IAC-19-D1.12 x 49199

Single-Person Spacecraft Transforms Weightless Operations

Brand Griffin[a]*, Robert Rashford[b] , Matthew Stephens[c], Samuel Gaylin[d] , and Dylan Bell[e]

[a] *Program Manager, Single-Person Spacecraft, Genesis Engineering Solutions, Inc., 4501 Boston Way, Lanham, MD 20706, USA,* bgriffin@genesisesi.com
[b] *President/CEO, Genesis Engineering Solutions, Inc., 4501 Boston Way, Lanham, MD 20706, USA,* rrashford@genesisesi.com
[c] *Lead Engineer, Single-Person Spacecraft, Genesis Engineering Solutions, Inc., 4501 Boston Way, Lanham, MD 20706, USA,* mstephens@genesisesi.com
[d] *Mechanical Engineer, Single-Person Spacecraft, Genesis Engineering Solutions, Inc., 4501 Boston Way, Lanham, MD 20706, USA,* sgaylin@genesisesi.com
[e] *Mechanical Engineer, Single-Person Spacecraft, Genesis Engineering Solutions, Inc., 4501 Boston Way, Lanham, MD 20706, USA,* dbell@genesisesi.com
* Corresponding Author

Abstract

The Single-Person Spacecraft (SPS) will radically transform our perception of extravehicular activity (EVA). Gone are the bulky pressure suits, lengthy pre-breathing, airlock pump down, and the risk of getting the “Bends.” They are all replaced by a small, form-fitting, spacecraft that allows rapid access to space without an airlock. Hand-over-hand translation gives way to flying directly to the work site and the pressurized gloves are replaced with multi-tool, force multiplying manipulators. Shaped around the astronauts’ weightless neutral body posture, the SPS cockpit eliminates space suit trauma that has resulted in abrasions, contusions, delaminated fingernails, and shoulder surgeries. Improvements to pressurized space suits are at a point of diminishing returns…the SPS offers a different solution. More than a replacement, it redefines the EVA architecture by significantly reducing overall system mass, complexity, and cost. Furthermore, because it is both piloted and tele-operated, it is the single solution for continuous EVA even for the infrequently occupied lunar Gateway. The SPS is within reach offering exciting new capabilities never conceived possible with suits. Integral propulsion means it can go where suits cannot and spend more time on the job. SPS provides servicing to aging life-critical ISS systems, the lunar Gateway, Mars transit vehicles, satellites and application for space tourism.

.

Keywords: Single-Person Spacecraft, EVA, MMU, Satellite Servicing, Human Space Exploration

Acronyms/Abbreviations

EMU	=	Extravehicular Mobility Unit
EVA	=	Extravehicular Activity
GN2	=	Gaseous Nitrogen
ISS	=	International Space Station
IDBM	=	International Docking Berthing Mechanism
LEO	=	Low-Earth Orbit
MMOD	=	Micrometeoroid/Orbital Debris
MMU	=	Manned Maneuvering Unit
ORU	=	Orbital Replacement Unit
PSI	=	Pounds per Square Inch
SAFER	=	Simplified Aid For EVA Rescue
SPE	=	Solar Proton Event
SPS	=	Single-Person Spacecraft
SLS	=	Space Launch System
WEI	=	Work Efficiency Index
WIF	=	Worksite Interface

1. Introduction

Changes to the space suit will not transform microgravity operations. Only a different solution can provide the capabilities necessary to truly improve future extravehicular activity (EVA). Shown in Figure 1 is the Single-Person Spacecraft (SPS), a non-suit solution that offers the overall integrated performance benefiting weightless operations across the entire human exploration architecture. The following paper describes why an EVA transformation is needed and the improvements provided by the SPS.

Fig. 1. The SPS transforms the architecture and operations of human exploration.

2. Missions and Environments

There is an obvious and natural division between weightless and “planetary” EVA. This is not only because of the different mission objectives but also different environments (Figure 2). The mission objectives for the Moon and Mars require going outside and it is presumed that every crewmember will have at least one planetary suit. However, for weightless environments, EVA is typically not the mission but a response to something outside needing attention. For this, it is presumed that not all crew would conduct EVAs, but like on ISS, there would be designated EVA trained astronauts. Under these conditions not every crewmember requires a suit, however, an on-orbit inventory of parts is required to accommodate re-sizing for visiting EVA astronauts. Because the SPS is sized for all astronauts it eliminates the time and additional parts for resizing while allowing all the crew to go outside.

