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The Wait-less EVA Solution: Single-Person Spacecraft

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Astronaut Don Pettit writes, "Nothing happens fast during the preparations for a space walk...it takes several days over about a week to prepare for a space walk." He is not the only one, astronaut Scott Kelly says, "For an astronaut, going outside is a dangerous undertaking that requires days of preparation." In fact, NASA reports it takes an average of over 58 crew hours to prepare for a single Extravehicular Activity (EVA), then it takes another 15 hours for post EVA servicing. This non-productive time is particularly bothersome because it is unavoidable for space suits and according to NASA rates, costs approximately $1.3M in crew time per EVA. Not included is the additional time for airlock pump down, collecting tools, translating hand-over-hand to the worksite, setting up foot restraints, then translating back, and repressurizing the airlock. The good news is there is a non-suit solution called the Single-Person Spacecraft (SPS) specifically designed for wait-less EVA. With SPS, astronauts can be outside in less than10 minutes, fly directly to the work site, use force-multiplying manipulators for repair, then fly back to the host spacecraft spending only minutes for post flight servicing. The SPS is under construction and poised to transform the future of EVA. It has broad application supporting International Space Station, and the Hubble Space Telescope with extensibility to the lunar Gateway, space tourism, and Mars transit vehicles.

I. Introduction

A typical 40 hour work week is five, eight hours days. It takes that amount of time plus an additional two more days for on-orbit astronauts to prepare for the average Extravehicular Activity (EVA). NASA reports that the average EVA preparation time is 58.25 hours[6]. Additionally, 15.83 hours, or approximately two more days of crew time, is dedicated to post EVA tasks. If these times were cut in half, they would still be jaw-droppers. Because most people are unaware of complexity and overhead for suited EVA, the purpose of this paper is to present these activities while

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[6] EVA Office Extravehicular Activity (EVA) Airlocks and Alternative Ingress/Egress Methods Document, NASA, EVA-EXP-0031, Baseline, 04/18/2018

comparing them to improved operations using the Single-Person Spacecraft (SPS) for EVA. A comparison summary is shown in Figure 1.

Task	Suited EVA	SPS Wait-less EVA
EVA Preparation	58 hours	10 minutes (6 min. for MMU)
Space suit fit	12 hours	No sizing (one size fits all)
Airlock depress	30-40 minutes	No airlock (direct access)
Translation	12-34% of EVA	Minutes
Airlock repress	15 minutes	Minutes (pressure equalization)
Suit doffing	25 minutes	No doffing (direct ingress)
Post EVA	15 hours	10 minutes (10 min. for MMU)
Training	100 NBL hrs./EVA	TBD Simulator hours
Gateway Ops	No EVA for 4 years	Early and continuous ops

Fig. 1 SPS EVA eliminates days of overhead astronaut time.

Most people appreciate the difference between weightless and planetary EVA. The confusion comes with having a similar space suit solution for both. Space suits are a logical choice for planetary exploration, but not optimized for weightless operations. This is the inspiration shaping the SPS. Referenced published papers detail the benefits of the SPS, however the focus of this paper is the overhead time. NASA sources are used for space suit data; of these three charts are included in the Appendix. SPS data draws on the similarity to the flight-proven Manned Maneuvering Unit (MMU) and results from development testing. Also, it is important to note that modular pressurized space suits including the current Extravehicular Mobility Unit (EMU) and the planned xEMU (exploration EMU) share the same overhead for weightless operations. The SPS is a vehicle designed to fit all crew using the same cabin atmosphere as the host (see Figure 2).

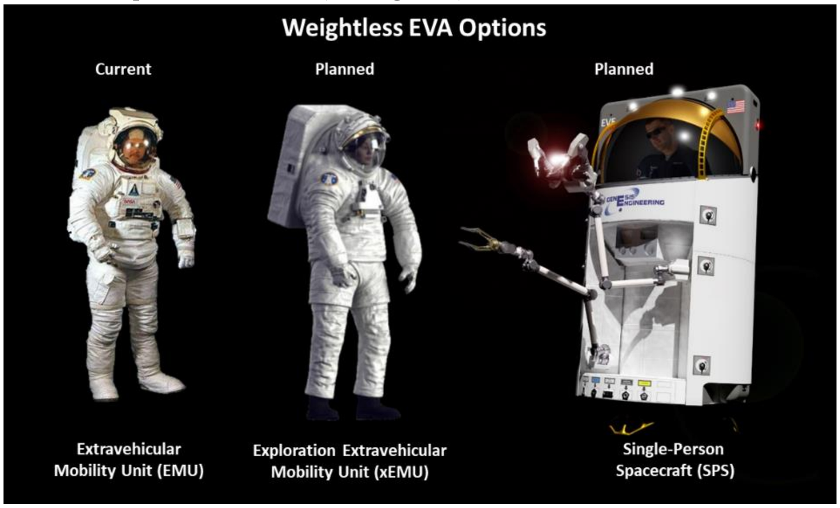


Fig. 2 The EMU, xEMU space suits and the SPS

Astronaut time has always been a precious space resource. Therefore, every effort is made to minimize task overhead and improve efficiency. Unfortunately, the trend for EVA is going the other way. Fifty years ago, Apollo astronauts spent considerably less time getting ready for an EVA than the current ISS astronauts. What is more troubling is that with space suits, the overhead for future weightless EVA will remain about the same as ISS.

Compared to "inside" astronaut time, being outside is extremely time sensitive. EVAs are planned around the limited quantities of life-critical oxygen, electrical power, and cooling water. Typically, this is 7 hrs. with a margin added. Even though an outside task may require more than the planned time, astronauts must return to the airlock. Not only is this EVA window constrained but next day opportunities are limited. Because of crew fatigue, a next day EVA with the same crew is unlikely. Sometimes flight rules require a rest day, otherwise, the 15 hours for post EVA tasks, and 12 hours for changing out the upper torso[7] combine to prevent a different crew from a next day EVA in the same suits. Of course, having 2 separate EVA crews and 4 suits is an option, but this comes with additional mass, resources, cost, and on-orbit storage volume.

If astronaut time is important, how important is it? To answer this, NASA has published an hourly rate for the ISS crew. It is $17,500 per hour[8]. Not counting the time "outside," the cost for preparation and post EVA time is $1,296,400!

