Evaluating Extravehicular Activity Access Options for a Lunar Surface Habitat

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***Abstract*— NASA's upcoming return to the moon includes a plan for longer duration lunar missions that prioritize science and surface exploration. The current Artemis Base Camp reference proposes a Surface Habitat (SH) that will support 2 to 4 crewmembers with adequate capability for living and working for 30 days or more. An important aspect of the SH's design will be its ability to support a high frequency of Extravehicular Activities (EVAs) for scientific and operational purposes. There are multiple EVA access options that can support EVA access from the SH to the lunar surface. This paper explores three unique options for EVA access: a traditional airlock, a suitlock, and a suitport-airlock.**

A traditional airlock utilizes a segregated, variable pressure volume, accessed by use of internal and external hatches, to provide EVA access. The airlock volume must be depressurized and repressurized for every EVA. A suitlock is similar in operation to the airlock, utilizing a segregated volume that is depressurized and repressurized for every EVA. However, in this case the suits are donned/doffed through a suitlock interface installed in the airlock bulkhead. EVA suits in a suitport-airlock are accessed through suitport interfaces that are installed in the airlock bulkhead as well, but the suitport-airlock stays in vacuum while the suits themselves remain pressurized, and the airlock does not have to be depressurized and repressurized for each EVA.

This study also evaluated the use of an airlock airsave system in conjunction with the traditional airlock and suitlock cases. This system captures a fraction of the airlock gas instead of venting all of the gas pre-EVA. The captured gas is then used to partially repressurize the airlock post-EVA.

In this study, each option is evaluated based on six different areas of analysis. The metrics include overhead time for EVAs, dust mitigation, consumables for resupply mass, system mass, safety and mission assurance, and programmatic considerations. The EVA access options are evaluated and compared under each area of analysis. The baseline case assumes the SH operates at 8.2 psia.

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1. INTRODUCTION

As NASA moves towards sustained human presence on the lunar surface, the agency plans to optimize surface architecture and crew operations to increase both crew and vehicle health and safety as well as increase crew availability for science and utilization activities. Recently, engineers and analysts with NASA completed a trade study investigating multiple options for a major aspect of the architecture on the lunar surface – surface habitat Extravehicular Activity (EVA) access. The systems that allow crew members to transition from vacuum to habitable volume and vice versa on the surface must be able to maximize the safety and health of both the crew and the vehicle, reduce the amount of required consumables, and also minimize the amount of time required to ingress and egress the habitat safely. This study examines three different system architectures for crew access to the Lunar Surface Habitat (SH): an airlock, a suitlock, and a hybrid suitport-airlock. For the purposes of this study, a ground rule was established that any EVA access option had to include the capability of functioning as a traditional airlock. This capability is required in the SH for contingency purposes, to support suit maintenance, and to support some logistics operations. All three options evaluated can function as a traditional airlock when required.

An Airlock Airsave system, which recovers the gas used to pressurize the airlock, is also examined as an option in combination with the three architecture options. Each system architecture is investigated at an assumed cabin pressure of 8.2 pounds per square inch (psi).

2. BACKGROUND

Airlock

A traditional airlock is a pressurized element, separate from the main habitat cabin, which is capable of pressurizing the volume to match the atmosphere of the cabin and depressurizing the volume to a vacuum so crew can egress to the lunar surface. It is accessible via two hatches- an external hatch to and from the lunar surface, and an interior hatch to and from the SH cabin. Figure 1 below shows a graphical design of the proposed SH airlock, not including don/doff stands.

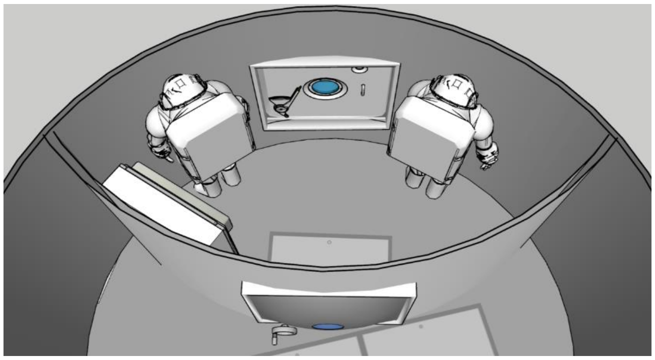

Figure 1. Graphical representation of a traditional airlock

In order to ingress and egress the SH, the airlock must be pressurized and depressurized for each EVA. The airlock must be pressurized to cabin pressure prior to opening the interior hatch, and it must be depressurized to vacuum prior to opening the exterior hatch.

