Extravehicular Activity Asteroid Exploration and Sample Collection Capability

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One of the challenging primary objectives associated with NASA's Asteroid Redirect Crewed Mission (ARCM) is to demonstrate deep space Extravehicular Activity (EVA) and tools and to obtain asteroid samples to return to Earth for further study. Prior Shuttle and International Space Station (ISS) spacewalks have benefited from engineered EVA interfaces which have been designed and manufactured on Earth. Rigid structurally mounted handrails, and tools with customized interfaces and restraints optimize EVA performance. For ARCM, EVA complexity increases due to the uncertainty of the asteroid properties. The variability of rock size, shape and composition, as well as behavior of the asteroid capture mechanism will complicate EVA translation, tool restraint, and body stabilization. The unknown asteroid hardness and brittleness will complicate tool use. The rock surface will introduce added safety concerns for cut gloves and debris control. Feasible solutions to meet ARCM EVA objectives were identified using experience gained during Apollo, Shuttle, and ISS EVAs, terrestrial mountaineering practices, NASA Extreme Environment Mission Operations (NEEMO) 16 mission, and during Neutral Buoyancy Laboratory testing in the Modified Advanced Crew Escape Suit (MACES) suit. This paper will summarize the overall operational concepts for conducting EVAs for the ARCM mission including translation paths and body restraint methods, potential tools used to extract the samples, design implications for the Asteroid Redirect Vehicle (ARV) for EVA, and the results of early development testing of potential EVA tasks.

Nomenclature

ARCM	=	Asteroid Redirect Crewed Mission
ARM	=	Asteroid Redirect Mission
ARV	=	Asteroid Redirect Vehicle
EMU	=	Extravehicular Mobility Unit
EVA	=	Extravehicular Activity
ISS	=	International Space Station
MACES	=	Modified Advanced Crew Escape Suit
MCC	=	Mission Control Center
NASA	=	National Aeronautics and Space Administration
NEEMO	=	NASA Extreme Environment Mission Operations
O_2	=	Oxygen
PLSS	=	Portable Life Support System
RCS	=	Reaction Control System
WIF	=	Worksite Interface

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I. Introduction

THE Asteroid Redirect Crewed Mission (ARCM) requires short duration Extra Vehicular Activity (EVA) capability for Orion. The EVAs will involve a two-person crew for approximately four hours. Currently, two EVAs are planned with one contingency EVA in reserve. Providing this EVA capability is very challenging due to system level constraints and a new and unknown environment. The goal of the EVA architecture for ARCM is one that builds upon previously developed operational concepts and lessons learned, while providing a stepping stone to future missions and destinations. The primary system level constraints are to 1) minimize system mass and volume and 2) minimize the interfacing impacts to the baseline Orion design. In order to minimize the interfacing impacts and to not perturb the baseline Orion schedule, the concept of adding "kits" to the baseline system is proposed. These kits consist of: an EVA kit (converts the Launch, Entry, and Ascent suit to an EVA suit), EVA Servicing and Recharge Kit (provides suit consumables), the EVA Tools, Translation Aids & Sample Container Kit (the tools and mobility aids to complete the tasks), the EVA Communications Kit (interface between the EVA radio and Orion), and the Cabin Repress Kit (represses the Orion between EVAs). This paper will focus on the EVA operations of asteroid exploration and sample collection. Investigation of historical EVA operations provided a foundation for the development of the operations concept of microgravity sampling techniques of an unknown asteroid body.

A notional EVA timeline is represented in Figure 1.

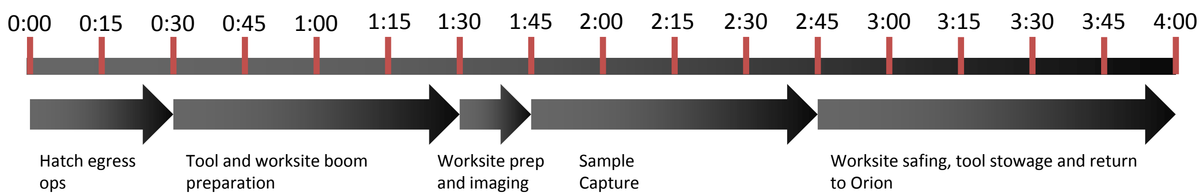

Figure 1. EVA Timeline.