The environments of Moon and Mars both have gravity and dust while weightless operations have neither. These conditions result in suit designs that use the legs for mobility and protective measures to minimize dust contamination. In weightlessness, the legs are not used for mobility instead suited astronauts use their hands and arms for translation and there are no provisions for dust protection. To ensure an efficient work environment the SPS is shaped around the astronaut’s weightless body posture and because it has integral propulsion it does not require legs or arms for translation.

When used appropriately there are benefits to commonality. However, forcing a common solution to span between these very different environments and mission objectives will likely compromise the performance of both resulting in higher costs. The incentive for commonality is further diminished

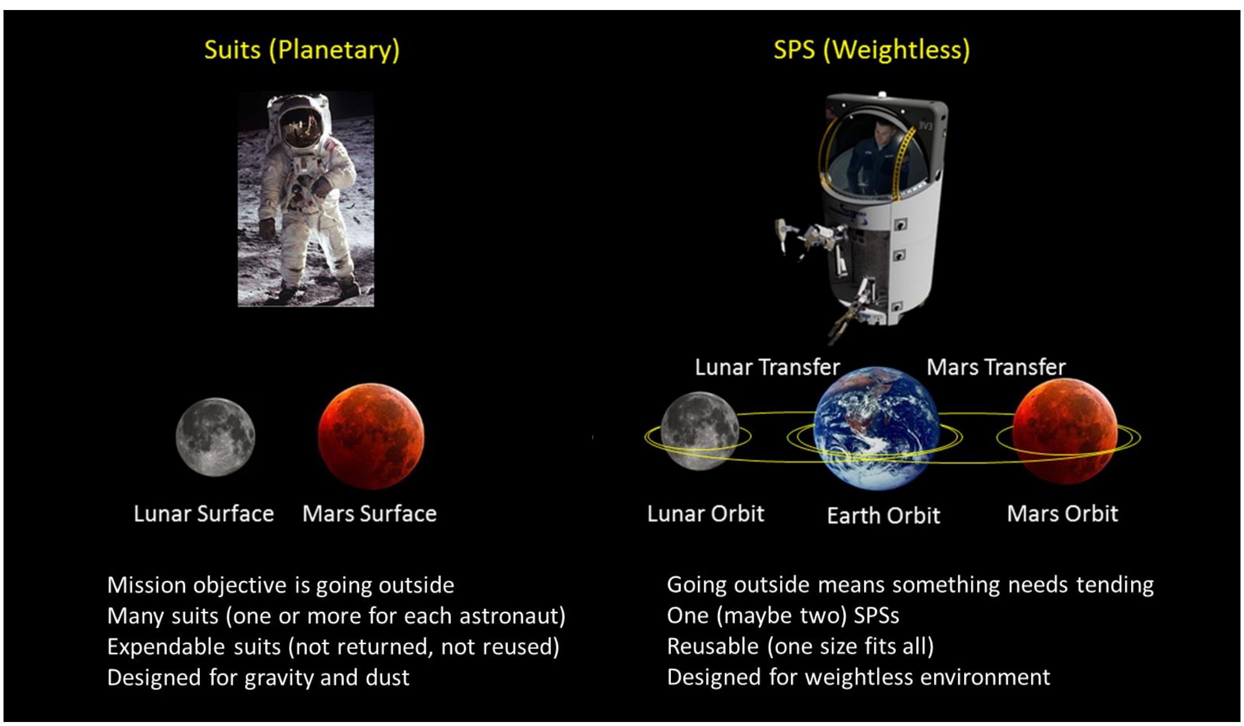

Fig. 2. A cost-effective EVA solution uses the SPS for weightless operations and space suits on the surface.

considering the large number of surface suits versus few for weightless operations and the schedule of infrequent weightless use versus heavy demand for planetary excursions. Another important consideration is that planetary suits are expendable. There is a mass penalty for each phase of the Earth return and it is doubtful that leaving the suits would be a reasonable option for next crew. In contrast, the SPS is reusable by all astronauts during a mission and by the next crew. Consequently, the approach presented in this paper recommends separate solutions for weightless and surface operation; the SPS for weightless and suits the Moon and Mars. Because suits are the default planetary solution, this paper will focus on the transformative impact of using the SPS. The breath of application includes low-earth orbit, lunar transit, lunar orbit (Gateway) [1], Mars transit, Mars orbit, the exploration of small bodies such as asteroids and the Mars moon Phobos. (Figure 3).