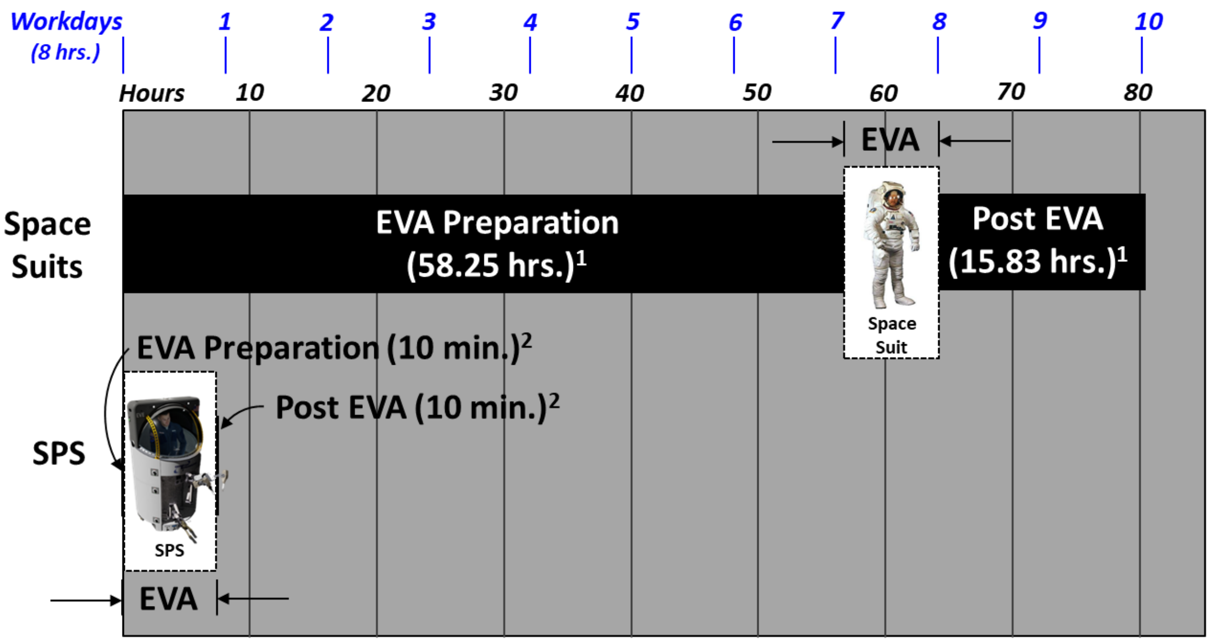
In contrast, the Single-Person Spacecraft requires only minutes not days for both preparation and post EVA tasks. Because the SPS has the same propulsion architecture as the MMU, it is assumed that preflight and post excursion times are similar. The MMU User's Guide shows 6 minutes for checkout and 10 min, for doff/stow. Although the SPS tasks would be automated, 10 minutes crew time was allocated for each pre and post flight activity. Assuming more

[7] Amy Ross, NASA Space suit engineer, Spacesuit Sizing Stymied a Historic NASA Moment, and It May Always Be Tricky. By Meghan Bartels April 03, 2019

[8] Human Spaceflight Continuity and the International Space Station, 2019 International Astronautical Congress, Washington D.C., Samuel Scimemi, NASA Director, International Space Station

than one crew member and tripling the time to equal one hour, this makes the SPS total crew overhead $17,500. This is a 99 percent reduction in the time and cost of suited EVA. Figure 3 shows the preparation and post EVA time for the EMU and SPS.

This difference is so significant that other comparisons may not be worth considering. However, there are other advantages to SPS EVA. Astronauts fly directly to the work site versus crawling back and forth. No resizing is required allowing different astronauts to use the SPS one-after-the-other. Not only is the SPS much more efficient it does not require an airlock and therefore is lighter, less complex, and less expensive than suited EVA.



1 EVA Office Extravehicular Activity (EVA) Airlocks and Alternative Ingress/Egress Methods Document, NASA, EVA-EXP-0031, Baseline, 04/18/2018
2 Includes 10 min. chk out and 10 min. shut down. (Compared to MMU chk out time = 6 min./ doff and stow =10 min. Manned Maneuvering Unit, Users' Guide, May 1978, MCR 78-517, NASA CR 151864). Note: C. Whitsett predicted a 2 min. chk out for the Space Station MMU, "Role of the Manned Maneuvering Unit for the Space Station," SAE 861834

Fig. 3 SPS provides a 99 percent reduction in EVA overhead time.

II. Different Solution Required

A "better" space suit will not make weightless operations more efficient. Only a different, non-suit solution can do that. Why? There are many reasons but five stand out: A. Transitioning from the spacecraft to space, B. The importance and complexity of fitting the space suit, C. Translating to and from the work site, D. Training, and E. Lunar Gateway operational readiness.

A. Transitioning from the Spacecraft to Space

Although not obvious, the hand, or more accurately, the pressurized glove, is the determining factor for transitioning to the space environment. Hands are essential for weightless suited EVA. They are used for getting to and from the work site, setting up foot restraints, operating tools, removing and replacing parts, opening and closing the airlock hatch, adjusting helmet visors, and operating the controls on the suit. As good as they are, EVA gloves are five-fingered balloons. Pressurized and constructed of many layers makes them stiff and cumbersome to use. Further complicating glove operations is that hand strength is dependent on the relatively small forearm muscles providing a strong incentive for low pressure to reduce glove stiffness. Low pressure is also preferred because it minimizes leakage, reduces joint torque, and improves mobility for translation and tool operation. For these reasons, spacesuits including the ISS Extravehicular Mobility Unit (EMU) and planned xEMU are designed to operate at 29.65 kPa (4.3 psi). The lower pressure means that the suit breathing gas must be pure oxygen to sustain respiration. The ISS, Orion, Soyuz, Dragon, Cygnus, and the planned lunar Gateway operate or will operate with an Earth-normal 80% Nitrogen and 20% Oxygen pressured at 101.4 kPa (14.7 psi). The overhead issue is the time required to safely transition between the higher pressure two gas cabin atmosphere and the space suit low pressure Oxygen system. Similar to scuba diving, astronauts must pre-breathe Oxygen to purge the Nitrogen from their system to avoid getting decompression sickness or the "Bends."[9]

Alternatively, the SPS uses the same cabin atmosphere as these spacecraft and therefore astronauts have immediate access without pre-breathing or the risk of the "bends." Figure 4 shows some of the effects of the "bends" and the transition difference between suited and SPS EVA.

