Past and Present Extravehicular Mobility Unit (EMU) Operational Requirements Comparison for Future Space Exploration

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This paper will address key design and development considerations and approaches for future extravehicular activity (EVA) needs by drawing on actual experiences in existing human space flight programs. As the space exploration directive, given by President Bush, sends humans out beyond low Earth orbit (LEO) for the first time in over three decades, EVA capabilities will need to expand in versatility and availability. Expansion in EVA versatility will include providing extravehicular mobility units (EMUs), spacesuits, with increased capabilities and flexibility in how they can be used, and the environments they are used in. Expansion of the availability of EVA capability is simply referring to the time required both in preparation for an EVA as well as the time and capability required for servicing the suits in between EVAs. This paper strives to review major past and present EMU operational requirements, and what drove these requirements. Secondly, a projection of what the future operational requirements may be for both zero-gravity suits used beyond LEO, and Lunar surface suits is presented.

I. Introduction

Throughout the past 40 years of human spaceflight, the capability and adaptability of humans to conduct extravehicular activities (EVA) for everything from experiment retrievals to lunar excursions, and from satellite repair to the current assembly of the International Space Station (ISS) has proven to be invaluable to the mission success of human spaceflight. Over the past 20 years there has been relatively little change in the EMUs as far as the working versatility and environment, or on-orbit availability and maintainability. The only real change in working environment has been a change from the majority of the work being performed within the environment of a Space Shuttle payload bay to the EMUs being used beyond these confines for the assembly and maintenance of the International Space Station (ISS). For versatility the major changes have been to the EMU gloves. Advances in on-orbit maintainability centered on logistics suit sizing issues and a minimal capability for replacing failed components. Despite recent maintenance activities that were driven by the inability to transport refurbished EMUs to the ISS due to the grounding of the Space Shuttle fleet following the Columbia accident, the actual maintenance and certification of the EMUs still take place at ground facilities.

Versatility is defined as:

“the quality or state of having many uses or applications” 13

In terms of spacesuits, versatility relates to the capabilities of the suits, and the ability to utilize the suits for several different types of EVAs or in a variety of environments. Through the present time, spacesuits have been designed for, and limited to, specific design envelopes dependent on the specific mission type for which they will be used. In the near future, with a permanent return to the Moon on the horizon, the first chance in over two decades to implement dramatic changes to the suit’s design to increase the versatility is presenting itself. This chance includes the time to review past spacesuits operating parameters and requirements, and to extrapolate into the future which of these parameters and requirements will continue to be acceptable, and which will need to be redefined.

Availability is defined as:

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For EVAs, this can be a relative definition based on one’s point of view, and past operational time required to achieve availability. There are two areas which availability can be broken down into. First is the preparation procedures and time required to conduct these procedures, and the second is the maintenance and servicing required on a periodic basis for continued availability of the suits. Over the history of the U.S. space program the availability of spacesuits for EVAs has varied in both areas. This is largely due to variation in mission types. Gemini, Apollo, and Shuttle based EVAs were conducted during relatively short duration missions with little to no servicing requirements during the missions. ISS based EVAs can be more directly related to the operations of spacesuits in the future, where most, if not all, prep and servicing will be completed on-location.

As manned spaceflight progresses along the exploration directive, EMUs capable of being used in two new working environments will be required. This includes zero gravity work beyond LEO, and the other being planetary surface operations. It can be seen that the previously mentioned expansion of the versatility and availability to conduct EVAs applies to suits to be used in both the weightless environment beyond LEO, and on the surface of other astronomical bodies, which in the relative near term is the lunar surface. Additionally, areas where the designs of these future EMUs allow for the use of commonality with the hardware designs of future manned spacecraft should be taken advantage. The use of common components between the EMUs and the spacecraft will allow for a reduction in EVAs specific ancillary support equipment. This will reduce EVA specific preparation and logistics overhead. Through careful review of operational requirements it will be possible to develop suits for these two environments with common components, as well as recommend areas to be considered for component commonality with the spacecrafts’ systems.