The planned duration of the two nominal EVAs is four hours. The relatively short duration is driven by a compromise between different criteria. Four hours were viewed as the minimum amount of time to accomplish the sampling tasks and the maximum amount of time it is reasonable for the MACES to work with the PLSS as designed. The feasibility study selected a Portable Life Support System (PLSS) for EVA rather than an umbilical[5]. The PLSS enables greater flexibility in translation of the EVA crew members on the integrated vehicle stack and the asteroid. The proposed operational concepts utilizes expandable booms and integrated features of the asteroid capture mechanism to position and restrain the crew at the asteroid worksite. These methods enable the capability to perform both finesse, and high load tasks necessary to collect samples for scientific characterization of the asteroid.

Two capture mechanism concepts are being pursued by the agency, in support of two differing goal. One mission concept captures a small asteroid in its entirety; asteroid diameter up to 10 meters. The conceptual capture mechanism design for this Small Boulder Capture mission consists of an inflatable bag that will cinch the asteroid to the Asteroid Redirect Vehicle (ARV) structure. The other mission concept will robotically capture a small boulder of up to 4 meters diameter sitting on a larger parent asteroid. The conceptual design for this Robotic Boulder Capture mission consists of robotic capture arms that will grasp the boulder. EVA accommodations will be critical for both designs to enable the asteroid exploration mission objectives. The EVA community will work with both capture mechanism teams to optimize the EVA worksites.

II. EVA Concept of Operations

A. Outbound Operations

During the 10-day transit time, the crew will have an opportunity to prepare the cabin and suits for the upcoming EVAs. Shortly after the Earth departure burn, the Orion cabin will be depressurized to 10.2 psi to facilitate minimal EVA pre-breathe times. The crew will then transform the vehicle and their Modified Advanced Crew Escape Suits (MACES) from the launch configuration to one that supports EVA. Figure 2 shows the MACES in its launch and entry and EVA configurations.

While en-route to the ARV, the crew will perform an EVA dry run including checkout of the MACES and Exploration PLSS, and practice suit donning. The EVA checkout activities will include communication checks between suits and the ground. Verification of suit performance will be jointly executed with the Mission Control Center (MCC). The crew will review the EVA preparation, vehicle depress, egress, and repress procedures to ensure adequate reach and access prior to doffing the suit. The EVA tools launched on Orion will be removed from their launch stowage location and configured for EVA. The crew also will perform final battery charging and install support hardware for mounting the Orion to ARV translational boom ("Gap Spanner Boom") near the EVA hatch.

Figure 2. MACES in Launch/Entry Configuration (left) and EVA Configuration (right).

B. EVA Prep

Prior to each EVA, the Orion RCS thrusters will be used to slew the stack to a +15° yaw. This attitude change will provide improved illumination of the EVA worksite, and the Orion thrusters will arrest any rates before the vehicle is mode configured to free drift for the duration of the EVA operations.

On the morning of the first EVA, the crew will complete post-sleep activities and initiate EVA preparations with suit donning. The suit will be purged of cabin air and pressurized with 100% Oxygen (O_2). The crew will then perform suit pressure integrity and system checks followed by a prescribed pre-breathe period. Based on similarity to Shuttle protocols, the in-suit pre-breathe duration will be approximately 40 minutes. Additional analysis is required to verify the time required to de-nitrogenate the MACES.

When pre-breathe and suit leak check are complete, the cabin depressurization will be initiated by the crew. Once at vacuum, the crew will open the hatch and disconnect the Enhanced MACES umbilicals. The sequence of umbilical disconnection and Exploration PLSS activation will be determined through future integrated testing and verification of the Orion, Exploration PLSS, and MACES systems.

