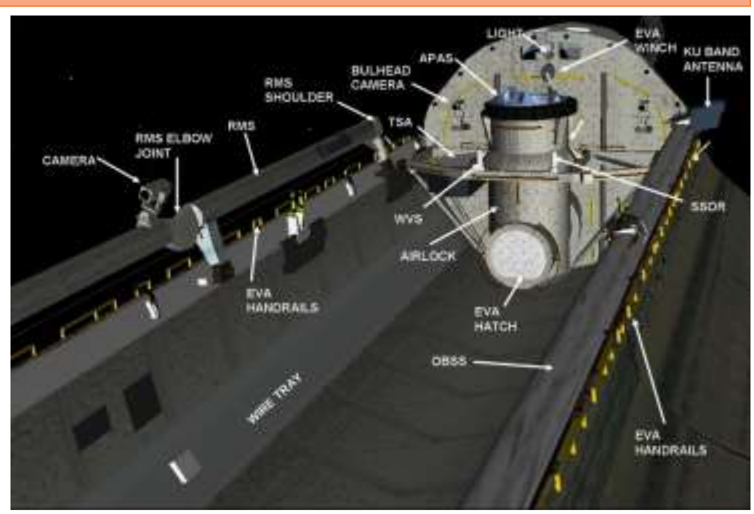
Suited Maneuverability, Crew Restraints, Mobility Aids, Translation Paths, Work Efficiency
For EVA in 0g, the hands are best suited to provide mobility by grasping objects and moving from one area to another. On the exterior of spacecraft, adequate surfaces to grasp may not be available in the needed locations or objects may be unsafe to touch or susceptible to damage. Mobility aids, such as handholds and handrails, must be provided to ensure safe translation. In some cases, mobility aids and restraints could be provided by the same equipment.

The spacesuit glove should determine the dimensional design of manual mobility aids. Shuttle handrails have a vertical clearance of 5.75 cm (2.26 in.), a horizontal clearance to other objects of 10.16 cm (4 in.), and a length of 15.2 cm (6 in.) to allow the astronauts to grip them while wearing the pressurized EMU glove. These dimensions will depend on the design of the glove to be used with the mobility aid. Skylab had both single and dual parallel handrails, and the dual handrails were reported to be very easy to use with both hands. To ensure easy recognition, handholds and handrails should be clearly visible, with a high visual contrast to the background, and be a standard color such as yellow. Handholds and handrails should accommodate crew restraints. Mobility aids should be located at terminal points and direction change points on established crew translation paths.

Shuttle EVA handhold dimensions



The design loads for mobility aids and attachments must accommodate the greatest momentum of the largest combination of EVA crew and transported objects (including another injured crewmember).



Standard Shuttle handrail locations

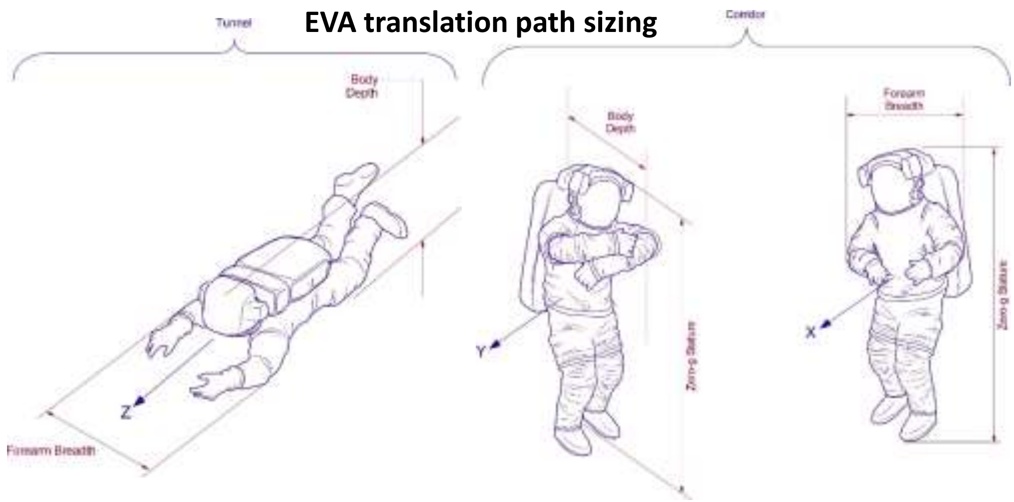
In addition, mobility aids should be installed in locations to prevent grasping of equipment not intended as a handhold or mobility aid. They should be positioned to support the stability of translation at the expected translation rates and direction changes A nominal translation rate of 0.5 to 1.0 ft/sec has been observed for unencumbered Shuttle EVA crewmembers. Translation paths on the Shuttle are along both sills of the payload bay, along the forward and aft bulkheads, and along the centerline (with payload-bay doors closed) for contingencies. Translation paths to support mission-specific EVAs also may be defined on a mission-by-mission basis.