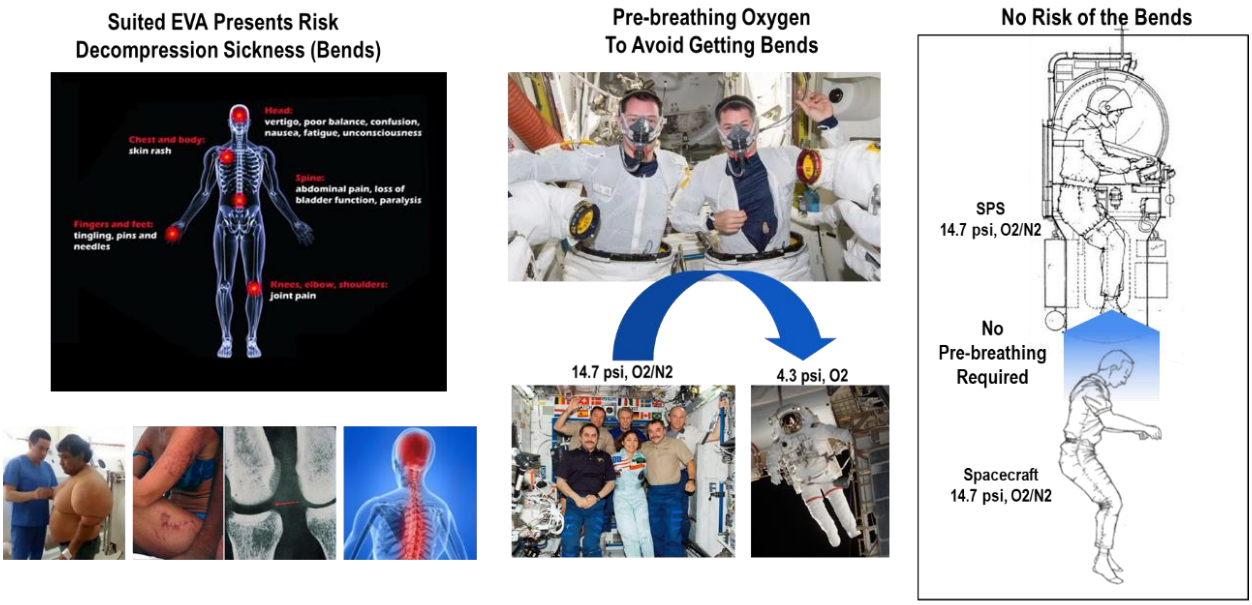


Fig. 4 Unlike space suits, SPS offers direct access to space without the risk of getting the "Bends."

Other factors to be considered with pre-breathing are hardware dependency and gas loss. The three denitrogenation protocols for EVA are exercise, campout, and in-suit light exercise (ISLE). With the exercise protocol, the lunar Gateway and Mars transit vehicle will require quick donning oxygen masks, serial use of exercise equipment such as the Cycle Ergometer Vibration Isolation System (CEVIS), and depressurizing an airlock to 70.33 kPa (10.2 psi). The campout protocol requires the masks and airlock depressurization to 70.33 kPa (10.2 psi). The ISLE protocol uses the suit and "slow motion hokey pokey" for denitrogenation prior to the EVA. The paper, "International Space Station (ISS) Extravehicular Activity (EVA) Gas Usage," cites the average prebreathe oxygen usage was 9.12 kg (20.10 lbm), while 0.944 kg (2.08 lbm) oxygen was used during the spacewalk, and 1.82 kg (4 lbm) air was loss per EVA. Other research suggests the ISLE protocol will reduce the quantity of oxygen required.

With SPS EVA, denitrogenation is not required therefore there is no need for the oxygen system or masks. Likewise, no exercise equipment or pumping is required. Ultimately, the SPS uses no dedicated oxygen and, assuming a SPS EVA gas loss equal to an ISS demating the Soyuz, loses only 20 percent of the air compared space suits using the ISS crewlock.

B. The Importance and Complexity of Fitting the Space Suit

It is hard not to overstress the importance of suit fit. Feet must be in the boots and hands in the gloves. This seems obvious, but with an inflated suit it is not guaranteed. Alexei Leonov says of the first EVA, "My feet had pulled away from my boots and my fingers from the gloves attached to my sleeves, making it impossible to reenter the airlock feet first." Only by lowering his suit pressure and a lot of work was he able to get back inside.

During Apollo, the suits were custom-made for each crew member. The Apollo A7LB weighed 85.7 kg (189 lbs.). With the Shuttle and ISS came a suit comprised of a kit-of-parts that could be resized on-orbit to fit individual crew members. The EMU weighs about 140.6 kg (310 lbs.) and resizing is not quick. NASA states that the average on-orbit fit verification is over 12 hours. In addition to making sure hands and feet are where they need to be, suit bending and

[9] This is a major safety concern because according to the Undersea Hypobaric Medical Society, "the resulting clinical manifestations include joint pains (limb bends), cutaneous eruptions or rashes (skin bends), neurological dysfunction (peripheral or central nervous system bends), cardiorespiratory symptoms and pulmonary edema (chokes), shock and death."

rotation must correspond with the astronaut's anatomy. "A proper space suit fit is particularly challenging because of NASA's desire to fit an incredibly diverse population (males and females from the 1st to 99th percentile) while developing a minimum number of space suit sizes."[10] As shown in figure 5, this represents a difference of 0.45 m (17.7 in.). Evidence of the complexity is that there are 106 on-orbit parts required to fit the ISS EVA population.