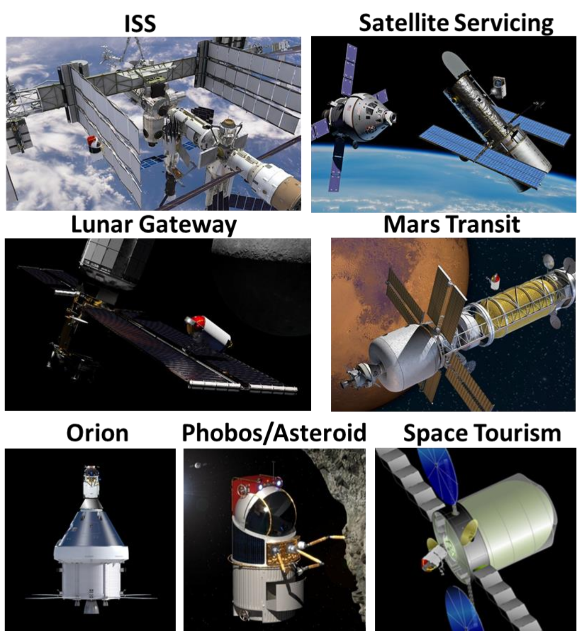

Fig. 3. The SPS is ideal for Low-Earth-Orbit and extensible to future lunar and Mars exploration.

3. Access to Space

3.1 Readiness

Right now, it takes a long time to get an astronaut outside. To avoid getting decompression sickness (the "Bends") it requires 12.5 to 14 hrs. for pre-breathing oxygen and airlock pump down before starting an EVA [2]. Because there is no pre-breathing or airlock, the SPS is ready to fly after a 10 minute pre-flight checkout. Much of the checkout can be automated but the time is comparable to the 6 minutes required for the MMU prefight. For ingress, the current 2.5 hr. will shrink to approximately 10 minutes which is equal to the MMU doff and stow time. Figure 4 shows the SPS departing from the host spacecraft.

Fig. 4. The SPS provides rapid access to space for all the crew without the risk of the "Bends."

3.2 Duration and Frequency

Another area of transformation is in EVA planning. Without the burden of lengthy pre-breathing, SPS excursions can be short or long, occur frequently, and be flown by different astronauts (Figure 5). This is different from suited operations where the incentive is to have long EVAs because of the extensive overhead. Suited EVA is fatiguing therefore a rest day is recommended between EVAs with the same crew. In contrast, operating the SPS will be similar to flying an airplane and thus physical exertion is not an issue for planning the frequency of excursions [3].

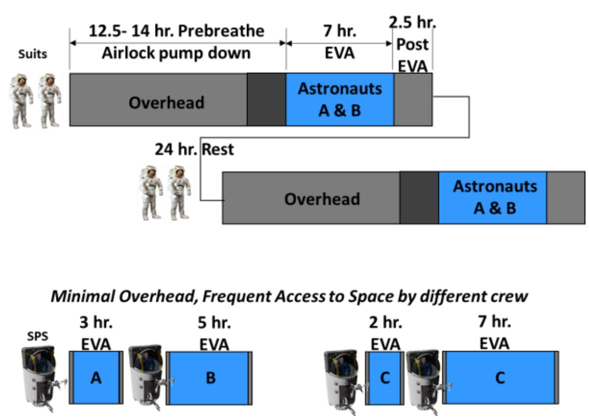

Fig. 5. SPS provides frequent access to space by different crew without or resizing suits.

3.3 Limitations due to crew sizing constraints

Usually suits are sized for the two designated EVA astronauts. The fit of a pressurized suit is very important and can take up to 12 hours [4] to resize for different crew member. Because the SPS is designed to accommodate the full astronaut population, all crew have access to space without resizing. This is transformative because it eliminates the on-orbit inventory of sizing parts and time required to fit all crew.