Suit Design Considerations

Suited Maneuverability, Crew Restraints, Mobility Aids, Translation Paths, Work Efficiency
Translation paths must accommodate suited crewmembers and their range of motion necessary for translation. Consideration should be given to the size and limited mobility of pressure suits. As shown in the figure below, the size of the translation path also depends on the orientation of the crewmember and direction of travel. If the crewmember is traveling in the x-direction (through chest) or y-direction (through shoulders), the translation path is considered a "corridor"; if the crewmember is traveling in the z-direction (through head), the translation path is considered a "tunnel." These different modes of translation will have different needs for clearance and mobility aids.

Translation-path dimensions should consider the simultaneous translation of crewmembers along the path, the size of equipment, and the intrusion of mobility aids into the path. Obstructions or equipment should not protrude into the translation path. Consideration should be given to the productivity loss associated with bottlenecks in frequently traveled paths.

EVA translation path sizing



Work efficiency is a measure of actual work accomplished compared to the overhead of preparing and cleaning up afterwards. For EVA, the preparation includes unstowage, suit checkout, suit donning, prebreathe, airlock depressurization, and egress. Cleanup includes airlock ingress and re-pressurization, suit doffing, and stowage. EVA operations should have an EVA total WEI of > 1.75, and an EVA day WEI of > 3.0. Increases in EVA WEI can be achieved by minimizing all aspects of the overhead, including prebreathe times. However, prebreathe is a small portion of the total overhead and does not need to be the focus of reduction. For Shuttle operations, oxygen prebreathe time is 18% and 25% of the total and EVA day overhead, respectively. For ISS, prebreathe is 15% and 38% of the total and EVA day overhead. To meet the WEI objective, efficiency improvements should occur in suit checkout, serving, donning, doffing, and post-EVA processing. Many combinations of cabin pressure, suit pressure, and EVA preparation overheads could be integrated to result in the desired WEI. The objective is to ensure that the EVA overhead is minimized through appropriate integrated design of the vehicle and EVA systems.

EVA work efficiency index (WEI) is defined as:
EVA time / (EVA preparation + prebreathe + A/L ops + EVA post-ops)
where A/L = airlock and ops = operations.

Suit Design Considerations

EVA Safety

Sharp Edges

All vehicle and habitat equipment and structures requiring an EVA interface must not have sharp edges or protrusions. If either exists then they must be covered to protect the crew and the crew's critical support equipment. Operational controls, such as training crewmembers to avoid certain objects, increases mental workload and fatigue, and should not be relied on.

Edge, Corner, and Protrusion Criteria – Edge and In-Plane Corner Radii*

	Radius				Remarks	Figure
Application	Outer in.	Outer mm	Inner in.	Inner mm		II.2-5 Referenced
Openings, panels, covers (corner radii in plane of panel)	0.25 0.12	6.4 3.0	0.12 0.06	3.0 1.5	Preferred Minimum	
Exposed corners	0.5	13	–	–	Minimum	A
Exposed edges: (1) 0.08 in. (2.0 mm) thick or greater	0.04	1.0	–	–		B
(2) 0.02 to 0.08 in. (0.5-2.0 mm) thick	Full radius		–	–		C
(3) less than 0.02 in. (0.5 mm) thick	Rolled or curled					D
Flanges, latches, controls, hinges, and other small hardware operated by the pressurized-gloved hand	0.04	1.0	–	–	Minimum required to prevent glove snagging	–
Small protrusions (less than approximately 3/16 in. [4.8 mm]) on toggle switches, circuit breakers, connectors, latches, and other manipulative devices	0.04	1.0	–	–	Absolute minimum unless protruding corner is greater than 120°	

* A 45-degree chamfer by 0.06 in. (1.5 mm) (minimum) with smooth broken edges is also acceptable in place of a corner radius. The width of chamfer should be selected to approximate the radius corner described above.