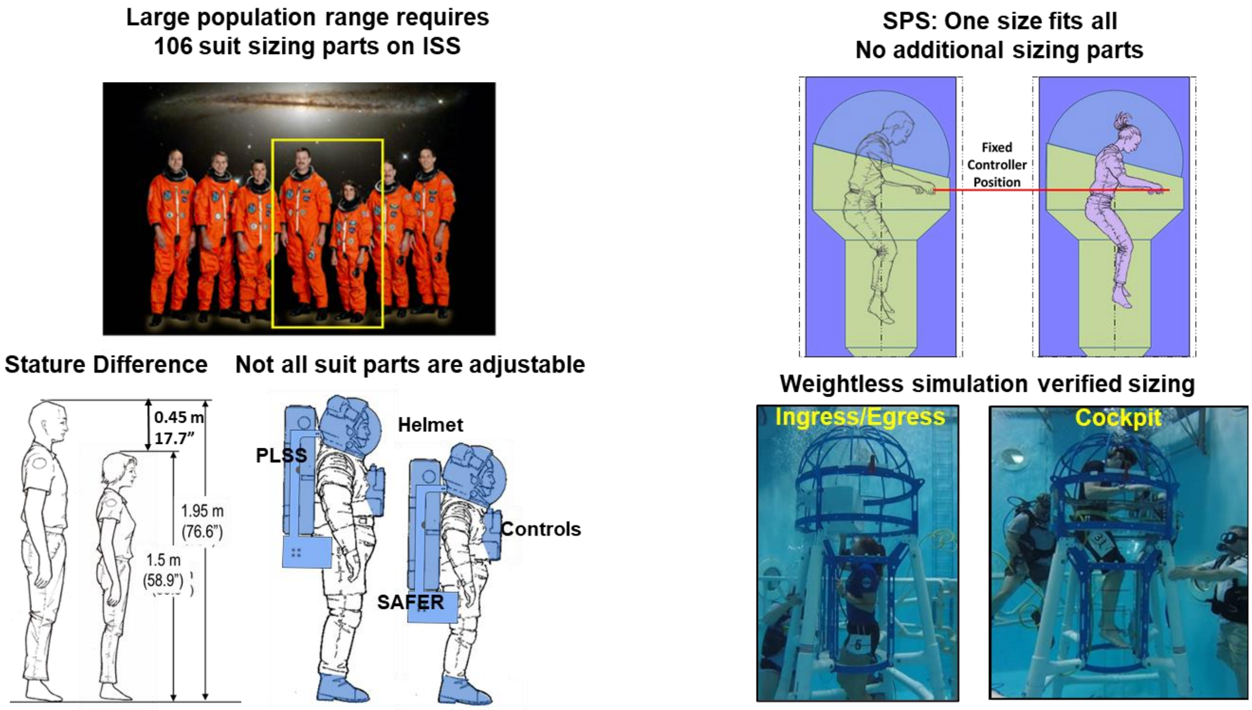


Fig. 5 One-Size-Fits-All SPS eliminates the mass and complexity of suit sizing.

In contrast, the SPS is designed to accommodate the entire astronaut population and only requires a few minutes to adjust the internal foot restraint for the next pilot. This is a significant time and mass savings while improving operations by allowing different astronauts to fly one after the other without resizing.

Lunar Gateway and Mars transit EVAs will take place outside of the earth's protective geomagnetic field. Therefore, astronauts are at a higher exposure risk to space radiation. There are at least two concepts for protective overgarments. The SPS design allows pilots to wear the overgarments shown in Figure 6, this is not possible for astronauts wearing a space suit.

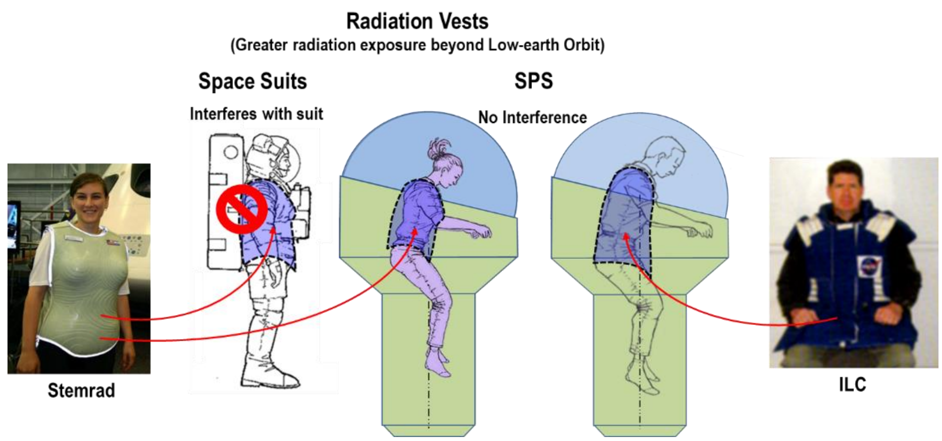


Fig. 6 SPS pilots can wear protective vests. This is not possible with Space suits.

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[10] Complexity of Sizing for Space Suit Applications, Benson E., Rajulu S. (2009) Complexity of Sizing for Space Suit Applications. In: Duffy V.G. (eds) Digital Human Modeling. ICDHM 2009. Lecture Notes in Computer Science, vol 5620. Springer, Berlin, Heidelberg

Even a proper fitting suit can induce trauma. In 2008, astronauts Carl Walz and Mike Gernhardt presented photographs of swelling, inflammation, and abrasions caused by contact with the inside of the space suit (Figure 7).[11] They went on to report that the trauma can occur with a minimal of EVA time. Even with proper suit sizing, parts of the astronaut's body press and rub against the rigid inner surface of the suit. This causes trauma at the contact points especially the hands, knees, and toes. Hand trauma is a concern because of the importance of grip and finger dexterity for weightless operations. Probably most significant is the high occurrence of fingernail delamination[12] with EVA astronauts. This is important because favoring painful or sensitive hands may compromise safety and performance. Neutral buoyancy is the preferred method for suited EVA training and although the suit may be neutrally buoyant, the astronaut and tools are still in earth's gravity. In an Aerospace Medicine report on injuries related to EVA suit design, it was reported that twenty-three astronauts have had shoulder surgery, two on both shoulders.[13] SPS provides astronauts a shirt sleeve environment; therefore, no suit induced trauma is anticipated.