3.4 Piloted and teleoperation

In addition to being piloted, the SPS is designed for teleoperation (Figure 6). The dual mode capability allows operations in potentially dangerous situations without risk to the astronaut. Another benefit is inspection, servicing and repair during lengthy periods of crew absence such as planned for the Lunar Gateway. Dual mode operation represents a significant and transformative enhancement for future space operations because it is not possible with suited EVA.

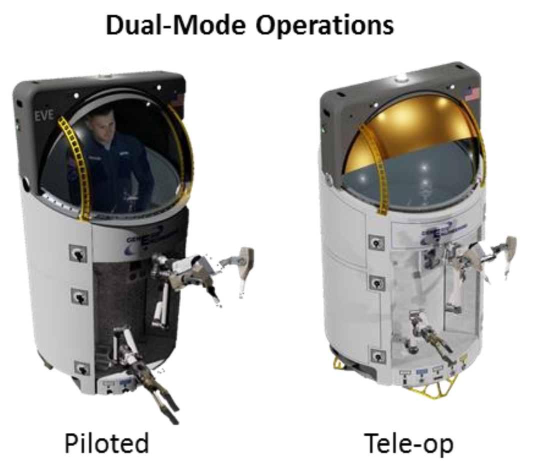

Fig. 6. One vehicle with two modes of operation transforms the perception of EVA.

3.5 EVA from a crew capsule

The planned crew capsules such as NASA's Orion, Boeing's CST 100, and the SpaceX Crew Dragon are not designed for suited EVA. In the past, suited EVA from a capsule meant venting the cabin air, designing the interior for vacuum, having all crew in EVA suits, and providing for repressurization. The SPS offers EVA access without these costly accommodations.

A compelling reason for SPS EVA from a capsule is servicing the aging Hubble Space Telescope (HST). HST was designed for suited EVA from the Space Shuttle and is now at risk because the Shuttle has been retired. SPS EVA from a capsule can extend its scientific life while no other vehicle can (Figure 7). Furthermore, this same approach is an efficient means of inspection and servicing of satellites and other spacecraft.

Fig. 7. With the Shuttle retired, the SPS offers Hubble servicing and repair from crew capsules.

3.6 Access to external systems

Suited crewmembers are restricted to pathways determined by the location of handrails and if available, can be positioned using a robotic arm. Propulsion is not an option because the MMU is retired and the SAFER is for emergency use only. In contrast, the SPS has integral propulsion allowing access to most external systems. Figure 8 shows the SPS working in area inaccessible by suited astronauts.

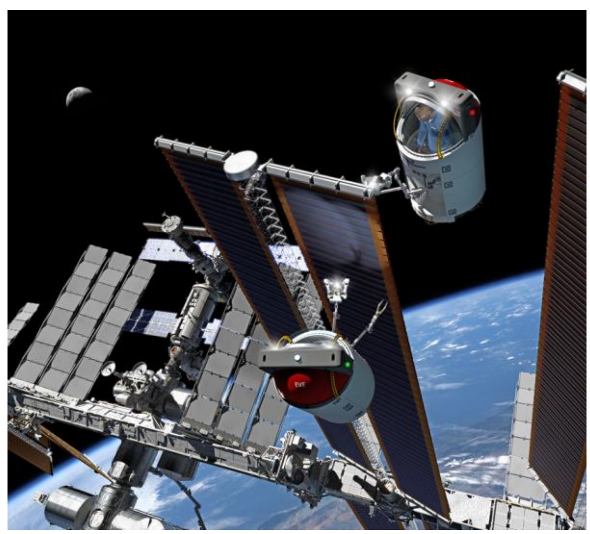

Fig. 8. SPS services external system that are inaccessible by suited crew members.

4. Efficiency

For all that it takes to conduct an EVA, it is important to spend most of the time at the job site. The Work Efficiency Index (WEI) is a common measure of EVA efficiency represented as a ratio of task time to overhead time. Apollo spacecraft used pure oxygen and therefore astronauts did not have to pre-breathe before EVA. Thus, the Apollo EVA WEI was 2.0. However, with a higher pressure oxygen/nitrogen atmosphere, the ISS WEI is between 0.39 and 0.43. Because NASA plans to use the same internal atmosphere as ISS for the lunar Gateway, suited EVA will have the same low efficiency WEI.