Suitlock

A suitlock is similar to the airlock in that the suitlock volume must be pressurized and depressurized each EVA to ingress and egress the SH. However, unlike an airlock, the crew does not enter the segregated volume prior to donning their suits, but instead ingress the suits through a bulkhead suitlock interface. Once inside the suit and detached from the interface, the crew close the pressure bearing hatches and can depressurize the suitlock volume and egress out to the lunar surface. When traditional airlock operations are required, the crew can enter the segregated volume via hatches. Figure 2 outlines the architecture and provides details on the SH ingress and egress process.

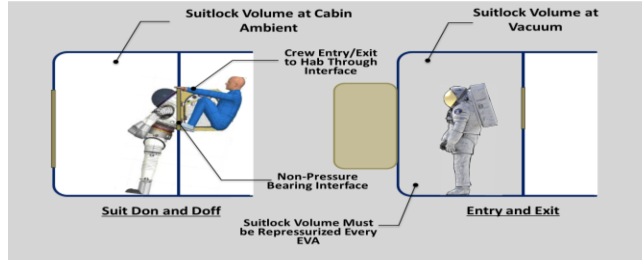

Figure 2. Suitlock interface

As noted in Figure 2, the suitlock interface itself is non-pressure bearing. Because of this, the volume must be pressurized to cabin pressure prior to attaching the suit to the interface and the pressure bearing hatches closed prior to depressurizing the volume.

Suitport-Airlock

Similar to the suitlock, the suitport-airlock allows crew to access their suits via a through bulkhead suitport interface. However, because the suit and suitport interface is pressure bearing, and can withstand a pressure differential of 8.2 psi, the airlock volume can remain at vacuum and does not need to be pressurized and depressurized for each EVA. Having the suitports in a fully functioning airlock allows the crew to conduct suit maintenance activities while shirtsleeve. When traditional airlock operations are required, the crew can enter the segregated volume via hatches. Figure 3 outlines the suitport-airlock architecture.

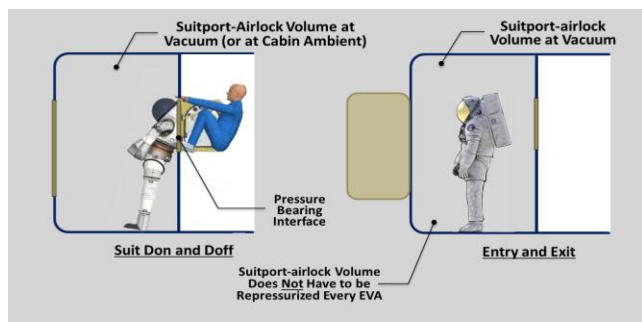

Figure 3. Suitport-Airlock system

Because the suit and suitport interface has a maximum pressure delta of 8.2 psi, if the cabin is at a higher pressure, the airlock must be pressurized to a differential following each EVA.

Airlock Airsave System

An airlock airsave system, or airlock gas recovery, captures a fraction of the airlock gas in lieu of venting it pre-EVA. The captured gas can then be used to partially repressurize the airlock post-EVA. The fraction of the gas recovered is a function of the pump down time allocated, and for this study it is assumed that the system can recover 90% of the gas used to pressurize the airlock. At this efficiency, the pump down time for a SH airlock at 8.2 psi is 35 minutes for the assumed airlock volume of roughly 13 cubic meters.

3. AREAS OF ANALYSIS

To compare the different architecture options, this study examines six different Figures of Merit (FOMs). The FOMs are EVA overhead time, dust mitigation, consumables resupply mass, system mass, safety and mission assurance, and programmatic costs and risks. Overhead time, resupply mass, and system mass are compared quantitatively, dust mitigation qualitatively, and safety and mission assurance and programmatic costs and risks can be compared both quantitatively and qualitatively.