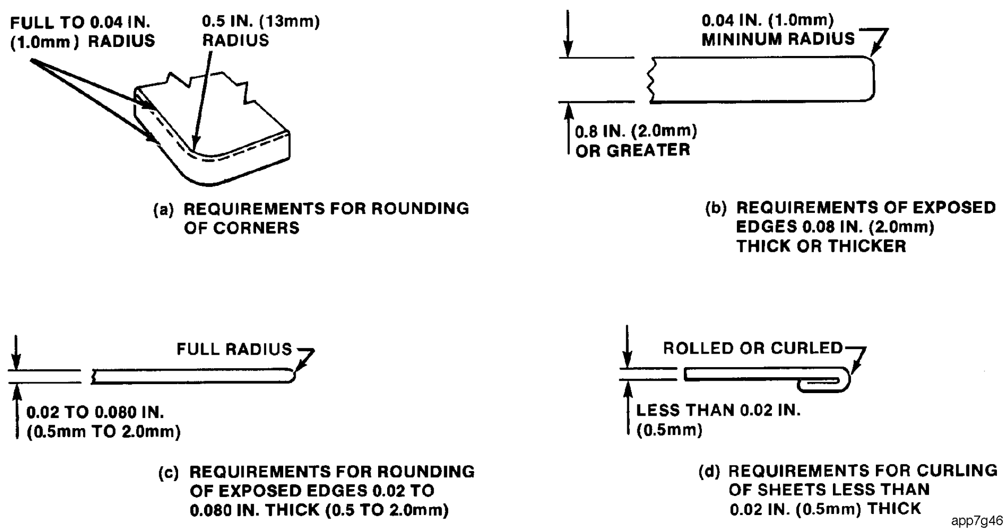
For materials less than 2.032 mm (0.08 in.) thick, used in a location accessible to EVA, edge radii should be greater than 0.0672 mm (0.003 in.). In addition, exposed edges should be uniformly spaced, not to exceed 1.27 cm (0.5 in.) gaps, flush at the exposed surface plane, and shielded from direct EVA interaction.

Suit Design Considerations

EVA Safety

Sharp Edges

Exposed corner and edge requirements



Snag and Sharp Edge Hazards

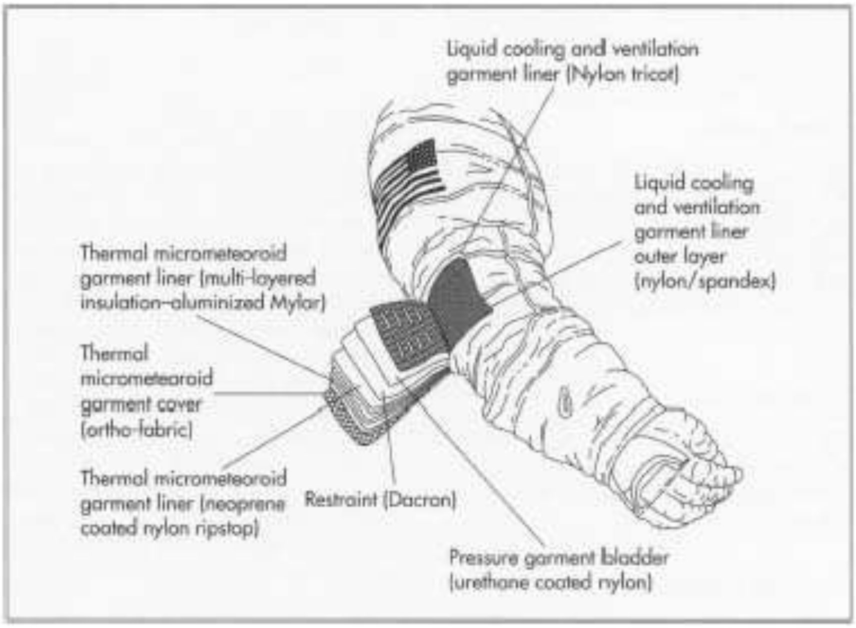
Application	Criteria/Remarks
Latching devices	Cover or design all latching devices to preclude gaps or overhangs that can catch fabrics or pressure-suit appendages.
Sheet metal structure, box and cabinet three-plane intersecting corners	Use spherical welded or formed radii unless corners are protected with covers.
Screw heads, bolts, nuts, nut plates, excess threads, and rivets that a crewmember can come in contact with	Design all screw heads and bolt heads to face the outside of the structure, if possible. Where nuts, nut plates, and threads are exposed, cover the nuts, nut plates, and threads in a secure manner that does not preclude removal of the fastener. Recessed heads or the use of recessed washers is recommended. Overall height of heads must be within 0.125 in. (3.2 mm) or covered unless more than 7 head diameters apart from center to center. Height of roundhead or oval-head screws is not limited. Screw heads or bolt heads more than 0.25 in. (6.4 mm) deep must be recessed or be covered with a fairing, except those intended to be EVA crew interfaces.
	Design rivet heads to face out on all areas accessible to crewmembers and to protrude no more than 0.06 in. (1.5 mm) unless spaced more than 3.5 head diameters from center to center. In all exposed areas where unset ends of rivets extend more than 0.12 in. (3.1 mm), or unset and diameter if more than 0.12 in. (3.1 mm), install a fairing over them. This applies to rivets such as explosive, blind, and pull rivets. Unset ends of rivets must have edges chamfered 45 deg or ground off to a minimum radius of 0.06 in. (1.5 mm).
	Allow a maximum gap of 0.02 in. (0.5 mm) only between one side of a fastener head and its mating surface.
	Prevent or eliminate burrs. Use of Allen heads is preferred. For torque-set, slotted, or Phillips head screws, cover with tape or other protective materials or individually deburr before flight.