In contrast, a 4 hour SPS excursion has a WEI of 12.0. For a 7 hr. excursion, the SPS WEI is 21 which is over 40 times more efficient than suited EVA. See Figure 9. This is the type of transformation needed to improve EVA for future human missions.

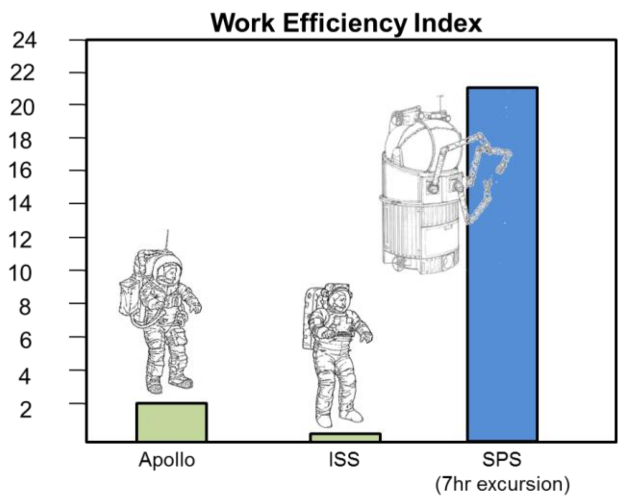

Fig. 9. Considering the overhead and limited life support resources, the SPS is the most efficient method of external operations.

5. Work Environment

The space suit is essentially a pressurized exoskeleton. Consequently, astronauts must work against the internal pressure and joint torque to perform any task. Gloved operation is particularly critical because of its importance to all tasks and the challenge of designing a pressure glove for space. Today's solution has up to 11 material layers which reduces tactile sensitivity and makes it difficult for grasping. The SPS transforms gloved operation by using manipulators. These are equipped with interchangeable tools offering force multiplying mechanical advantage along with continuous grasping without fatigue. Cameras and lights on the end-effector provide excellent work conditions in and out of shadows. Manipulators and end-effectors can be changed out to match the job, but the baseline concept is evolved from surgical robot technology.

Space suit helmets are fixed; they do not turn like motorcycle helmets. This means that if turning the head inside the helmet does not provide adequate visibility then the astronaut needs to turn the body for a better view. With a large bubble canopy, the SPS is designed to provide excellent visibility even from a fixed location. Adding to line-of-sight visibility are body-mounted and manipulator cameras providing images on cockpit displays.

Possibly the most transformative benefit of the SPS is the on-board information system (Figure 10). Current EVA relies on an external chest mounted alpha-numeric display for suit information. For scheduled tasks, astronauts conduct pre-flight neutral buoyancy simulations assisted by audio communications from ground control. The SPS features internal color monitors with access to look up diagrams, check lists, and videos of planned and contingency tasks. Vehicle, navigation, communications and caution and warning are also provided. Informed astronauts are productive astronauts and this is why the SPS is equipped with an on-board information system. Furthermore, Mars communication time can be up to 24 minutes therefore it is essential to reduce ground dependency by providing immediate EVA information for the crew.

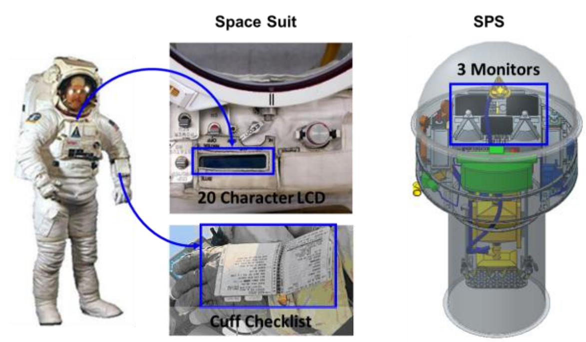

Fig. 10. SPS information system has multiple displays with on-board menus to reduce the dependency on ground support.

6. Orbital Replacement Unit/Sample Handling

Because EVA astronauts need both hands for translation it is difficult to carry anything. Tools are carried on the chest otherwise there is little real estate left for transporting an Orbital Replacement Unit (ORU) or as proposed for the lunar Gateway, a geologic sample. A robotic arm provides this capability on ISS but it has limited reach and is a heavy and expensive option.