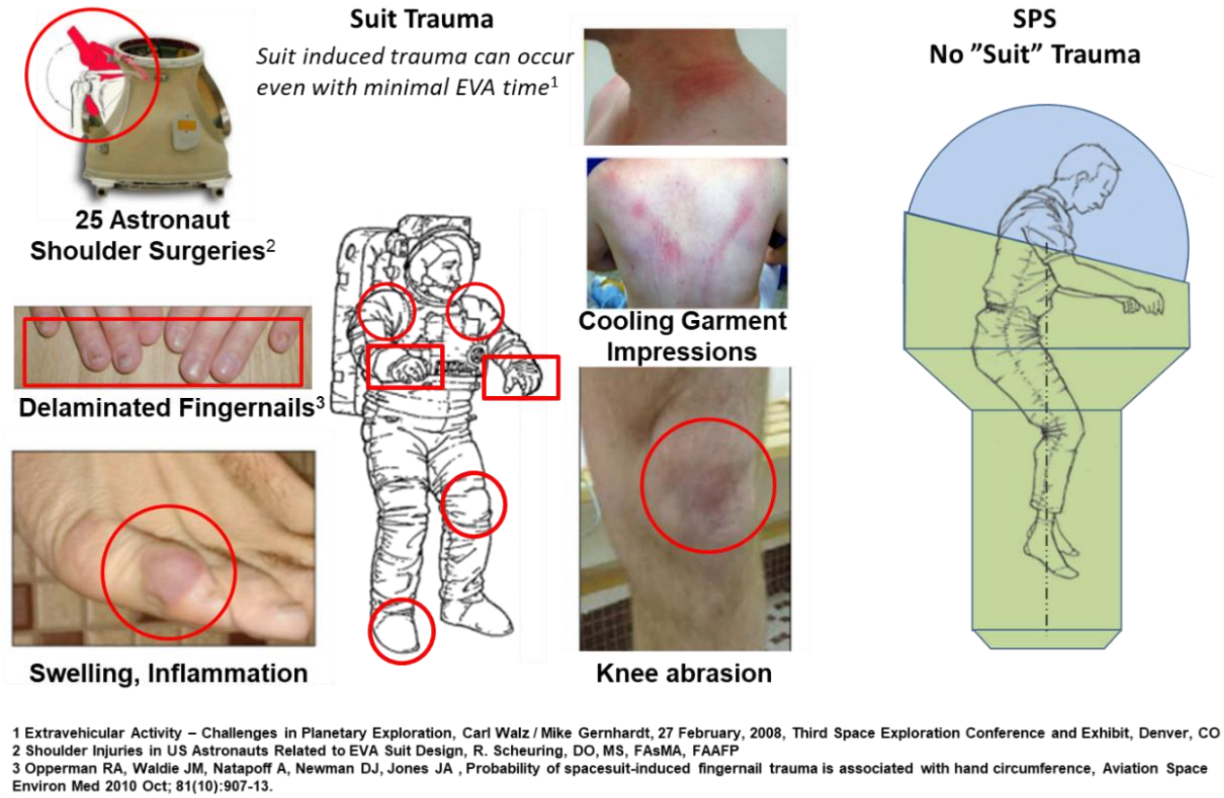

Figure 7 There is trauma to astronauts even with a good suit fit. No trauma with the SPS.

There is another important difference between space suits and the SPS related to fit. This is "hands-in" capability. The conformal fit of arm and glove does not allow astronauts the ability to bring their hands into the suit torso or helmet. Why is this important? For suits, water in the helmet is a life-threatening problem because there is no way to move the water from the face. Albeit not a frequent occurrence, this has been reported five times. (See Figure 8) Although still an issue in the SPS, free floating fluids are easily managed without threat to life. Another hands-in difference affects the operation of controls. With pressurized gloves, astronauts have restricted motion and diminished tactility when operating external controls. SPS pilots, on the other hand, have the benefit of bare-handed access to conventional displays and controls as well as the ability to eat and drink during the EVA.

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[11] Extravehicular Activity – Challenges in Planetary Exploration, Carl Walz / Mike Gernhardt, 27 February, 2008, Third Space Exploration Conference and Exhibit, Denver, CO
[12] Probability of Spacesuit-induced Fingernail Trauma is Associated with Hand Circumference, Opperman, R.A, et al, Aviation Space Environmental Medicine, Oct. 2010
[13] Shoulder Injuries in US Astronauts Related to EVA Suit Design, R. Scheuring, NASA Flight Surgeon, DO, MS, FAsMA, FAAFP, Aerospace Medical Association, May 11, 2012

C. Translating to and from the work site

Not all spacecraft are designed to accommodate EVA astronauts. For ISS there are prescribed EVA translation paths defined by handrails with tether restraint points. The pathway surface is designed to withstand kick loads and has a smooth, snag-free finish that will not damage gloves or suit. Translation in a space suit is slow going. EVA astronaut, Mike Massimino says “In space there’s no resistance to any move you make, so you have to go really slow.”[14] Adding to this, in a paper on EVA task work efficiency[15], authors C. Looper and Z. Ney report the following ISS translation times: 15 minutes for translation to PMA1; 14 minutes for tool configuration/translation to worksite; and 21 minutes to stow tools/translation to SO. See Figure 9. As mentioned, EVA is time-constrained because of the limited life support resources. So, these resources are being consumed getting to the work site and need to be preserved for getting

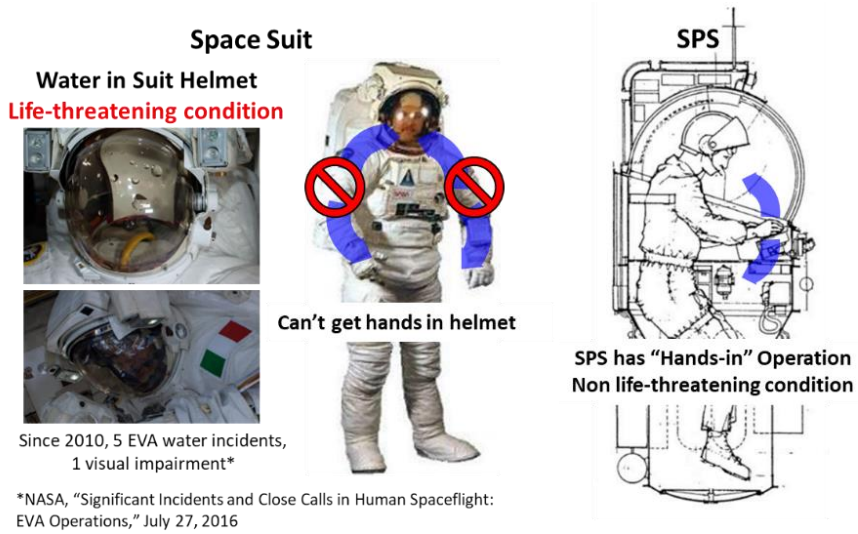
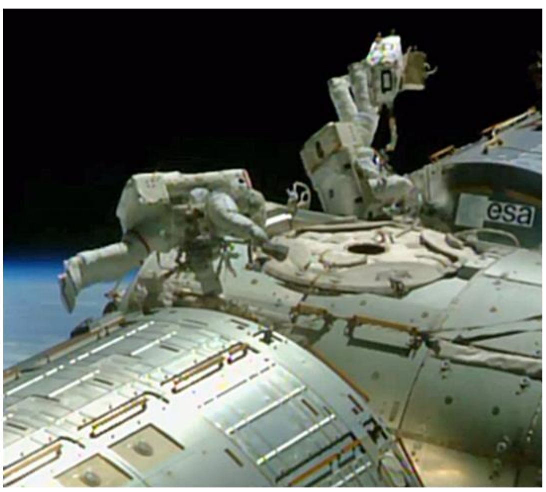