Suit Design Considerations

EVA Safety

Micrometeoroid and Orbital Debris Impact (MMOD)

MMOD may range in size from microscopic grains to small rocks and larger rocks. Even microscopic elements can cause significant damage to spacecraft at orbital velocities and could easily create a tear in a spacesuit and injure the crewmember. While the probability is low, the seriousness of an impact is high enough to warrant consideration of protection during EVA, when a crewmember is most vulnerable. The Shuttle EMU includes a seven-layer micrometeoroid garment of aluminized Mylar laminated with Dacron, topped with a single-layer fabric combination of Gortex, Kevlar, and Nomex.



Layers of the EMU suit

Entrapment

The limited mobility in a pressure suit may increase the likelihood of an EVA crewmember getting an appendage trapped in a wedge or hole from the size of a gloved finger to that of the whole body. This may become hazardous if the crewmember is not able to slowly and carefully become unencumbered. Because the amounts of consumables in a pressure suit are limited, being trapped too long could be life-threatening. In addition, struggling to become free may damage the suit, including tearing it, which could lead to decompression. To prevent this from occurring, translation paths must be sized to permit a suited crewmember to turn around. Uncovered round or slotted holes must be smaller than the smallest crewmember's finger width or larger than the largest crewmember's finger width. Suit design and operations should be considered when sizing intermediate-sized openings, to preclude entrapment. This also applies to IVA interfaces that may require pressure-suited crewmembers to use them.

Electrical Hazards

The EVA environment may include more numerous and dangerous electrical hazards than the IVA environment, due to the external placement of power sources such as batteries and solar arrays. Preventing contact with electrical hazards can be accomplished by placing electrical contacts out of nominal translation paths, and by placing mobility aids in locations to preclude inadvertent contact with hazards. In the event that maintenance or repair is needed on or near areas that may present an electrical hazard, safe access must be provided, as well as protective covering for any accessible metal suit parts and tools. *See OCHMO-TB-021 Electrical Shock for additional information.*

Suit Design Considerations

EVA Acoustics and Noise

The acoustic environment in the suit should provide high-quality audio to and from the crew during EVA, comfortable working noise levels inside the suit, and broadcast-quality audio for video transmission. To achieve these objectives, EVA suits will have to be designed from the beginning to produce a minimum of noise; control acoustic resonances in the closed space of the suit; minimize acoustic reflections from the helmet visor; incorporate state-of-the-art microphones, speakers, and electronics; and use high quality digital encoding of the speech and audio. The life support systems of current EVA suits are sources of noise. Also, the suits have acoustic resonances common to any enclosed volume. Each of these sources of noise and resonances can be controlled by careful attention to the acoustic details of the suit. Noise can be reduced through source or resonance controls.

- Noise Source Control – It is best to modify the designs of the life support systems to eliminate or reduce the noise at the source. This involves measuring noise levels generated by each subsystem early in the design, identifying the sources of noise, and reducing them.
- Resonance Control – When the noise source is minimized, then absorption techniques like mufflers and sound-absorbing foam can be used to further reduce the generated noise to acceptable levels. Resonances of the suit system can be controlled by using sound-absorbing foam, so that that the resonances are damped. The helmet is a very reverberant space, and this can make speech communication more difficult.