In preparation for the design and development of the next generation of EMUs and spacecraft from which EVAs will be staged, it is essential that operations personnel be involved from the beginning to define operational requirements for these EMU and spacecraft designs. Through a comparison of operational requirements, it will be possible to identify the common major hardware elements between past, present, and future suit designs. With this information hardware design and development engineers will be able to apply past component designs to future EMU designs, areas where design commonality between the suits and spacecraft are possible, and will also be able to identify component areas that will require additional development to meet the versatility and availability requirements of the next generation of EMUs.

II. Gemini Spacesuit

For the United States, the use of EVAs in the space program began during the Gemini program of the 1960’s. Over the course of just one and a half years the U.S. conducted nine EVAs during five different missions. The versatility of the suits used was relatively limited, although their capabilities did expand over this time. Initially, the Gemini suit was to provide a life support system with 15 minutes of life support capability through an oxygen purge flow system, but this changed prior to its first use as the planned tasks quickly exceeded this time constraint. What resulted for Gemini EVA missions was a semi-closed loop system using an ejector flow system where 25% of the flow was vented overboard for CO2, temperature, and humidity control. Additional cooling was provided by a water-boiler heat exchanger. Controls were limited to verifying ventilation flow, and the status of the emergency system. The oxygen and power for the suit was provided through an umbilical of lengths ranging from 25 to 50 feet, depending on the mission, connected to the vehicle supplies. A basic emergency system could provide 30 minutes of oxygen and battery power to the suit if the umbilical became disconnected.

The Gemini era suits were custom fit pressure garments that were similar to the Mercury program suits, essentially modified high altitude aircraft pressure suits, and required limited preparation prior to depressing the vehicle for egress. This is due to their single mission use and fairly basic system used for life support. Another factor for the minimal required preparation time, was that the vehicle environment was a 100% oxygen environment nominally regulated at 5.1 psia. Since the crew had been in this atmosphere there was no prebreathe requirement, to prevent decompression sickness, prior to depressing to vacuum, where their suits would be maintaining a suit
pressure of 3.7 psia. By a prebreathe time period not being required prior to the EVA the required preparation time for the EVA is significantly reduced. Space vehicles no longer operate with a pure oxygen environment. Therefore, to reduce, or eliminate a prebreathe time period in the future, other options, such as a higher pressure EMU, will need to be examined.

III. Apollo EMU

Due simply to the nature of the requirements for conducting lunar surface EVAs, the versatility of the Apollo EMUs was significantly expanded from that of the Gemini era spacesuits. First of all, and most obvious is the working environment which the Apollo EMUs were capable of operating within. Instead of the more benign environment of low Earth orbit (LEO), the Apollo EMUs were designed for operation on the Lunar surface within a 1/6 G gravity field, within temperature extremes of nearly +/- 300 degrees Fahrenheit. Also, the lunar soil presented the possibility of cleaning issues for the seals and outer surfaces of the suits.

Due to the need to operate within a gravity field, the mass of the EMU became a factor. These suits, including the portable life support system (PLSS) and oxygen purge system (OPS), were on the order of 85 kg (185 lb), of which approximately 20 kg (44 lb) was the pressure garment assembly (PGA). As in Gemini, the PGA was custom tailored for each crewmember.

There were actually two types of life support systems used during the Apollo era, both nominally operating at 3.75 psia. The first was very similar to the Gemini style, umbilical, semi-closed loop system, which fed off of the spacecraft systems for oxygen and power. This system was employed on three EVAs during the Moon to Earth transit to retrieve film canisters from the Apollo service module. This system used gas ventilation, at a flow rate of 10 cubic feet per minute, for cooling, CO2 removal, and humidity control. In this configuration, the heat removal capacity of the system was a maximum of about 991 btu/hr. The OPS, which was the emergency oxygen supply used on the lunar surface, was also connected during these EVAs to provide 30 minutes of emergency oxygen supply.