The SPS propulsion system is based on the MMU which successfully rescued and transported two large satellites. The Westar IV satellite weighed 1222 lb. (555 kg). See Figure 11. Because it is not constrained to handrails, foot restraints, or the reach of an arm, the SPS provides the work site flexibility and payload capability

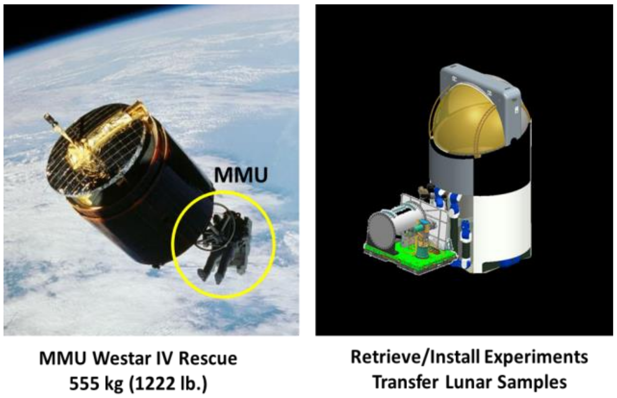

Fig. 11. Using the MMU-type propulson, the SPS is capable of trasporting large objects.

to support most EVA operations, In addition to maintenance and repair, external experiments can be relocated as well as lunar samples collected and transferred for earth return. A mini airlock in the SPS berthing vestibule provides a pass-through capability without contamination and minimal air loss.

7. Safety

With the SPS many suited EVA safety issues are eliminated, while others are significantly reduced. Gone is decompression sickness (the Bends), suit trauma (including delaminated fingernails and abrasions), life-threatening loose water in the helmet, the fire risk in pure oxygen, and physical fatigue. There have been 25 astronaut shoulder surgeries attributed to wearing the space suit [5]. Examples of suit trauma are shown in Figure 12. These are not an issues with SPS operations.

Better micrometeoroid/debris and radiation protection are provided with the SPS. A Whipple bumper coupled with multi-layer insulation offer ISS-like micrometeoroid/debris shielding while polyethylene layering and a special astronaut vest offer radiation protection. See Figure 13 However, a new safety concern is running out of propellant. Although this could also be an issue with the SAFER, the SPS relies on propulsion for mobility. The good news is that the SPS uses the same propulsion system as the human-rated MMU complete with redundant supply and cross-strapped supply plumbing. Additionally, the SPS includes two emergency options for propellant.

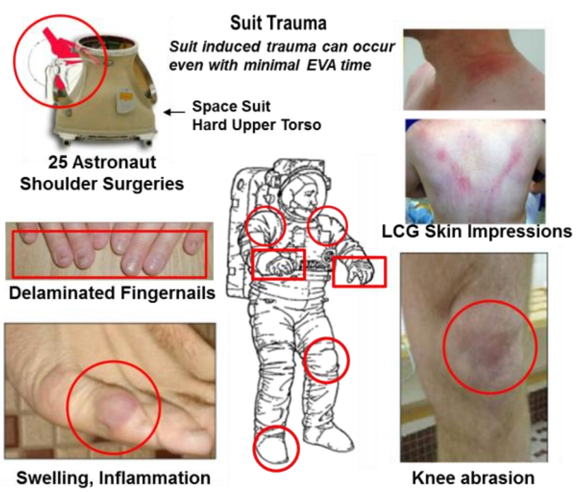

Fig. 12. SPS operations eliminate suit trauma including the fingernail delamination and shoulder surgery associated with suited EVA.

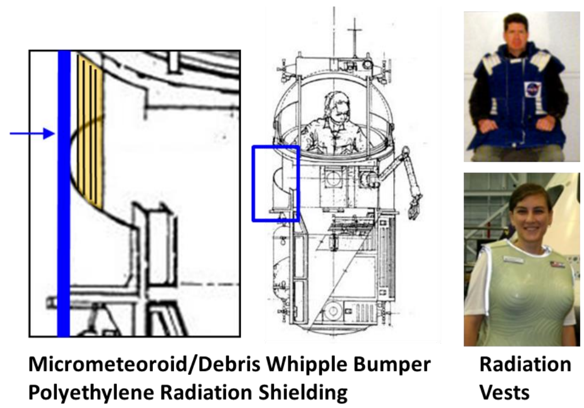

Fig.13. SPS provides layered micrometeoroid/debris and radiation protection.