EVA Overhead Time

EVA overhead time defines the crew time required for the crew to ingress and egress into and out of the SH cabin using the different system architectures.

Dust Mitigation

An important factor of maintaining vehicle and crew health is to prevent dust from entering into the habitat element. The dust mitigation FOM qualitatively describes each EVA access system architecture's ability to reduce dust infiltration into the SH.

Consumables Resupply Mass

Each system requires gas and fluids to support both the EVAs and the pressurization of the system, and these gas and fluids need to be resupplied each mission. The mass of the gas and fluids required to support EVA access operations is compared for each system.

System Mass

System mass measures the mass that the EVA access system contributes to the SH.

Safety and Mission Assurance

Safety and mission assurance identifies potential hazards in design and/or operations concerning potential loss or injury of crew, damage to the SH, and impacts to mission objectives.

Programmatic Costs and Risks

Programmatic costs and risks encompass the added cost to the SH mission due to the EVA access system, the programmatic risks considerations, and schedule impacts caused by the EVA access system.

4. MISSION PARAMETERS AND ASSUMPTIONS

This study examines the ability of the different EVA access systems to support a Lunar SH mission. In order to ensure accurate comparisons, the different systems were compared with the same mission assumptions described below.

General Mission Info

The Artemis Base Camp (ABC) missions will enable a sustained human presence on the lunar surface for the first time in history. The ABC consists of two pressurized habitats, the SH and the Pressurized Rover (PR). Four crew members will occupy the ABC, with two crew being in the SH and two crew being in the PR [1]. The crew will be in their respective elements for about 28 days, a total of about 33 days on surface, with the crew swapping elements halfway through the mission. A key assumption in this trade is that the EVA suits are suitport compatible for all options based on the PR architecture already having been delivered to the lunar surface with suitport technology included; therefore, the additional mass on the suits themselves are not included in the FOMs. It should be noted, however, that late into the development of this paper, NASA ruled out suitports for delivery with the PR and the availability for suitports being ready for SH delivery are currently uncertain. The final value of the FOMs in this study may vary due to the unavailability of suitports on the PR, but the final comparative results of the SH will remain the same.

SH Environment Control and Life Support Systems (ECLSS) Configuration

The ECLSS configuration onboard the SH affects both the gas and fluid requirements of the mission as well as the required logistics transfers in and out of the SH, which will require an EVA. For this study, the SH includes a regenerative ECLSS system consisting of an Oxygen Generator (OGA), a Water Processor Assembly (WPA), a Urine Processor Assembly (UPA), and a Brine Processor Assembly (BPA). It is assumed that the PR crew will transfer clean water from the SH to the PR, and wastewater and urine from the PR to the SH for water recovery. As noted previously, the transfers to the PR assume suitport capability on the PR.

Airlock

All EVA access system options are capable of operating as a traditional airlock that that allows for incapacitated crew rescue and logistics transfer. This, in part, establishes a minimum airlock size. Additionally, the airlock for each option is designed with sufficient volume and bulkhead area to accommodate suitlocks or suitports. This study assumes an airlock volume of 15 cubic meters. For all options, the airlock is used for logistics transfer and EVA suit maintenance.

SH EVA Cadence

For each EVA access system, the SH crew conducts two two-crew EVA events a week of up to 8 hours duration each. Twice during the mission, the PR crew must conduct planned suit maintenance inside the SH airlock. In addition, the system must support contingency suit maintenance. While the EVA cadence and quantity is the same for each EVA access system, the airlock pressurizations are not. Table 1 below outlines the SH crew's EVA schedule and the repressurizations required to support each EVA operation. In Table 1, the Suitport Repress column value represents the amount of dual suitport (2 crew) pressurizations and includes bringing the suits up to dormancy pressure. For each EVA operation required, the data in Table 1 documents the amount of airlock pressurizations required.