The second set of life support equipment used during Apollo was a system for lunar surface operations. This was an independent closed loop system which provided the crewmember the capability to traverse away from the Lunar Excursion Module (LEM). By the last Apollo lunar mission, the capability of the PLSS provided for a maximum duration EVA of 8 hours. New subsystems were employed for power, CO2 removal, cooling, and humidity control. Power was provided by a silver-zinc (AgZn) battery, providing 25.7 amp-hours of power. The suit nominally would draw 2.6 to 2.8 amps. Carbon dioxide removal was accomplished by circulating the ventilation flow through a lithium hydroxide (LiOH) bed where the CO2 was removed from the flow by chemical reaction with the LiOH. Crewmember cooling was provided through conduction from cooled water flowing through plastic tubes in a liquid cooling garment (LCG). The LCG was basically a tight fitting garment with plastic tubing woven into it. Water, which was cooled by a sublimator flowed through the LCG to maintain the crewmember’s body temperature. The sublimator, which provided the cooling to the LCG water, consumed a maximum of eight pounds of water from its own supply during the longer duration EVAs. The sublimator also provided the means for humidity control. As the ventilation flow was cycled through the sublimator, the moisture in the flow would condense and be removed. Oxygen for this system was provided from a supply bottle in the PLSS which when filled, contained 1.75 lbs of oxygen at approximately 1400 psi.

With a self contained system such as this, it was important to have feedback provided to the crewmember to alert them to any problems so that they could take corrective action. For this, there was a combination of alert tones and warning flags that were used by the crewmember to determine what malfunction was taking place. The flags covered four areas; feedwater pressure, vent flow, suit pressure, and O2 flowrate. Telemetry from the EMU systems was also transmitted to the flight controllers in Houston. It included both EKG data for the surgeons, as well as PLSS performance in eight areas.

There were provisions for two primary categories of emergencies during a lunar EVA. The first type was associated with a failure in the oxygen system, for which the OPS could provide a 30 minute emergency supply.
The second type was associated with a failure in the cooling system. For this failure the buddy secondary life support system (BSLSS) could be used. The BSLSS used an umbilical to connect the two crew members together so that one with a functioning cooling system could provide cooling to a crewmember with a failed cooling system. Communication redundancy was provided by including two independent radio systems and also including redundancy within the comm cap itself to accommodate for possible failures.

The checkout requirements of the EMU, prior to depressurizing for the lunar EVAs, were relatively straightforward. It included checkouts of the communications system, verification of the suit pressurization, and verification of a functional OPS.¹⁵ To maintain the availability of the EMUs in between the lunar EVAs, there were some servicing requirements for the EMU. These were performed during the PLSS Recharge Procedures and included; change outs of both the battery and LiOH cartridge; recharging the sublimator feedwater and O₂; inspection and lubrication of seals, orings, and pressure zippers; and application of antifog to the inside of the helmet.¹⁵ There was minimal maintenance that could be performed on damaged components. This included replacement of seals and o-rings, and the capability to perform minor pressure bladder repairs.¹⁵ Part of the reason for only minimal maintenance possibilities was that there were no spare PLSS components, other than batteries and LiOH cartridges, carried on the missions.¹⁸

IV. Shuttle EMU

The Space Shuttle era EMU design drew directly from the Apollo lunar EMUs. The low earth orbit (LEO) environment where they are used was more benign with respect to thermal extremes, approximately -170 degrees Fahrenheit to +235 degrees Fahrenheit, and there was no longer the issue of the negative impacts of the lunar soil.⁹ ¹⁰ ¹¹ Unlike the Apollo lunar EMUs though, the Shuttle EMUs were designed for reuse. Shuttle era EMUs were no longer a custom fit garment, and implemented a hard upper torso (HUT) design verses the soft goods style used in all previous spacesuits. The elimination of custom sizes led to the development of HUTs with five standard sizing categories (XS, S, M, L, XL), having a common waist interface, to accommodate crewmember sizes from a fifth percentile American female to a ninety-fifth percentile American male. Due to budget constraints only the medium, large, and extra-large HUTs were built. Softgood components were also built in standard sizes. These variously sized components were then assembled, during ground processing, to the stature of the EVA crewmembers for a particular mission. After a Shuttle mission, the components were then disassembled for reuse, and an EMU, with sizing for the next crewmember to use a particular PLSS, was assembled. Operationally, the Shuttle EMUs are self sufficient life support systems, but are nominally connected to servicing and cooling umbilicals (SCU) at various times throughout an EVA. The SCU can provide oxygen, cooling, power, and communications to the EMU.