Reference OCHMO-TB-035 Acoustics for additional information on acoustic limits and noise control.

EVA Lighting

Most lighting considerations for interior spaces in spacecraft may be extended to the EVA environment. The lighting conditions for EVA operations, however, are generally much more dynamic than those within spacecraft. In low Earth orbit, the surfaces of the vehicle experience a full sunrise-sunset-sunrise cycle about every 90 minutes. Under these conditions, shadows can move across work sites at angular velocities exceeding 4 degrees per minute. Unless large exterior surfaces are adjacent to and angled favorably relative to the work site and the sun, not much reflected “fill” light can be expected to illuminate the deep shadows. Direct solar illumination in low Earth orbit is on the order of 132,000 lx (Earth Fact Sheet). Assuming Earth's average visual albedo is 0.367, “earthshine” reflected from the planet and illuminating the nadir surfaces of a spacecraft in low Earth orbit may be calculated to be about 50,000 lx or less. The earthshine is “diffuse,” originating from all points on the visible planetary disk, with the overall reflected illumination depending on the average reflectance of the surfaces viewed from the spacecraft and the proportion of the planetary body’s surface that appears from orbit to be lighted by the Sun. Similar direct solar illumination levels would be expected for EVAs in lunar orbit, with light-dark periods determined by the orbit altitude and geometry. There is less variation in illumination on the nadir surfaces of a spacecraft during lunar orbit than in Earth orbit, because there is less variation in reflectance over the Moon’s surface than there is in the terrestrial case. Since the average lunar visual albedo is 0.12 (Moon Fact Sheet), reflected illumination levels in lunar orbit are a third or less of those in orbit about Earth. In orbit around Mars, direct solar illumination is approximately 43% of that in low Earth orbit, or about 57,000 lx. Mars’ albedo is 0.15 (Mars Fact Sheet), compared with Earth’s value of 0.367. Reflected illumination from Mars’ surface onto a spacecraft in orbit about the planet at an altitude typical of low Earth orbit is calculated to be on the order of 20,000 lx or less.

Suit Design Considerations

EVA Lighting

The EMU helmet visor attenuates the incident visible light by about 8% to 15%. Some of this loss is attributable to ultraviolet and antireflective coatings necessary to protect the spacefarer from sunburn and to minimize reflected glare inside the helmet. The current external sun visor transmits 16% +/- 4% at 555 nm. If attenuation by the helmet sun visor is not great enough to allow EVA visual tasks to be performed at a particular time, the tasks may need to be shifted in time to periods when adverse solar lighting is not present.

The sun visor provides protection from thermal and light conditions on the lunar surface. The eyeshades can also be lowered to reduce low-angle solar glare. When facing toward the sun, the center eyeshade assembly may be lowered and the viewport door adjusted to provide additional solar glare protection.

Lunar equatorial regions, such as those explored by the Apollo missions, are strongly illuminated by the Sun. The incident sunlight is not scattered by atmospheric dust or moisture, as encountered on Earth, so shadows on the surface are stark, just as in orbit. There is no aerial perspective (hazy view of distant objects), and the Moon is smaller in diameter than the Earth, so the lunar horizon is nearer to the observer than that on Earth. These effects tend to distort visual distance judgment to make distant objects on the Moon appear closer than they actually are. The relative uniformity of the surface reflectance and color of the lunar regolith conspire to obscure surface details when they are observed looking in the Sun's direction or with the Sun to one's back. Only when viewed at an oblique angle to the Sun's rays are shadows cast by surface irregularities apparent to afford visual cues to objects' relative size and shape. The lunar south pole has areas of near-constant solar illumination and all lighting is oblique. Certain permanently shadowed features have been identified in this region, including craters near the poles. Elevated features cast very long shadows. Surface exploration by astronauts will require extensive provisions for artificial lighting. Long-term habitations near the southern pole may make use of extensive solar reflectors on elevated surfaces to supply "fill lighting" in some permanently shadowed work areas. Unlike the Moon, Mars exhibits a day-night cycle similar in length to that of Earth. The thin atmosphere affords a small degree of diffusion to the distance-attenuated solar illumination. The predominant red ochre reflective characteristic of the soil colors all reflected light red. Explorers immersed in this environment for an extended period will likely notice a shift toward less sensitivity to redder light as their color perception adapts to their surroundings. Any color-coded markings for use on Mars should be designed with color adaptation in mind.