Table 1. Pressurizations required for each EVA access system

	Airlock	Suitlock	Suitport-Airlock	
	Airlock Repress	Airlock Repress	Airlock Repress	Suitport Repress
Crew Initial Ingress	1	1	1	1
Logistics Op #1	1	1		1
Week 1 Utilization EVA #1	1	1		1
Week 1 Utilization EVA #2	1	1		1
Logistics Op #2	1	1		1
Interim Suit Maint. (Opt.)	2	2	1	
Week 2 Utilization EVA #1	1	1		1
Week 2 Utilization EVA #2	1	1		1
Logistics Op #2	1	1		1
Crew Swap Entry	1	1	1	
Crew Swap Exit	1	1	1	
Week 3 Utilization EVA #1	1	1		1
Week 3 Utilization EVA #2	1	1		1
Logistics Op #4	1	1		1
Interim Suit Maint. (Opt.)	2	2	1	
Week 4 Utilization EVA #1	1	1		1
Week 4 Utilization EVA #2	1	1		1
Logistics Op #5	1	1		1
Crew Final Egress	1	1	1	
TOTAL	**21**	**21**	**6**	**14**

5. Results

The results of the study compare each EVA access system both with and without the airlock airsave system across all six FOMs.

EVA Overhead Time

EVA overhead time describes the required time to ingress and egress the SH airlock. For each EVA access system, there are different required operations to allow the crew safe access to and from the lunar surface. For the airlock system, the crew ingress the airlock and don their suits, then depressurize the cabin to egress to the lunar surface and must repressurize the airlock post EVA. For the suitlock system, the crew ingress their suits via the suitlock interface, followed by detaching from the interface and depressing the airlock prior to final egress and must repressurize the airlock post EVA. With a suitport system, the crew only needs to ingress their suits via the suitport interface (the airlock portion is already depressurized), then detach from the interface and egress the airlock. The airlock portion of the suitport-airlock is repressurized as needed for shirtsleeve use. For all operations the egress operations are repeated for ingress operations, however in reverse. Additionally, if suitlocks or suitports are not used, the crew must clean the suits and remove regolith prior to entering the SH cabin. Figure 4 below shows the required EVA overhead times, in minutes per EVA, for each of the EVA access systems [2].

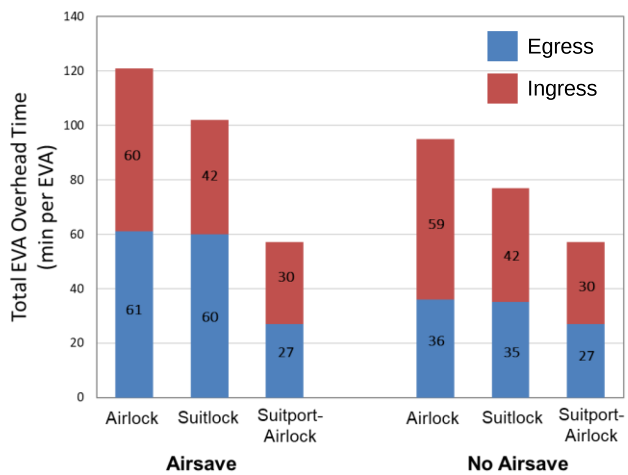

Figure 4. EVA overhead times for the EVA access systems

Dust Mitigation

Lunar dust and regolith can have a severe impact on the function of SH systems and on crew health. Utilizing the suitlock or suitport-airlock systems potentially reduces dust intrusion into the SH cabin by reducing the need to open the interior airlock hatch to the SH cabin. The suitport system and suitlock system, however, do support logistics transfer through its interface, allowing logistics to be brought into the SH cabin without introducing a dust path. For all EVA access systems, the crew must open the interior airlock hatch to conduct suit maintenance, introducing a dust path. Figure 5 below describes the results of the qualitative analysis of dust mitigation for each EVA access system.

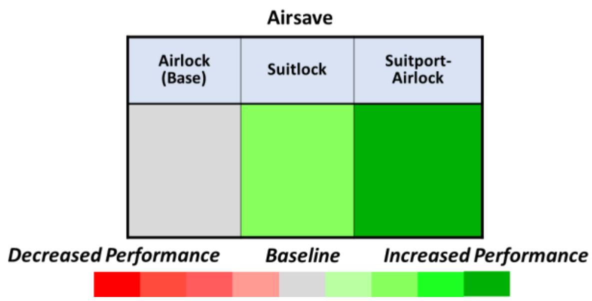

Figure 5. Qualitative comparison of dust mitigation capabilities of the EVA access systems

Consumables Resupply Mass

Each EVA access system requires a unique amount of gas for pressurization, which needs to be resupplied for each mission. For the airlock and suitlock systems, the full airlock volume must be pressurized every EVA. The suitport-airlock system does not require a full airlock pressurization every EVA, outside of EVAs conducted through the airlock, but does require the small volume between the suit and suitport to be pressurized for every EVA. As noted previously, using the airlock airsave system can recover 90% of the gas in the airlock for future pressurizations. Table 2 shows the total logistics resupply mass to support an ABC surface mission.