Much of the same life support capabilities that existed with the Apollo PLSS were transferred to the design of the Shuttle era closed loop PLSS. These included the technology that was used for the CO₂ removal, cooling, power, and humidity control. For CO₂ removal, replaceable LiOH canisters continued to be used, and nominally provide over seven hours of capability.⁸ As with the Apollo lunar EMUs, crew cooling is provided by circulating water through a sublimator, and then through tubing in a liquid cooling and ventilation garment (LCVG). The LCVG is essentially the LCG with vent ducting, for the return loop of the ventilation circuit, attached to the extremities. The sublimator water supply contains about 9 lbs of water total. This includes the volume of both the primary and reserve tanks .²⁰ The cooling can remove an average of 1000 btu/hr of heat for a seven hour EVA. As with the lunar EMU PLSSs, the ventilation circuit is designed to flow through the sublimator for the condensing and removal of humidity from the atmosphere. Power for the EMU was still provided by a AgZn chemical battery having 26.6 amp hours for a seven hour EVA drawing at 3.6 amps, and powers the suit at a minimum of 16 volts. A major upgrade in the battery is the capability for recharge. The original Shuttle EMU batteries were capable of six recharge cycles before falling below the minimum required charge capacity for a nominal EVA.⁸ The oxygen for the crewmember’s pressurization and breathing is provided from two oxygen tanks filled with a total of 1.2 lbs of oxygen to 850 psi.⁴ Although this should be sufficient for a nominal 6 hour EVA, these tanks are easily rechargeable during an EVA by connecting the SCU to the EMU.

The Shuttle EMUs provide significantly more control and insight into the functioning of the systems than the Apollo EMUs. Through the use of the display control module (DCM), mounted on the chest of the EMU, the
crewmember can control the various systems, including; suit pressure, power, communications, cooling water circulation, ventilation flow, and status various parameters of the EMU on the display. The caution and warning system (CWS) of the EMU will alert the crewmember to a wide variety of problems via alert tones and messages on the display. The caution and warnings include the areas of pressurization, ventilation, oxygen and water use, CO2 levels, and power system failures. While monitoring the conditions of the EMU, the CWS uses a number of software states, based on the current suit configuration, to determine when system limits have been exceeded. Also monitoring the EMUs are MCC flight controllers, who receive a data downlink from the EMUs once every two minutes. The balance of the two minutes of EMU telemetry is the crewmember’s EKG readings. The EKG readings are provided realtime to the MCC flight surgeons for monitoring of the crewmember’s health.

As with the Apollo EMUs, the Shuttle EMUs provide emergency capabilities for failures of various systems. A failure of the ventilation system would require a crewmember to open their helmet purge valve to exhaust CO2 buildup from the nasal-oral area. A loss of cooling could require the crewmember to open their DCM purge valve, to exhaust a portion of the atmosphere, including humidity, CO2, and heat, overboard from the return leg of the ventilation loop. This valve is larger than the helmet purge valve and when open places the EMU into a semi-open loop mode. In either of these cases, or if suit pressurization integrity is compromised at a flowrate equal or less than that from the DCM purge valve, the SOP will provide for a minimum of 30 minutes of oxygen pressurization above 3.3 psid. In the area of communications, to provide for possible failures, redundancy is provided through a backup radio and also redundant components were included within the comm cap itself.

With the Shuttle EMUs, the checkout and preparation procedures became lengthier than the corresponding procedures from the Apollo EMUs. A checkout procedure of 60 minutes is performed on-orbit on the EMU prior to its use. These procedures verify proper operation of the suit pressure regulation, CWS, radios, fan/pump assembly, and emergency oxygen supply. On the day of EVA, prior to ever depressing the airlock, there are several hours of procedures and prebreathing by the EVA crew which need to be completed. These procedures required two hours of work, plus up to four hours of the EVA crew breathing pure oxygen while pressurized in their EMUs to reduce the potential for getting decompression sickness. Post EVA, as with the Apollo era EMUs, a LiOH cartridge replacement, water recharge, and oxygen recharge are required. The batteries were now rechargeable, verses one-time-use, and require about a day to recharge. Additional servicing includes biocide cleaning of the inside of the pressure bladder. Possible maintenance of the EMUs, while on-orbit, was still limited, and included only the ability to change-out a failed SOP with one from another EMU.