Reference OCHMO-TB-001 Artemis Lighting Considerations Overview for additional information lighting considerations for future Artemis missions, including Moon surface EVAs.

Craters and regolith formations at the lunar South Pole area showing complete darkness and long shadows. Generated by NASA JSC NASA Scientific Visualization Studio.

Suit Design Considerations

Suited Visual Performance

A crewmember in a spacesuit may have a restricted field of view (FOV) because of limitations imposed by the suit, helmet, and visor assembly. The EVA suit must provide adequate FOV to perform suited IVA and EVA operations. Concurrently, consideration should be given to the placement of critical EVA equipment within the visual limits of the helmet. Equipment required to be seen by a pressure-suited crewmember must be located within the FOV of the crewmember. Equipment mounted to the helmet (e.g., head mounted displays) for suited operations must not obstruct the FOV. The helmet visor must provide adequate visual resolution to perform all expected tasks, including vehicle repair and maintenance, and scientific objectives such as identification of geologic samples. If a visor is used, it should promote an adequate FOV to perform EVA tasks and prevent tunnel vision.

Depending on the size and shape of the visor, it may have some refractive distortion, which affects the perceived shape and location of objects in the peripheral vision. Refractive distortion must not interfere with task performance or contribute to spatial disorientation.

In addition, the capability to reduce glare and contrast ratios must exist. The Sun or other bright light sources may be in the FOV, and reflective surfaces such as the spacecraft exterior or lunar surface will be much brighter than the surrounding blackness of space, creating glare.

Due to the close proximity of the mouth and nose to the visor, and the relative humidity in the suit atmosphere, fogging of the visor is possible. This can be dangerous, preventing the crewmember from seeing handholds and hazards. The EMU visor allows the crewmember to view the EMU boots during EVA workstation and restraint ingress.

EMU Helmet Visual Performance

System provision	Parameter	Performance		
Helmet optical visibility	Field of view	120 deg. left and right in the horizontal plane. 105 deg. down and 90 deg. up in the vertical plane		
	Critical area of vision	Vertical	90 deg 1.57 rad	
		Superior-temporal	62 deg 1.08 rad	
		Superior	85 deg 1.48 rad	
		Inferior-temporal	85 deg 1.48 rad	
		Inferior	70 deg 1.22 rad	
Optical distortion	No visible distortion or optical defects detectable by the unaided eye (visual acuity 20/20) at the typical “as worn” position			
Transmittance	Nanometers (nm)	UV	Luminous	IR
		200	300 400	700 700+
Thermal/coating optical characteristics	Characteristics	Inner protective visor	Outer sun visor	
	Transmittance			
	550 nm	70% min.	16 ± 4%	
	1100 nm	N/A	10% max.	
	Solar reflectance			
	550 nm	5% max.	40% min.	
	2400 nm	70% min.	N/A	
	700 nm	N/A	55% min.	

Suit Design Considerations

EVA Safety

Radiation

Radiation events may pose a greater danger to EVA crewmembers than their IVA counterparts. This is partly because a suit affords minimal radiation protection compared to a spacecraft, and because taking shelter (e.g., ingress) when an event occurs may take a long time depending on the distance between the crew and the spacecraft or other radiation protection. EVA suits must provide or accommodate radiation monitoring and alerting functions to allow the crew to take appropriate actions. A personal passive dosimeter is required by the Code of Federal Regulations and Occupational Safety and Health Administration (OSHA) for monitoring astronaut radiation exposure. The standard passive dosimeters used for ISS/Shuttle/Mir by U.S. and Russian scientists are installed inside the pressurized part of the suit. Placing active dosimeters inside the pressurized suit allows the crewmember to select a shielding location that is appropriate for the skin or organ dose that the crewmember is receiving. Current state-of-the-art dosimeters used by U.S. scientists require the presence of oxygen to function properly. ***See OCHMO-TB-020 Radiation Protection.***

Chemical Contamination

Some EVA worksites or translation paths to worksites will be located on the spacecraft's exterior. These locations may contain hazardous materials to which an EVA crewmember may be exposed. The design of translation paths should avoid contact with potential contamination sources (e.g., jets, engines, fuel lines, fluid purge valves, and gas venting) when possible. ***See OCHMO-TB-015 Spaceflight Toxicology.***