C. EVA, Small Boulder Capture

The first EVA commences when the Orion hatch is open and the crew is operating on the Exploration PLSS. The EVAs will be designed to be no longer than four hours long. The priorities for this first EVA will include sample retrieval, contextual and detailed photographic observations, as well as EVA tool and translation aid deployment. Reference Figure 1.

With both crew members participating in the EVA, no crew member will be in the Orion to provide checklist narration. EVA support personnel in MCC will provide detailed procedure narration and management. This model has been successfully performed during several International Space Station (ISS) stage EVAs. For this mission, a three to four second round trip communications delay will require some additional crew autonomy and communications protocol adherence. However, a delay of this duration is not sufficient to cause insurmountable challenges or changes to operations based on previous analog testing. Crew aids will be used to minimize the impacts of communication delays. These could range from simple paper cuff checklists to more complex electronic versions capable of receiving uplink procedure deltas in real-time

Figure 3. EVA crew exiting Orion with Translation Boom.

during the EVA. In addition to providing EVA procedure narration, MCC personnel will monitor the vehicle and relay caution and warning information to the crew. The first hour of the EVA will focus on Orion egress and configuration of tools at the worksite. To avoid risking damage to thermal protection materials on the Orion structure, the crew will need to deploy a translation bridge between the hatch and the aft structure of the ARV. An EVA crew member positioned in the hatch opening will secure one end of a small telescoping boom to a mounting bracket interface inside the hatch. The opposite end of the boom will be guided into a soft-dock receptacle secured on the ARV. Preliminary design concepts are being evaluated in government fiscal year 2014. Figure 3 shows the first EVA crew member exiting the Orion and installing the Gap Spanner translation boom. The bridging boom will not be permanently installed between the Orion and the ARV as this would preclude hatch closure and undocking.

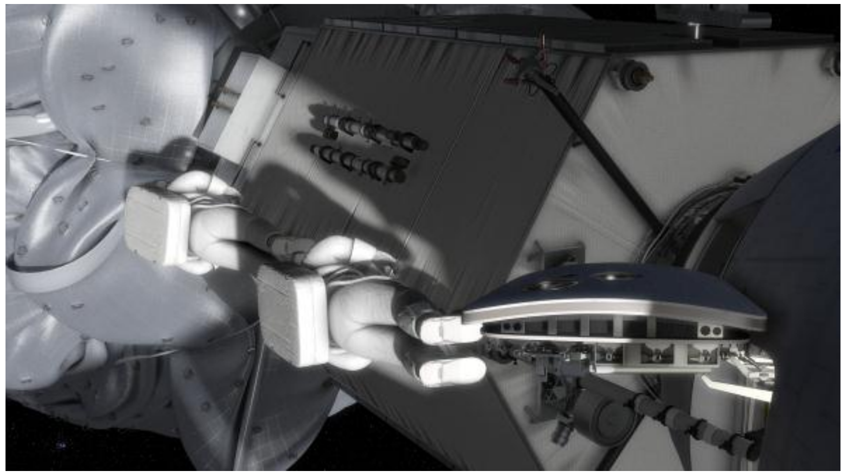

Figure 4. EVA crew on ARV translation path from Orion toward asteroid.

The first EVA crewmember (EV1) will translate across the boom to the ARV structure where he/she will then attach the soft dock with a locking feature, if required. Each EVA crew member will configure his or her safety tether to minimize the need to swap from one tether to another while maximizing access to all EVA worksites along the mated vehicle stack. Each safety tether will be anchored near the Orion hatch and routed to avoid damage to delicate hardware such as sealing surfaces, solar arrays and antennas. At present, it is assumed that a 55-foot EVA safety tether will provide sufficient reach for this mission. A final step in crew egress will involve deployment of a thermal and debris cover across the hatch opening for the duration of the EVA. The cover will be simple and easily

Figure 5. Crew retrieving tool from ARV toolbox.

deployed. Figure 4 shows EVA crew members translating along EVA handrails installed on the ARV bus structure after departing the Gap Spanner boom between the Orion and the ARV.