V. International Space Station EMU

With the beginning of operations of the International Space Station (ISS), the need for a capability to conduct EVA operations without a Shuttle present came to fruition. To this end, it was decided that the Shuttle EMUs, with a few modifications, would be the spacesuits used on the ISS.

In terms of versatility the number of times which the EMU batteries are capable of being recharged increased to 32 times, verses only the six recharges possible with the original version. Another modification was to the CO2 removal capability. The EMUs used on the ISS now use a regenerable Metox (metal oxide) canister, instead of the LiOH. Unfortunately, to gain the regenerative capability, some CO2 removal capacity had to be sacrificed. The Metox canisters capacity provide for CO2 removal at an average crew metabolic rate of 850 Btu/hr for eight hours, while the LiOH could provide CO2 removal for an average metabolic rate of 1000 Btu/hr for seven hours.

A new capability, not available with the custom fit Apollo era suits, or even with the original version of the Shuttle EMUs, is that of resizing or replacement of the spacesuit assembly (SSA) EMU arms and lower torso assembly (LTA) components while on-orbit. This capability provides both contingency capabilities for component failures, as well as reduced logistic requirements for changes in crew members. An additional new modification to the EMUs is the capability of on-orbit changeout of any of four different orbital replacement units (ORUs) for reasons of either component failure, sizing, or component end of life. These four components are the PLSS, HUT, DCM, and the SOP. The resizing capability combined with the EMU ORU capability allowed for the possibility of launching only replacement components, verses a replacement EMU, which was planned to reduce logistical
demands. The EMU ORU capability has not been exploited to its fullest extent, although the resizing and replacement capability of the SSA is routinely utilized.

The working environment which crewmembers would find themselves in was very similar to that of the Shuttle payload bay. One issue that did arise though, was that of keeping a crewmember’s hands warm. For this, glove heaters were installed at the fingertips of a new version of the EMU gloves, with an On/Off switch located on the back of the gloves. This proved successful in maintaining a comfortable temperature in the gloves.

Along with the previously mentioned modifications to the Shuttle era EMUs, there were significant changes in the operations of the EMU to maintain their availability. Changes to the EVA preparation activities include the addition of suit sizing procedures, LCVG water fill procedures, and slightly longer checkout and day of EVA preparation procedures. The LCVG water fill was previously performed on the ground, prior to a Shuttle mission, but for station crews the LCVGs are not filled until just prior to their first use. These changes are due to keeping the EMUs on orbit for long periods of time, verses a short duration Shuttle mission.

As far as on-orbit servicing and maintenance is concerned, the additions to the Shuttle based EVA procedures include Metox regeneration, water servicing, battery maintenance, and the possibility of a more thorough “mid-term checkout” being required. The Metox canisters are regenerated during a 14 hour process. These Metox canisters are capable of 55 regeneration cycles over nine years, with the only maintenance being the replacement of o-ring seals after 27 cycles. Water servicing, consisting of a dump and fill of half the feedwater supply, is conducted every 180 days. The EMU battery maintenance is required to be performed every 85 days to maintain battery capacity. A “mid-term checkout” is a more extensive checkout with a two hour fan run time which is required if an EVA, mid-term checkout, or ground processing has not been performed within the previous 369 days.

With the use of EMUs on the ISS, the first use of EMU to spacecraft component commonality was introduced. This is in the form of using the EMU Metox canisters to provide CO2 removal within the ISS airlock module while the module is sealed off from the rest of the ISS during EVA preparation activities. The possibility of extending this commonality to other areas with future EMUs and spacecraft may help to provide redundancy, and reduce overall mission system component requirements.

VI. Exploration

With the beginning of the “Exploration” era, laid out by President George Bush at the beginning of 2004, there is little, if any, debate within the EVA community that a new EMU design will be required. The real work will be in properly defining operational and hardware requirements for the new design, or possibly designs, and matching these with hardware components possessing the required technological maturity. As has been the theme throughout this paper, the operational requirements will need to incorporate areas such as the EMU versatility, including capabilities and working environment envelope. Additionally, as has been highlighted in recent years with the continuous manning of the ISS, and will only continue to become more important as humans return permanently to the Moon, it is important to limit the amount and level of operational preparation required, and maximize the ability to conduct on-orbit maintenance and servicing, for the maintaining of continuous EMU availability.