Table 2. Required annual logistics resupply mass for the SH mission with different EVA access systems

	Annual Fluid Logistics Resupply Mass (kg)	
	Airsave	No Airsave
Airlock	510	861
Suitlock	510	861
Suitport-Airlock	495	533

Table 2 highlights the savings of the airlock airsave system when needing to pressurize the whole airlock volume. Without it, the savings that are produced by the suitport-airlock system increase significantly.

System Mass

Inclusion of additional EVA access systems will increase the weight of the airlock which affects delivery requirements. For this study, the baseline case for all metrics is the airlock without the airlock airsave system. Table 3 shows the added mass of each of the systems included.

Table 3. Added system and equipment mass of the different EVA access systems

	Added Systems Mass (kg)	
	Airsave	No Airsave
Airlock	139	-
Suitlock	179	40
Suitport-Airlock	249	110

The suitlock system requires only additional hatches for the suitlock interface and increases the system mass by only 40 kg. The suitport system requires additional hatches for the suitport interface, and also requires additional restraints, jumpers, and other equipment. EVA suit mass is also increased due to the suitport interface plate.

Safety and Mission Assurance

Ensuring crew safety is the most important aspect of planning human space missions. For this study, safety risks can stem from multiple factors. System complexity, suit exposure, dust intrusion, EVA overhead times, and more can factor into the possible loss of crew or mission. To compare the three EVA access systems, the airlock again will be used as the baseline case. For the suitlock, the addition of hatches and sealing surfaces that require time and training to ingress and egress result in an increased risk for crew safety. The suits remain in a pressurized environment, however, and not requiring opening the interior airlock hatch reduces dust intrusion into the SH cabin. The suitport-airlock system introduces additional hatches as interfaces as well, but across a pressure differential increasing the risk to crew safety. Also, the suits remain in a vacuum for increased periods of time, which results in them being continuously exposed to pressure differential, increasing the risk of suit failure, or required maintenance. Figure 6 details the qualitative assessment of the safety and mission assurance metric. While the airlock airsave option does reduce logistics requirements, it does not have a significant effect on safety and mission assurance as the airlock can still be pressurized rapidly in an emergency situation.

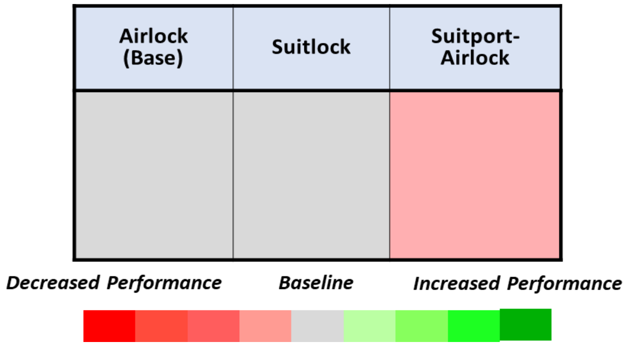

Figure 6. Qualitative comparison of the effects to safety and mission assurance of the different EVA access systems

Programmatic Costs and Risks

The programmatic costs and risks encompass the cost and schedule required to develop the EVA access systems as well as implement them into the SH design, and the risks that each system introduces. Once again, the airlock is used as the baseline assumption. The airlock requires little new technology development. The suitlock system requires the development of the suitlock interface; however, this non-pressure bearing interface system should be a straightforward design and will introduce limited additional programmatic cost. In addition to the suitlock interface on the airlock bulkhead, the current EVA suits would require modifications to use the suitlock system.