Fig. 8 Space suits do not accommodate hands-in operation.

Hand-over-hand Translation

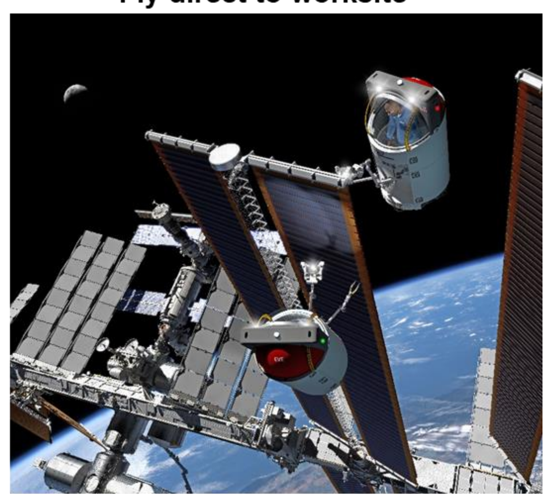


Increment 9 PRCM Replacement EVA

Activity	Time (min.)
Hatch to Strella	9
Translation to PMA1	15
Translation to SO	5
Tool config, trans to worksite	14
Stow tools, trans to SO	21
Translation to PMA1	10
Translation to Piers	16

Elapsed EVA Translation times

Fly direct to worksite



“...the MMU can return to the airlockfrom the furthest point on the Space Station (146.3 m (480 ft.)) in less than a minute.”

Role of the Manned Maneuvering Unit for the Space Station, C. E. Whitsett, NASA, JSC SAE 861834

MMU ~ SPS Performance

	MMU	SPS
Delta V (m/s)	13.7*	10.8*
Nom. Range (m)	137	same
Operation (hr)	6	same
Propellant	GN2	same
Prop mass (kg)	5.9	9.52
No. Thrusters	24	same
Thrust (N)	7.56	same
Tank Press (kpa)	20,684	same

*Usable Delta V

Fig. 9 Translation in space suits consumes 12-34% of the EVA resources.

[14] I Am an Astronaut. This is What it Like to Walk in Space, M. Massimino, Newsweek, May 9, 2020

[15] Extravehicular Activity Task Work Efficiency, C Looper and Z. Ney, SAE 2005-01-3014

back to the airlock. In another paper[16] on EVA work efficiency, the same authors said, "Ultimately, how efficiently these work objectives can be performed is dependent upon how much time has to be dedicated to overhead tasks such as translation, support equipment operation, and worksite setup/cleanup." They compared 7 US and Russian EVAs stating that translation times varied from 12 percent to 34 percent of the EVA time. There was additional time required for support equipment and work site preparation. The SPS uses the same propulsion architecture as the flight proven Manned Maneuvering Unit (MMU) allowing astronauts to fly directly to and from the worksite. In comparison to suited EVA, the MMU can return to the airlock from the furthest point on Space Station (about 146.30 m (480 ft)) in less than one minute.[17] This is important because minimizing translation overhead time means more time can be spent on the job rather than consuming limited resources on going to and from work.

D. Training

SPS crew training is another significant time-saver that offers substantial cost savings. For weightless operations, space suits use neutral buoyancy, parabolic aircraft, and a flat floor. All require special conditions (e.g. water facility, aircraft, and precision flat floor) and are operated by specially trained personnel. Most often NASA uses the Neutral Buoyancy Laboratory (NBL) for training. The NBL is the largest indoor water pool in the world and is supported by more than 200 employees, including 60 core divers.[18] A training session consists of two astronauts in suits weighted for neutral buoyancy along with safety divers, utility divers, and control room personnel. For safety, personnel and equipment maintain current certification requirements and the facility has a hyperbaric chamber for treating the bends (Figure 10). According to NASA's Behind the Scenes, Spacewalk Training, "You will practice every task dozens of times before you ever leave the Earth, until you can do it correctly every time…By the time you're ready to fly into space, you will have spent more than 100 hours underwater practicing for your spacewalks."