What versatility from the previous EMU designs is applicable to the future, and what new versatility might be required? Looking first at the capabilities of the EMU, several basic areas can be highlighted. First off, based on previous EVA experience, the required duration for continuous use of an EMU should support a minimum of an eight hour EVA, with the capability included to recharge, or regenerate all consumables without terminating the EVA. This will provide for the possibility of an extended duration EVA and contingency capabilities. Also, it will provide for less constrained EVA capability for future missions with unforeseen objectives. This does not necessarily mean that all consumables required to meet this time must be loaded into the EMU at the start of the EVA, but that at a minimum they can be replenished during the EVA through umbilical connections from any of a variety of locations, including landing vehicles, permanent bases, rovers, or supply carts. This practice is used to some extent today with the capability of replenishing the EMU oxygen supply through the SCU on the ISS.

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In order to limit the logistical supply demands a new EMU should have minimal use of consumables. To conserve the use of oxygen, the EMU will need to be a closed loop system, verses an open, or semi-open loop system. Based on this requirement, cooling will continue to need to be provided by a conductive means, such as an LCVG. This minimizes the introduction of humidity into the EMU, which reduces the possibility of fogging of the visor, and minimizes the required capacity of the condensate removal system. Based on the experience of the past spacesuits, an average cooling capability of 1000 Btu’s per hour will be sufficient, provided that peak cooling of 2000 Btu’s per hour for 15 minutes is available. Cooling for the Apollo and Space Shuttle/ISS EMUs was provided by the use of a sublimator, which consumed water during the EVA. The use of a nonconsumable cooling system will be necessary to avoid logistics requirements for water, as there is with today’s EMUs. This will be an area of major redesign, and will also be required for operation of the EMU within an atmosphere. A closed loop system will also require CO2 removal capability similar to that which has been provided for the Apollo lunar PLSS and the current EMU PLSS, using a regenerable cartridge, similar to the Metox canisters. One recommended change will be to provide for the capability of changing out, or regenerating, the CO2 removal cartridge while conducting an EVA. This eliminates the necessity to terminate an EVA based on expending the capacity for CO2 removal capability.

Emergency capabilities of the EMU should continue to include secondary methods for pressurization, CO2 removal, and cooling, with enough capacity to provide the crew the capability to return to a location where they can safe the EMU. The current 30 minute minimum for this will need to be reviewed. Safing can be provided by vehicle umbilical or by returning to a pressurized environment. Based off of previous experience, built in redundancy for communications should be provided. Redundancy in other areas can be considered, but use of additional redundancy will need to be evaluated against the added suit mass, and the use of replaceable assemblies for on-site maintenance, which will be discussed briefly.

The capability of realtime downlink of suit telemetry to flight controllers needs to be maintained until transmission time delays make it impractical. This will allow flight controllers to monitor the EMU systems to see failures before they occur and allow for adequate time to terminate an EVA if required. Also, controllers can assist a crewmember with realtime calls if they are experiencing suit failures. Along with this information being downlinked to flight controllers, the status of the various EMU systems, and caution and warning messages should be provided directly to the crewmember. Current technology should be able to provide advanced display and audio to the crewmember to assist them with instructions for emergency situations. Additionally, the EMU telemetry should be transmitted to the vehicle, or base, for monitoring by a non-EVA crewmember. This will be particularly important once crews are sent on deep space missions where the time delay in radio transmissions limits the amount of realtime assistance that can be provided by flight controllers on Earth.

Another capability to include in a new EMU design is one that has proven very useful for operations on the ISS. This is the resizing capability and modular structure of the EMU. Included in this would be the use of standard sized components verses custom fits. This eliminates the need to transport new EMUs each time there is a rotation of crewmembers from a station or base, and results in only a transportation of sizing components specific to the new crewmembers. It is anticipated that custom gloves will still be required to provide acceptable dexterity and comfort for long duration EVAs.