Pyrotechnic valves are placed in the system to allow bypassing the low pressure regulators thus freeing upstream nitrogen for propellant. Another pyrotechnic valve allows access to a tank of 3000 psi emergency breathing air. Like with any vehicle, the operator needs to monitor fuel consumption, but should an issue arise, these features provide for an emergency return.

8. System Mass

Using the SPS offers a significant reduction in system mass. For example, with two SPSs, the overall mass can be reduced by 5437 kg (11,788 lb.) compared to suited EVA using the ISS Quest airlock. See Figure 14. Although it is possible to have a different airlock configuration, most concepts, including NASA's lunar orbiting Gateway, show Quest-type airlocks. Regardless of airlock configuration, conventional EVA requires two suits, two SAFERS, a pump, cooling garments, tools, translation and worksite aids, and a sizing inventory to accommodate visiting crew. The SPS only requires a berthing vestibule.

9. Contamination

The breadth of SPS utility extends to the exploration of low-gravity asteroids and moons. Some NASA studies have seriously considered visiting the Mars

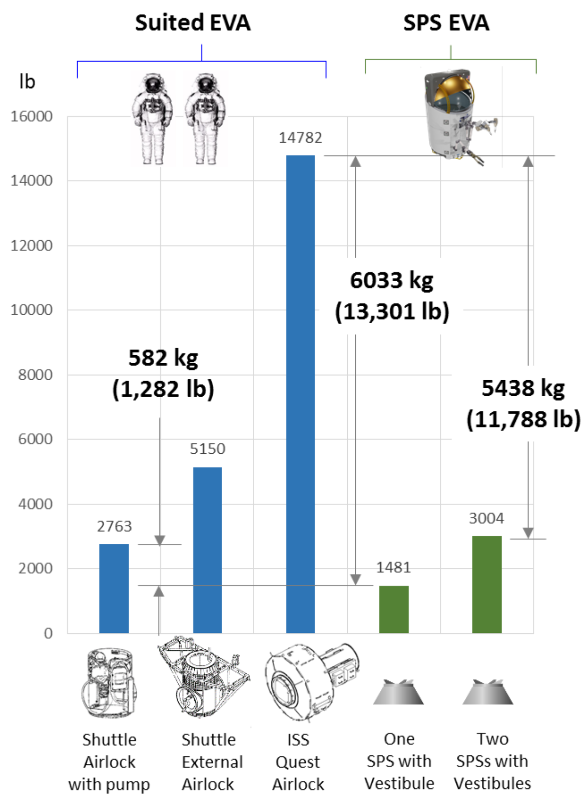

Fig. 14. The SPS is the low mass EVA solution.

moon Phobos before landing on the planet. Phobos is small with very low gravity and like asteroids this condition makes walking difficult to impossible. Therefore, using the SPS propulsion system with robotic arms is an excellent method of data gathering and sample collection. Another benefit is that any contamination stays outside. This is important because the lunar "dust" on the Apollo astronauts' suits was unavoidably brought inside. This dust, or shards of Basalt, worked its way into the suits and cabin air causing heath concerns and issues with suit joints. As long as suited astronauts pass through an airlock contamination will be a problem.

10. Consumables

For all human spacecraft, cabin air is a precious commodity; especially far away from earth in lunar orbit. Modules are designed for a minimum of leakage and the ECLSS is intended to reclaim most of the cabin air. To further minimize losses, it is assumed a small volume airlock similar to the ISS Crewlock would be equipped with a pump. Even with this small volume, ISS documentation reports that after reclaiming 90% of the airlock gas, 1.6 kg (3.6 lb.) of cabin air is lost per EVA.

The SPS does not need an airlock or pump, but does require venting the berthing vestibule before separation. The vestibule volume is expected to be similar to the Progress/Soyuz connection to the ISS where the air loss is 0.3 kg (0.64 lb.) This means that the unrecoverable air loss for suited EVA is 5.5 times more than the SPS.

For decades, there has been much hope for replenishing consumables with In Space Resource Utilization (ISRU). Until there is confidence in extraction techniques, methods of liberating volatiles, containment, liquefaction, transport, and quality certification in low gravity environments, we will depend earth-delivered, life-critical consumables. Ultimately, it doesn't matter whether the resources are from the earth or made in space, they are still precious and costly. Solutions that preserve consumables must be favored over less efficient alternatives. Assuming a frequency of six EVAs per year the SPS is expected to lose 35% fewer consumables or 66.8 kg (147.3 lb.). Figure 15 compares the savings using the SPS.