The crew will translate on rigid EVA handrails mounted along the ARV bus and proceed to retrieve tools from the ARV toolbox, located along the translation path (Figure 5). Two telescoping Stabilization Booms will be mounted to the ARV exterior with launch restraint fittings. A series of boom sockets will be pre-integrated around the circumference of the ARV flange near the interface to the bag. These sockets could be similar to the Worksite Interface (WIF) sockets used on ISS.

Crew safety and operational simplicity dictate that sample retrieval worksites be chosen where the rock is within easy reach from the bag surface. The crew will select a socket for Stabilization Boom operations based on ease and value of sample collection. Rotational joints will be incorporated into the boom interfaces to allow access to multiple asteroid sample retrieval worksites from a single bus mounting point. Figure 6 shows the EVA crew setting up for boom operations, and figure 7 illustrates the crew collecting samples while stabilized in a boom-mounted foot restraint. Initial EVA concepts utilize the high tension winch cables in the ARV capture design as well as a network of fabric tether points on the bag to aid in crew and tool translation and restraint at worksites. Each of these concepts will be tested in ground simulations to further refine requirements and demonstrate the associated techniques. Defining a method of 'cutting' through the bag to access the asteroid requires further study. Material choices and

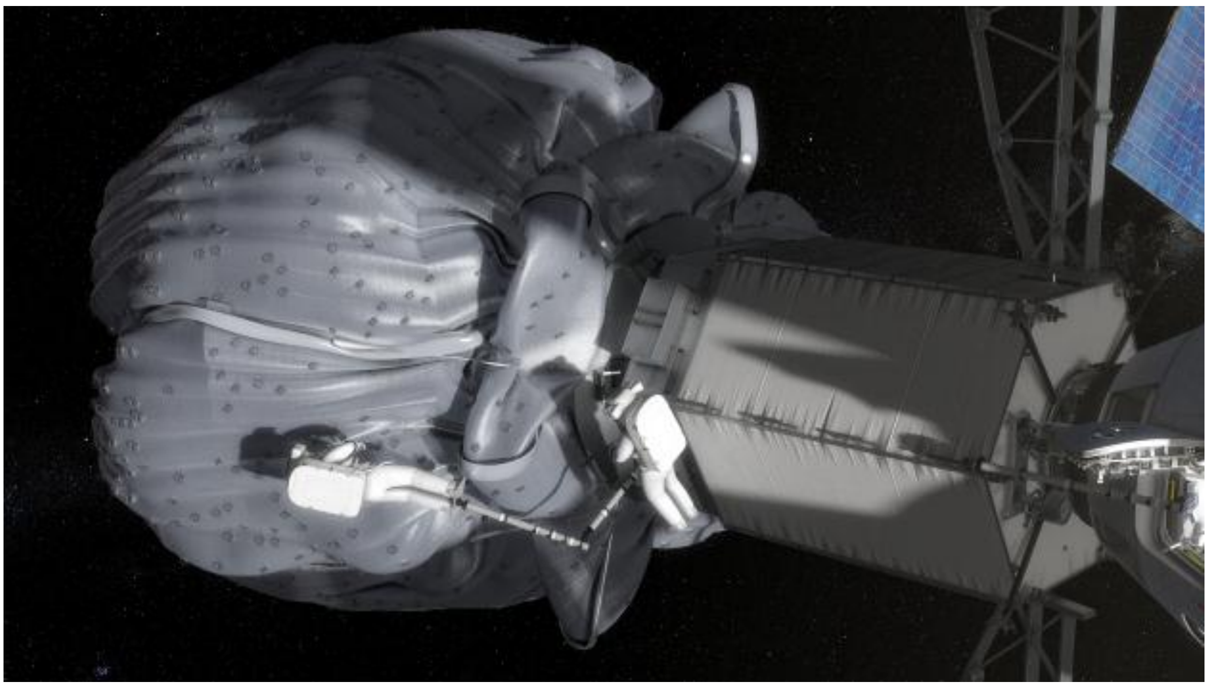

Figure 6. EVA crew setting up for stabilization boom operations.

specific bag or capture mechanism design will heavily influence methods of gaining access to the asteroid. Initial bag material selections of vectran with kapton layers seem to be relatively easy for crew to cut during testing.