Decompression

In addition to selecting a cabin and suit pressure combination, ppO_2, and prebreathe that result in acceptable DCS risks during nominal operations, provisions for treatment of DCS must be made. By allowing the spacesuits to increase to higher pressures, crewmembers have the ability to quickly treat DCS symptoms. A contingency loss of suit pressure is a serious hazard, leading to injury and eventually death if uncontrolled. The primary causes of suit decompression are likely to be a tear or puncture of the suit's pressure garment, or failure of the suit's environmental control system. Tears and punctures could occur from sharp edges or micrometeoroids. ***See OCHMO-TB-037 Decompression Sickness (DCS).***

Injury Treatment and Incapacitated Crew Rescue

In the 0g EVA environment, injuries are most likely to result from electrocution or the impact of a micrometeoroid or orbital debris. During extraterrestrial microgravity surface operations, such as on the Moon, additional risks of injuries expand to include ambulation injuries (such as ankle sprains), falls from heights, and surface work-related injuries, as well as those related to extraterrestrial surface transport vehicles. In the event a crewmember becomes ill or injured while in the suit, the ability must exist for a suited crewmember to transport an injured or incapacitated suited crewmember. After an injured or ill-suited crewmember is brought into the pressurized cabin, the design of the suit must allow another crewmember to quickly gain access to the injured part of the body and areas used for diagnosis or treatment, including the head, neck, and chest, and to administer care in the suit, such as providing medication, wound care, and CPR. After initial stabilization, the suit must allow assisted suit egress and not rely on the injured crewmember to help.

Back-Up

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

Referenced Technical Requirements

NASA-STD-3001 Volume 2 Revision E

[V2 11001] Suited Donning and Doffing The system shall accommodate efficient and effective donning and doffing of spacesuits for both nominal and contingency operations.

[V2 11125] Suit Materials Compatibility Pharmaceuticals, topical treatments and cleaning materials shall be compatible with suit materials (internally and externally).

[V2 11126] Suit Materials Cleanability The suit materials (internally and externally) shall be compatible with the expected cleaning materials and methods.

[V2 11006] Suit Pressure Set-Points The suit shall provide the capability for the crewmember to select discrete suit pressure set-points within the suit operating pressure ranges during pressurized and unpressurized suited operations.

[V2 11007] Suit Equilibrium Pressure Suits shall maintain pressure within 1.72 kPa (0.25 psi) after the suit has achieved an equilibrium pressure for a set-point.

[V2 11009] Continuous Noise in Spacesuits Suits shall limit suit-induced continuous noise exposure at the ear to NC-50 or below without the use of auxiliary hearing protection.

[V2 11010] EVA Suit Radiation Monitoring The suit shall provide or accommodate radiation monitoring and alerting functions to allow the crew to take appropriate actions.

[V2 11011] Suited Crewmember Heat Storage The system shall prevent the energy stored by each crewmember during nominal suited operations from exceeding the limits defined by the range 3.0 kJ/kg (1.3 Btu/lb) > ΔQ stored > 1.9 kJ/kg (-0.8 Btu/lb), where ΔQ stored is calculated using the 41 Node Man or Wissler model.

[V2 11013] Suited Body Waste Management – Provision Suits shall provide for management of urine, feces, menses, and vomitus of suited crewmembers.

[V2 11028] EVA Suit Urine Collection EVA suits shall be capable of collecting a total urine volume of $V_u = 0.5 + 2.24t/24$ L, where t is suited duration in hours.

[V2 11014] LEA Suit Urine Collection LEA suits shall be capable of collecting a total urine volume of $V_u = 0.5 + 2t/24$ L throughout suited operations, where t is suited duration in hours.

[V2 11015] Suit Urine Collection per Day – Contingency For contingency suited operations lasting longer than 24 hours, suits shall be capable of collecting and containing 1 L (33.8 fl oz) of urine per crewmember per day.

[V2 11016] Suit Feces Collection per Day – Contingency During contingency suited operations, suits shall be capable of collecting 75 g (0.17 lb) (by mass) and 75 mL (2.5 fl oz) (by volume) of fecal matter per crewmember per day.

[V2 11017] Suit Isolation of Vomitus Suits shall be shown to not create any catastrophic hazards in the event of vomitus from the crewmember.

[V2 11018] Suited Field of Regard Suits shall provide a field of regard sufficient to allow the crewmember to accomplish required suited tasks.

[V2 11019] Suit Helmet Optical Quality Suit helmets shall have sufficient optical qualities to allow the crewmember to accomplish required suited tasks and maintain a level of SA necessary to maintain safety.