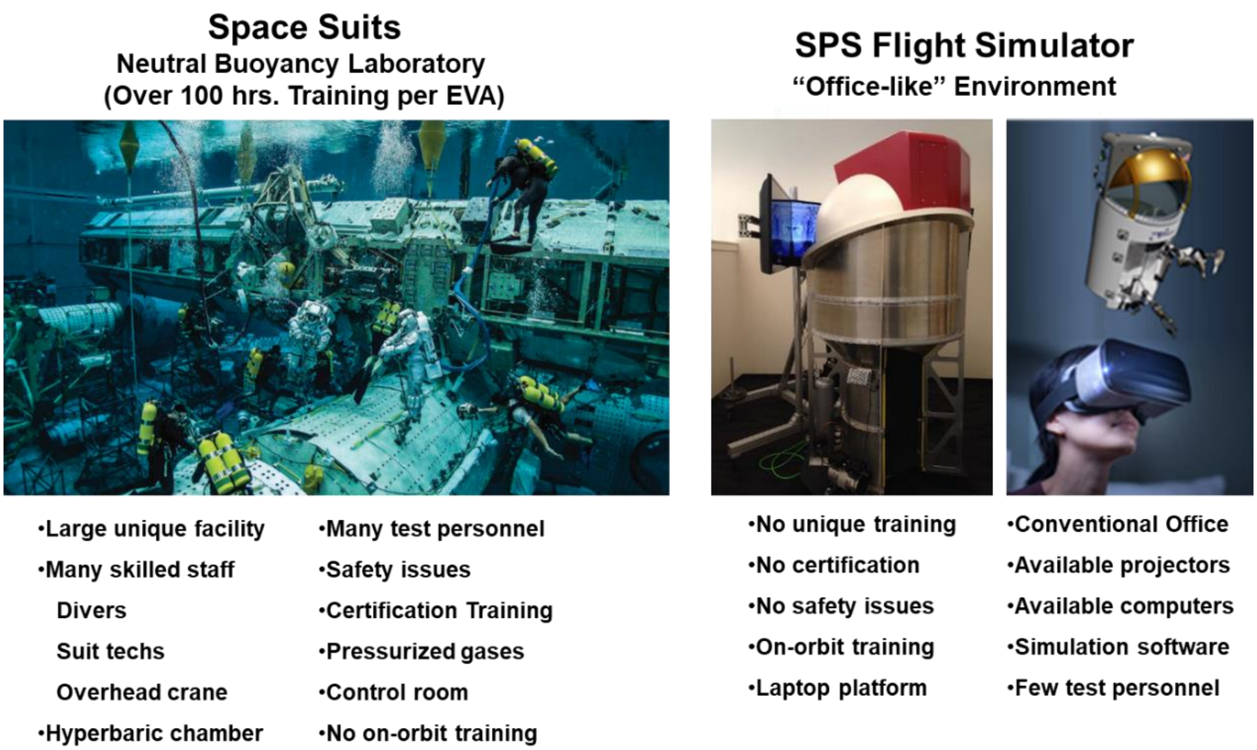


Fig. 10 Space Suit neutral buoyancy training is resource intensive requiring astronauts, support divers, and control room personnel. SPS training is agile and less expensive using the simulation environment.

[16] Quantifying EVA Task Efficiency, C. Looper and Z. Ney, AIAA 2006-5766
[17] Role of the Manned Maneuvering Unit for the Space Station, C. E. Whitsett, SAE 861834
[18] "Behind the Scenes Training," NASA. May 30, 2003, Retrieved March 22, 2011

The current contract to support the facility has a three-year base period is valued at $67.6 million with two one-year options totaling $52.3 million.[19] For Gateway, a new flight-like neutral buoyancy mockup would need to be constructed and additional neutral buoyancy xEMUs training suits would be required.

In contrast, the SPS approach uses proven aircraft/spacecraft-like simulation both for agile, low-cost development of the vehicle and for follow-on training. Early development is done by engineers in a conventional office environment, then as control and display concepts mature, a SPS cockpit is configured for operations assessment. For the simulator, the operator inputs are linked to modeled to SPS performance for accurate flight control around Gateway, ISS, or other spacecraft. This approach is low cost because it does not require special facilities or unique safety certifications. It allows anytime access and emergency procedures can be performed without risk to hardware or personnel. Another important feature is that it is possible to maintain proficiency on-orbit with virtual "laptop" simulations.

E. Lunar Gateway Operational Readiness

Shown in Figure 11 is the buildup sequence for NASA's planned Lunar Gateway. The airlock is delivered 4 years after the start and is the last element to be delivered. Without the airlock, there will be no suited EVA. This puts the Gateway at risk because there is no way for the visiting crew to repair or service external hardware. In contrast, the SPS offers a wait-less EVA solution. Not only does it provide for early EVA for the crew, but because the SPS can be tele-operated for earth, it enables continuous EVA. This capability is even more important because the Gateway is planned to be occupied for only one month out of the year. The SPS EVA solution allows the astronaut's time be focused on scientific opportunities of Gateway's unique location outside the earth's magnetic field and close to Moon versus the overhead for suited EVA.

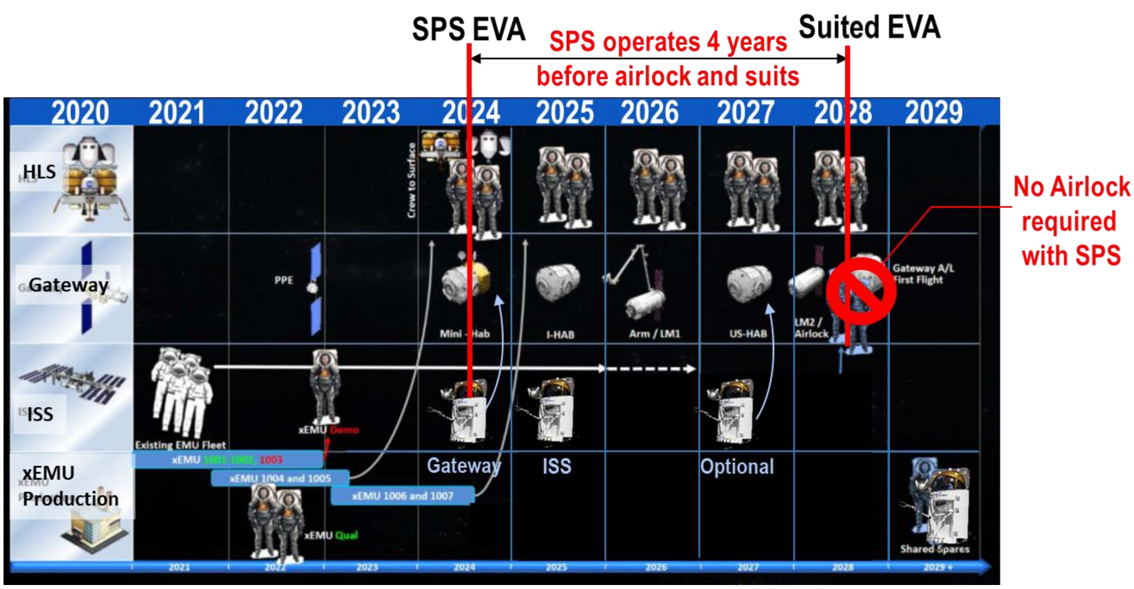


Fig. 11. SPS provides EVA four years earlier than suits including continuous operations when the crew is not there by using tele-operation from earth.