As the crew ventures onto the bag to explore the asteroid and collect rock samples, EVA complexity increases due to the uncertainty of the asteroid properties. Plans for EVA translation, tool restraint and body stabilization must accommodate the variability of rock size, shape and composition, as well as the unknown characteristics of the capture mechanism. EVA tool design must accommodate the hardness and brittleness of the asteroid. The rock surface will introduce safety concerns for cuts to gloves and space suit soft goods, visor abrasion and debris control. Mission feasibility is based on experience with ISS EMU gloves. Assessment of durability of the EMU glove against the rock surface is forward work; possible risk mitigation may include the use of a sacrificial over-glove, which has precedence in ISS flight operations. It is not reasonable to assume that rock fragments will be perfectly contained; opening the bag and breaking off rock samples will release material into the area. The key concerns are ensuring that rock fragments do not impact the suit or vehicle with high kinetic energy and that the interior of the Orion be kept clean. The helmet visor design will include abrasion-resistant coatings to protect from dust damage and suit outer layer material will be designed to prevent propagation of dust into the Orion interior. Tools and operational techniques will have to be designed to minimize debris liberation and associated energy. Based upon the properties of the lunar Distant Retrograde Orbit (DRO), high energy recontact of liberated material with the vehicle is not likely to pose a risk.

EVA objectives on the asteroid will be varied. Geological samples may include hammer chips, core samples, soil, float collection, and others. Tasks may include deployment of a sensor array on the asteroid for acoustic testing or long term monitoring, or demonstration of anchoring techniques to the rock surface. As possible, imagery will provide MCC situational awareness, geological context, and provide an avenue for public engagement. EVA task definitions will evolve as the mission matures. Definition of the specific objectives is forward work to be coordinated with the scientific, commercial, and international spaceflight communities. Initial mass available to the ARCM may limit asteroid utilization on this first mission. Extending the ARV platform for follow-on missions will provide more utilization options and allow for more detailed studies based on the results of the preliminary data captured by the ARCM

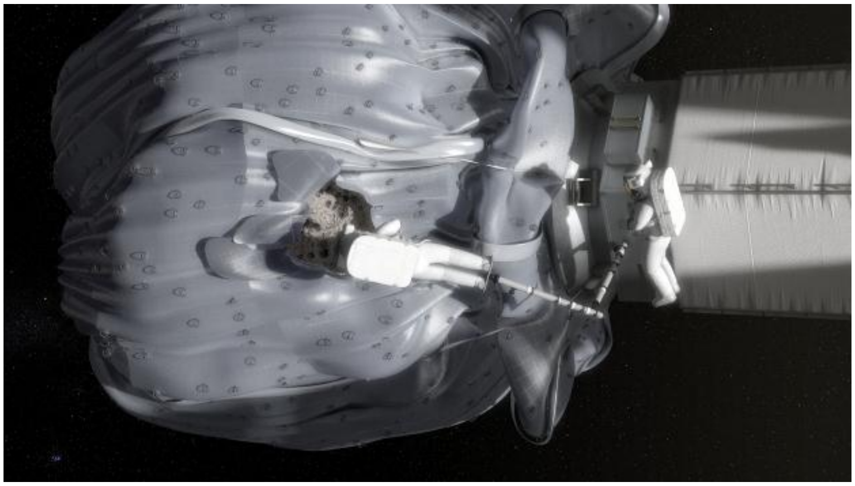

Figure 7. Sample collection from stabilization boom.

Collection of asteroid samples for return to Earth will be a high priority mission objective. Preserving sample purity will impose requirements on collection techniques and hardware design features of the sample containment system. The conclusion of the EVA will focus on cleanup and ingress. At the end of the first EVA, the crew may pre-deploy tools and translation aids as get-aheads for the second EVA. On both EVAs, the boom used to bridge the gap between the Orion and the ARV will be retracted into the Orion to allow hatch closure and to clear the undock corridor. Collected samples will be stowed in the containment kit and secured inside the Orion. The crew will then connect their umbilicals and transfer to vehicle life support. The choreography of the second EVA will mirror the first, without the burden of initial set-up tasks.