[V2 11020] Suit Helmet Luminance Shielding Suit helmets shall provide protection to suited crewmembers from viewing objects with luminance that could prevent successful completion of required suited tasks.

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the OCHMO Standards website

Referenced Technical Requirements

NASA-STD-3001 Volume 2 Revision E

[V2 11021] Suit Helmet Visual Distortions Suit helmets shall be free from visual distortion.

[V2 11022] Suit Helmet Displays Suit helmet field of regard shall be unencumbered if helmet- or head-mounted displays are provided.

[V2 11023] Suit Information Management The system shall allow the crewmember to effectively input, store, receive, display, process, distribute, update, monitor and dispose of relevant information on consumable levels, suit status and alerts, and biomedical data.

[V2 11100] Pressure Suits for Protection from Cabin Depressurization The system shall provide the capability for crewmembers to wear pressure suits for sufficient duration during launch, entry, descent (to/from Earth, or other celestial body) and any operation deemed high risk for loss of crew life due to loss of cabin pressurization (such as in mission dockings, operations during periods of high incidence of micrometeoroids and orbital debris (MMOD) or complex vehicle maneuvers).

[V2 11024] Ability to Work in Suits Suits shall provide mobility, dexterity, and tactility to enable the crewmember to accomplish suited tasks within acceptable physical workload and fatigue limits while minimizing the risk of injury.

[V2 11025] Suited Nutrition The system shall provide a means for crewmember nutrition in pressure suits designed for surface (e.g., Moon or Mars) EVAs of more than 4 hours in duration or any suited activities greater than 12 hours in duration.

[V2 11029] LEA Suited Hydration The system shall provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 2 L (67.6 fl oz) per 24 hours for the LEA suit.

[V2 11030] EVA Suited Hydration The system shall provide a means for on-demand crewmember hydration while suited, including a minimum quantity of potable water of 240 mL (8.1 fl oz) per hour for EVA suited operations.

[V2 11027] Suited Medication Administration The system shall provide a means for administration of medication to a suited, pressurized crewmember for pressurized suited exposures greater than 12 hours.

[V2 11031] Suited Relative Humidity For suited operations, the system shall limit RH to the levels in Table 11.2-1—Average Relative Humidity Exposure Limits for Suited Operations.

[V2 11032] LEA Suited Decompression Sickness Prevention Capability LEA spacesuits shall be capable of operating at sufficient pressure to protect against Type II decompression sickness in the event of a cabin depressurization.

[V2 11033] Suited Thermal Control The suit shall allow the suited crewmembers and remote operators to adjust the suit thermal control system.

[V2 11034] Suited Atmospheric Data Recording Systems shall automatically record suit pressure, ppO_2, and $ppCO_2$.

[V2 11035] Suited Atmospheric Data Displaying Suits shall display suit pressure, ppO_2, and $ppCO_2$ data to the suited crewmember.

[V2 11036] Suited Atmospheric Monitoring and Alerting Suits shall monitor suit pressure, ppO_2, and $ppCO_2$ and alert the crewmember when they are outside safe limits.

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Referenced Technical Requirements

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[V2 11039] Nominal Spacesuit Carbon Dioxide Levels The spacesuit shall limit the inspired CO2 partial pressure (PICO2) in accordance with Table 11.3-1—Spacesuit Inspired Partial Pressure of CO2 (PICO2) Limits.

[V2 11040] Contingency Spacesuit Carbon Dioxide Levels for Partial Gravity Scenarios The spacesuit inspired CO2 partial pressure (PiCO2) shall not exceed 20 mmHg during contingency scenarios up to a duration of 1-hour.

[V2 11037] EVA Suited Metabolic Rate Measurement The system shall measure or calculate metabolic rates of suited EVA crewmembers.

[V2 11038] EVA Suited Metabolic Data Display The system shall display metabolic data of suited EVA crewmembers to the crew.

[V2 11101] Incapacitated Crew Rescue (ICR) Resources shall be provided to rescue an incapacitated suited crewmember(s).

Former NASA Administrator Jim Bridenstine, left, high fives Kristine Davis, a spacesuit engineer at NASA's Johnson Space Center, wearing a ground prototype of NASA's new xEMU during a demonstration of the suit, Tuesday, Oct. 15, 2019 at NASA Headquarters in Washington. Photo Credit: (NASA/Joel Kowsky)

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