The suitport interface requires an increased cost for development, as compared to both the airlock and the suitlock system. Additionally, the EVA suits will also require significant increased DDT&E times and cost to adapt a suitport capable suit. For the airlock airsave options, the DDT&E costs are low as the airlock airsave system is a mature technology and is currently used onboard the International Space Station (ISS). Figure 7 shows the qualitative comparison of the programmatic costs and risks of the EVA access systems, relative to the airlock with an airsave system.

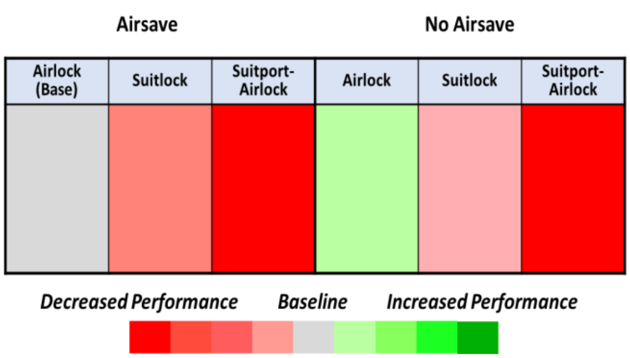

Figure 7. Qualitative comparison of the programmatic costs and risks of the different EVA access systems

Summary of Results

Each metric examined provides insight of where each EVA access system can be beneficial, as well as where they become problematic. The baseline airlock system has a low development cost and reduced risk; however, the annual logistics mass requirements and dust mitigation restrictions provide reason to investigate multiple options. The suitlock system decreases the dust intrusion that the airlock cause; however, it does not reduce logistics mass requirements nor does it significantly reduce EVA overhead time. Additionally, the suitlock system is not yet developed and would require programmatic DDT&E costs and introduce schedule risks. The suitport-airlock system reduces logistics mass requirements, EVA overhead time, and dust intrusion compared to the airlock and suitlock systems; however, the suitport interface requires a significant amount of DDT&E costs and time for both the interface and the EVA suits to be ready for an ABC mission. Additionally, the suitport system increases the mass of the SH, which would have to be modified if it were to support a suitport-airlock. The airlock airsave option reduces logistics mass requirements; however, savings are only significant for airlock and suitlock systems.

6. CONCLUSION

Selection of an EVA access system for the SH will be complex and will involve weighting of the relative importance of the FOMs discussed in this paper. In lieu of recommending an EVA access system, the result of this study details the importance of analyzing multiple options of system architectures to support future human space flight missions. The different systems detailed in this study each provide benefits to the SH and the ABC mission. Comparing the benefits and shortcomings of each option provides insight into which system should be selected or further researched in order to support final selection and to begin technology development. The result of this study is a significant resource for NASA stakeholders and decision makers when planning long-term ABC missions as well as short-term research and technology development. With the data described in this paper, any decision on the SH EVA access system will be backed by thorough studies and investigation.

REFERENCES

[1] ESDMD-404 Artemis Base Camp Reference Mission. NASA Internal. 2022.

[2] A-SPAT Debriefing, NASA Internal Document. 2018.

BIOGRAPHY

Chel Stromgren *currently serves as the Chief Scientist of Binera, Inc. Risk Analytics Division. In this role, Mr. Stromgren leads the development of probability and risk-based strategic models and strategic analysis of complex system development. Mr. Stromgren has supported NASA in the analysis of Space Shuttle and International Space Station operations in the post-Columbia environment and has led the development of strategic campaign models for the lunar exploration initiatives. He holds a Bachelor of Science degree in Marine Engineering and Naval Architecture from the Webb Institute and a Master of Science degree in Systems Management from the Massachusetts Institute of Technology*

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Natalie Mary *is experienced in human space flight as an accomplished International Space Station (ISS) flight controller at NASA Johnson Space Center (JSC) and is currently a lead systems engineer for the Aerospace Corporation in the Extravehicular Activity (EVA) and Human Surface Mobility Program (EHP). Natalie's focus is on systems engineering such as requirements, architecture, interfaces, and operational concepts for the Artemis Program EHP projects and cross stakeholder integration for Moon to Mars programs. Natalie received a B.S. in Aerospace Engineering from Texas A&M University and is an INCOSE Certified Systems Engineering Professional (CSEP).*