D. EVA, Robotic Boulder Capture

At the time of this paper, the agency is considering both the Small Boulder Capture Concept and a Robotic Boulder Capture Concept for the design of the robotic capture mechanism. The Robotic Boulder Capture Concept capture mechanism is designed to capture a small boulder of up to 4 meters diameter sitting on a larger parent asteroid. EVA operations differ from the description in the preceding section in the methods that the EVA crewmembers access the asteroid. The Robotic Boulder Capture Concept does not include a capture bag (reference Figure 8); therefore, the sample sites are accessible without the need to cut and open a bag. Further, the exposed boulder allows for timeline planning and contextual observations prior to EVA for boulders sized approximately 2 meters to 4 meters in diameter

Since the EVA crew member will require translation aids to assist in their body positioning and stabilization, it is desirable for the capture mechanism structure to be used as an EVA translation aid. Continued maturation of the Robotic Boulder Capture Concept design is needed to accommodate EVA induced loads into the capture mechanism structures without shifting the boulder within the capture mechanism and thus creating a

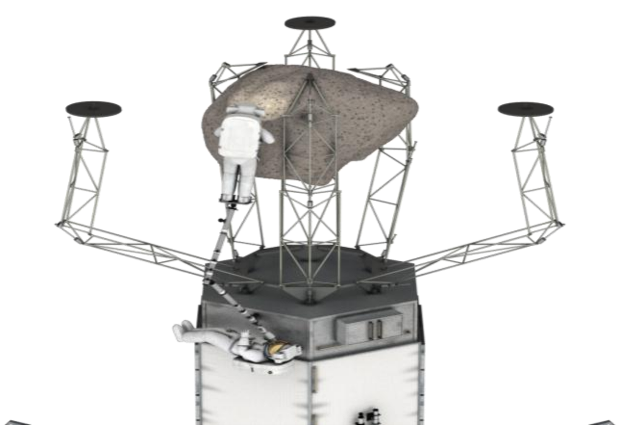

Figure 8. EVA crew member accessing asteroid on Robotic Boulder Capture Concept capture

potential pinch or entrapment hazard for the EVA crew member.

The last difference to note for the Robotic Boulder Capture Concept is the integrated stack attitude during EVA. As described in section B, the integrated stack is slewed to +15° yaw attitude prior to the start of EVA to provide the necessary light and thermal conditions for the EVA operations. If the boulder is smaller in diameter than the Orion-ARV stack, shadowing from the vehicle may require a larger attitude change. Future work is needed to analyze the thermal performance of Orion in this attitude.

E. Post EVA

Once the hatch has been closed and latched, the crew will initiate the repress of the cabin by opening the repress kit tank valve. The feasibility assessment assumes the crew will control the repress by cycling a manual valve as needed for crew comfort and planned holds. The repress will be paused to perform a cabin leak check to verify the integrity of the hatch seals. Assuming a successful leak check, the crew will open the valve and complete the repress to 10.2 psi. The regulator will slowly close, reducing the flow rate as the cabin pressure approaches the regulator set point. This allows the crew freedom to continue other activities without monitoring the cabin pressure. Operation for the first and second repress would be identical.

Following repress, the crew will assist each other with suit doffing. Prior to depressurizing the suits, the crew should inspect the gloves for areas of possible damage and follow up with photos after suit doffing. Most suit refurbishment tasks can be left for the next day, but charging of the suit and tool batteries will likely need to start that evening to ensure they are fully charged to support EVA 2. A space-to-ground conference should occur to discuss any suit fit issues and unexpected challenges during EVA 1 that could impact the planned tasks for EVA 2, including asteroid sampling objectives.