The working environment of these next generation EMUs will be a combination of the ISS EMUs and Apollo EMUs. The worst case of these two is the Apollo lunar EMUs. The thermal and dust environment was previously mentioned, and will need to be reassessed, along with the required protection from radiation and MMOD, to determine an appropriate level of shielding.

As far as increasing the availability of the EMU, work will need to be completed in both the areas of preparation, maintenance, and servicing to reduce the time required for each of these.

To increase the potential for availability, the EMU will need to be designed such that most, if not all, maintenance and servicing can be performed on-site. For missions where resupply is possible this will limit the resupply upmass requirements, and on missions where resupply is not a possibility this will provide the opportunity for certifiable repair work to be completed on the EMUs to ensure mission success. For this, the packaging of the
next generation of EMU PLSS must become replaceable modules at the assembly level, and possibly more serviceable at the component level. The assembly level being a replaceable unit made up of components. These are actually two layers deeper than the current EMU ORU capability with the PLSS, SOP, DCM, and HUT. The serviceability at the component level may be difficult to attain in certain assemblies where a variety of very specialized tools would be required for repair. The inclusion of these specialized tools in the vehicle’s inventory would have to be balanced against simply increasing the inventory of spare assemblies. This modularity will effectively simplify replacement operations and allows for isolation during troubleshooting without compromising any neighboring modules.17 If this modularity is combined with assembly and component commonality with the vehicles, it will also then serve to reduce the EMU required up-mass, and reduce the stowage requirements for EMU unique hardware on future vehicles, stations, and bases. The use of shared modules will also provide redundancy in the event of an emergency. For standard servicing and preparation for an EVA, potential areas of commonality include the use of common batteries and CO2 removal cartridges.

Expanding the idea of commonality further, the EMU LSS could even be utilized, in its entirety, in the vehicle LSS. In this manner, the EMUs would not merely function as spare LSS component modules, but it would also effectively exercise the EMU within the cabin environment before being pressed into future EVA service. This plan also minimizes EMU specific servicing during periods without EVA activity, since much of its operation would already be assured. One example of a long duration storage issue resolved by this plan is circulation of a stagnant EMU cooling water supply. Several EMUs, perhaps in pairs, could be periodically rotated through the vehicle life support system interfaces and be maintained in service condition with minimal preparation for an EVA.

Another preparation activity which could be reduced through a combination of the design of the EMU and the design of the space vehicles is the prebreathe required for the crewmember prior to depressing to vacuum for an EVA. A combination of increase in EMU pressure, and reduction and potentially a change in composition of the vehicle’s atmosphere can be balanced to reduce the amount of nonproductive time spent during EVA preparation activates.

All of these items will help to reduce the crew time required to have an EMU available for EVA.

VII. Flight Control Operators Input to EMU Designs

Rather than complete the design expeditiously and only later have flight controllers observe testing of the finished product, operational input should be sought out and encouraged throughout all design phases. Committing to operational input early in the design process will alleviate ‘second guessing’ system functions later and streamline ground testing efforts. The Flight Operations perspective can provide a reality check for design engineers and direct design and development efforts toward more significant areas of concern, such as the human factors of crew interfaces. Selecting among several viable life support system candidates, a single new design concept may prove to be a controversial decision, but it should be well evaluated and have received thorough consideration among all experienced EVA team members including the operations team.

VIII. Conclusion

Over the course of the last 4 decades of EVA we have witnessed the transformation of space suits from enhanced flight pressure suits in the Gemini era, to a separable garment and EVA backpack in Apollo, and finally to a segmented sizing components integral to the backpack. We are now at the crossroads of the next generation suit design and NASA must make decisions to proceed with specific design objectives. Future suits are likely to be fashioned as a blend of Apollo and ISS era suits, possibly serving in some vehicle ECLSS capacity. The new pressure garment is expected to have sizing variability including spare replaceable segments that can be easily replaced as needed to support the mission. The Life Support System will be of a modular design at the assembly level and will, to some degree, be serviceable at a component level. This will facilitate the EMU availability for nominal operations, and versatility in various environmental conditions. Regardless of the design path decided upon for the next generation of EMUs to be used in the exploration of space beyond Earth orbit, including the EVA MOD
personnel in the project effort is paramount, to bring their unique operations insight into the design of the next generation of EMUs.
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