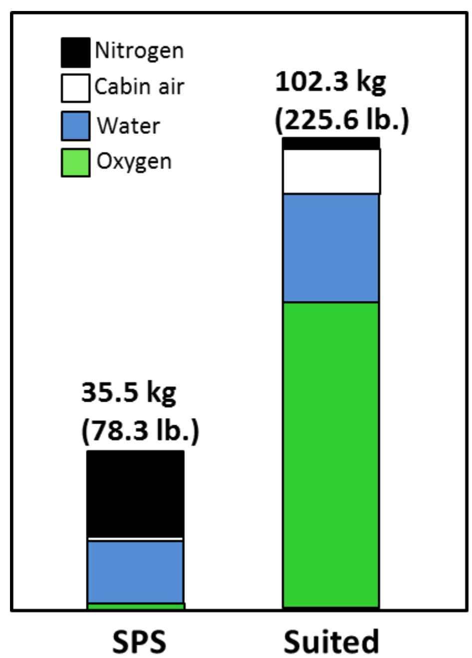

Fig. 15. SPS minimizes the loss of life critical consumables.

11. Training

The SPS will transform training. No longer will astronauts don space suits and simulate EVA tasks using neutral buoyancy and specially constructed flight-like mock-ups (Figure 16). Maintaining the Neutral Buoyancy Laboratory with all of its requirements and certifications is a very expensive proposition. This will be replaced by flight simulators. It is cost effective and preferred for aircraft and spacecraft to use flight simulators for development and crew training. Simulators are a safe way of exposing the crew to both nominal and contingency operations without the overhead and risk of neutral buoyancy. Furthermore, there is electronic control over the environment allowing day and night simulations for operations on the latest configuration of satellites, telescopes, habitats, and asteroids.

Fig. 16. SPS flight simulator training is safer, less expensive, and more agile than neutral buoyancy.

12. Conclusions

Vice President Pence has laid out a very aggressive plan for the United States to land humans on the Moon by 2024. Right now, there is no lunar space suit for astronauts to wear. One way to make this happen is to focus NASA development on a new surface suit while buying the SPS for the Gateway and future weightless operations. This is the safest, most efficient, least expensive, and lightest solution. Another benefit is that because the SPS is currently in development it would be ready to support the schedule of the Vice President’s bold vision.

Acknowledgements

The SPS team would like to acknowledge contributions from SRI International, Paragon Space Development Corporation, METECS, AMRO, US Space and Rocket Center, Design Force and Alvin Drew.

References

[1] B. Griffin, R. Rashford, M. Stephens, S. Gaylin, C. Woo, J. Lutter, and D. Harvey, Single-Person Spacecraft Favored for Gateway EVA, AIAA 2018-5245, AIAA Space Forum, Orlando, FL, September 17-19, 2018.

[2] C. Walz, and M. Gernhardt, “Extravehicular Activity – Challenges in Planetary Exploration,” 27 February, 2008, Third Space Exploration Conference and Exhibit, Denver, CO.

[3] B. Griffin, R. Rashford, M. Stephens, J. Lutter, C. Woo, S. Gaylin, R. Bousquet, M. Klappenberger, M. Belz, and D. Harvey, Single-Person Spacecraft: Progress Toward Flight Testing, AIAA 2017-5103, AIAA Space Forum, Orlando, FL, September 12-14, 2017.

[4] NASA spokeswoman Brandi Dean said that “It would have taken 12 hours to get another medium spacesuit ready and potentially compromised safety.” March 26, 2019, https://www.apnews.com/b5de006769d6411d803b395dabac4e4f

[5] Schaezler,B., Cook, A., Leonard, D., and Ghariani, A., “Trending of Overboard Leakage of ISS Cabin Atmosphere,” AIAA 2011-5149

[6] Scheuring, R., “Shoulder Injuries in US Astronauts Related to EVA Suit Design,” NASA Flight Surgeon, DO, MS, FAsMA, FAAFP, Aerospace Medical Association, May 11, 2012.