III. Conclusion

By being the Wait-less solution , the SPS saves millions of dollars and weeks of on-orbit astronaut time. This alone is an attractive reason for transitioning to the SPS for future EVA, especially for Gateway and Mars transit missions. But there are other good reasons; SPS EVA is the lighter, safer, and more efficient solution offering both piloted ops and teleoperations for expanded versatility. Using SPS would allow NASA to reduce the scope of new suit development focusing instead on surface operations while realizing important cost savings.

[19] CONTRACT RELEASE: C10-044, NASA Awards Neutral Buoyancy Laboratory, Space Vehicle Mockup Facility Support Contract

Appendix

An Appendix is included to provide the NASA reference material used to quantify the space suit claims. Although these charts are in the public domain, they are included to minimize the literature search required to verify the numbers. Furthermore, the significant improvements offered by the SPS are not dependent on exact values but more on the magnitude of difference. Ultimately, changes in the space suit will not change the results.

Extravehicular Activity Management Office

Vehicle Consumables

- **Per a single ISS EVA, what is the total consumables impact?"**
  - _58.25_ hrs. of Crew Time is required on average to prep the EVA System (pre EVA)
    - Beginning prior to the EVA itself, Tools Logistics, Procedure Review, etc (everything up to EVA prep on EVA day)
  - _12.25_ hrs. of Crew Time is required on average for OFV
  - _12.42_ hrs. of Crew Time is required on average for EVA prep
    - On EVA day minus time out EVA – includes 2 EV and 1 IV)
  - _0.9_ lbm O2 per suit per IV Activity - ALCLR (Loop Scrub)
  - _0.15_ lbm O2 per suit per IV Activity – On-Orbit Fit Verification (OFV)*
  - _5.13_ lbm O2 ISLE Prebreath Protocol gas loss per suit/crewmember
  - _1.0_ lbm Air residual Airlock depress gas loss
  - _0.80_ lbm O2 per suit for post EVA recharge
  - EVA Consumables *lost during the EVA itself*
    - _0.89_ lbm O2 per suit per EVA (lost to EMU Suit Leaks and Met Rate)
    - _4-6_ lbm H20 assumed per suit per EVA (Sublimator Cooling Water recharge, ullage)
    - _2_ lbm (32 oz) H20 drinking water per Crew per EVA**
    - _____ W*h Battery Recharge (post EVA)
    - _____ W*h MetOx Regen Oven (post EVA)
    - _6:39_ h Crew Time of the EVA itself (time not spent doing other things)
  - _15.83_ hrs. of Crew Time is required on average for post EVA servicing
    - After the EVA itself, cleaning the EMU, re-stowing all components and tools, recharge/refill operations, etc

*OFV's only occur once per crew for their time on orbit, NOT every EVA a given crew member conducts

** Drinking water is not actually tallied in the bottom line summary b/c it would have otherwise been consumed with or without the EVA by the human

Source: EVA Office Extravehicular Activity (EVA) Airlocks and Alternative Ingress/Egress Methods Document, NASA, EVA-EXP-0031, Baseline, 04/18/2018

Interim ISS Use and Pricing*

	Resources	Reimbursable Value	Annual ISS Resources	Maximum Allowed per Company per Year
Available Immediately	Upmass (Passive Cargo)	$3,000 per kg	175 kg	50 kg in a form factor of single CTBE*s
Available Immediately	Trash Disposal (Passive Cargo)	$3,000 per kg	175 kg	50 kg
Available Immediately	Downmass (Passive Cargo)	$6,000 per kg	125 kg	35 kg
Available Immediately	Conditioned Cargo (Round Trip)	$13,500 per kg	Not available at this time	--
Available Immediately	Powered Cargo (Round Trip)	$18,000 per kg	Not available at this time	--
Available Immediately	ISS Expedition Crew	$17,500 per hr	90 hrs	25 hrs
Available for Private Astronaut Missions	Regenerative Life Support and Toilet	$11,250 per crew per day	Available as needed	--
Available for Private Astronaut Missions	Crew Supplies (Food, air, crew provisions, supplies, medical kit, exercise equipment, etc.)	$22,500 per crew per day	Available as needed	--
Available for Private Astronaut Missions	Stowage	$105 per CTBE per day	Available as needed	--
Available for Private Astronaut Missions	Power	$42 per kWh	Available as needed	--
Available for Private Astronaut Missions	Data Downlink	$50 per GB	Available as needed	--

* Unit for size of bag used to transport cargo from visiting vehicles, such as SpaceX, Northrop Grumman, or H-II Transfer Vehicle (HTV), to the International Space Station. Dimensions are 19 in x 16.25 in x 9 in, (48.3 cm x 41.3 cm x 22.9 cm). Weight limit is 60 lbs (27.2 kg).

Source: Human Spaceflight Continuity and the International Space Station, 2019 International Astronautical Congress, Washington D.C., Samuel Scimemi, Director, International Space Station; Loverro D. NASA Associate Administrator, "Commercializing Low-Earth Orbit," AIAA Webinar Forum, April 20, 2020

Gateway same as ISS

PREBREATHE PROTOCOL	Shuttle 10.2 Staged Decompression (12 hrs at 10.2)	ISS: 4 hour In Suit	ISS CEVIS Exercise (Using ISS O2)
EVA Overhead Activities	TIME IN MINUTES	TIME IN MINUTES	TIME IN MINUTES
Suit checkout	115	185	185
REBA powered hardware checkout	25	25	25
SAFER checkout	30	30	30
Airlock config	95	90	90
Consumables Prep	60	120	120
EVA prep - prebreathe related	RETIRED [illegible]	0	80
EVA prep - EMU related	30	30	30
Suit donning & leak check	60	60	60
SAFER donning	Completed during Prebreathe	Completed during Prebreathe	Completed during Prebreathe
Purge	8	12	12
Prebreathe	75	240	60
Airlock depress	15	30	40
Airlock egress	15	15	15
Airlock ingress	15	15	15
Airlock repress	15	15	15
Suit doffing	25	25	25
SAFER doffing & stow	10	10	10
Post EVA processing	105	90	90
TOTAL	758	992	902
EVA WORK EFFICIENCY INDEX	0.51	0.39	0.43

Source: Walz, C. and Gernhardt, M., "Extravehicular Activity – Challenges in Planetary Exploration," 27 February, 2008, Third Space Exploration Conference and Exhibit, Denver, CO

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