Asteroid dust introduces contaminates to the habitable environment that are potentially hazardous to crew respiration and vision. During repress and post-EVA operations, the crew will remove asteroid dust from the suits with a combination of brushing, wipes, and the Orion vacuum. The EVA gloves will likely carry the most amount of dust contaminate, thus mission-specific handling and post-EVA stowage will be planned to minimize the contaminate risk. Due to the high likelihood the EVA glove handling protocol will require containment, a second set of gloves will be included in the EVA Suit Kit to support the second EVA.

F. Non-EVA Days

On the day between EVA 1 and 2, the crew will focus on suit refurbishment and reviewing changes to the EVA 2 plan. After the suit consumables have been refreshed, the crew can make any necessary suit sizing adjustments and perform a fit verification if needed. The crew will then reconfigure tools and tethers for EVA 2.

It may be necessary to leave some Orion-launched EVA tools in the ARV toolbox to avoid down mass limitations and maximize capability to return samples. This would have the added benefit of making these tools available should subsequent missions be able to utilize them. There will be a minimum complement of EVA tools required for return in the Orion. These tools are required to protect for a potential manual docking mechanism release contingency during undock.

G. EVA Abort

The EVA abort philosophy will be similar to that of ISS-based EVAs in that the Secondary Oxygen Pack will be sized to protect the crew in the event of a suit leak while they retreat to the Orion and repress the cabin. Further testing will refine the time required for the crew to reach the safety of the Orion from the farthest point on the asteroid; initial estimates suggest 30 minutes should be sufficient.

There are some unique risks associated with this mission. Unlike ISS and Shuttle EVAs, the ARCM will not have the up mass capability to provide redundant spares for all EVA suit hardware. Many failures could cause a loss of EVA capability. In the event of some Exploration PLSS failures, it may be prudent to proceed with a single person EVA while the second crew member remains on umbilical life support. This is a shift from recent mission risk acceptance in that the umbilical-based crew would be unable to conduct a rescue should the crew member on the asteroid become incapacitated. Based upon the mission cost and potential benefit of EVA objectives, this risk trade may be appropriate. The risk due to high energy micrometeoroid debris will be lower than EVAs in Low Earth Orbit (LEO). The asteroid sampling tasks will include inherent exposure to sharp rocks which increase the risk of glove or soft goods cuts. Therefore, follow-on trade studies will determine if there is any high priority EVA spare hardware which should be flown to protect the second EVA if damage is incurred during the first spacewalk. Additionally, LEO EVA crew members have had the capability to return to Earth in the event of a severe case of decompression sickness. Because of the inability to rapidly return to Earth, all decompression risk will need to be accepted or managed in-situ. Procedures developed for ISS EVA decompression sickness recovery will provide foundation for procedures to manage this risk in the ARCM. The issue of contingency accommodations for survival of multiple days suited in the event of a cabin depressurization is common to missions beyond LEO and must be considered for ARCM and either deemed "accepted risk" or mitigated with appropriate hardware.

H. Return Operations

On Flight Day 15, after five days at the asteroid, the crew will undock the Orion and depart. Prior to a successful separation, EVA suits and tools will remain configured to protect for a possible contingency EVA to manually separate the vehicles. If such an EVA were required, the duration would be approximately one hour. Orion Service Module gas is budgeted to protect for a contingency EVA of this type. Furthermore, it is likely that one of the EVA crew members would remain on umbilical life support throughout such an EVA as they would also be required to pilot the vehicle to a safe distance after separation. When undocking and separation are complete, the Orion commences the nine day transit back to Earth. The crew will stow EVA hardware and reconfigure the MACES to the entry configuration. On the day prior to re-entry, the crew will repress the cabin back to 14.7 psi using Service Module gas. On re-entry day, the crew will configure the cabin for entry before donning the Enhanced MACES.

III. EVA Functionality Kits

The EM-2 Orion does not support EVA. Reducing the crew complement from four to two provides additional internal stowage and mass capability. This recovered mass and volume allows for the addition of ARCM mission kits which will extend the capability of the Orion to support the ARCM flight. The fundamental design guideline for the kits is to provide the necessary functions self-contained within the kits with minimal changes to the baseline Orion EM-2 configuration and ground support equipment.

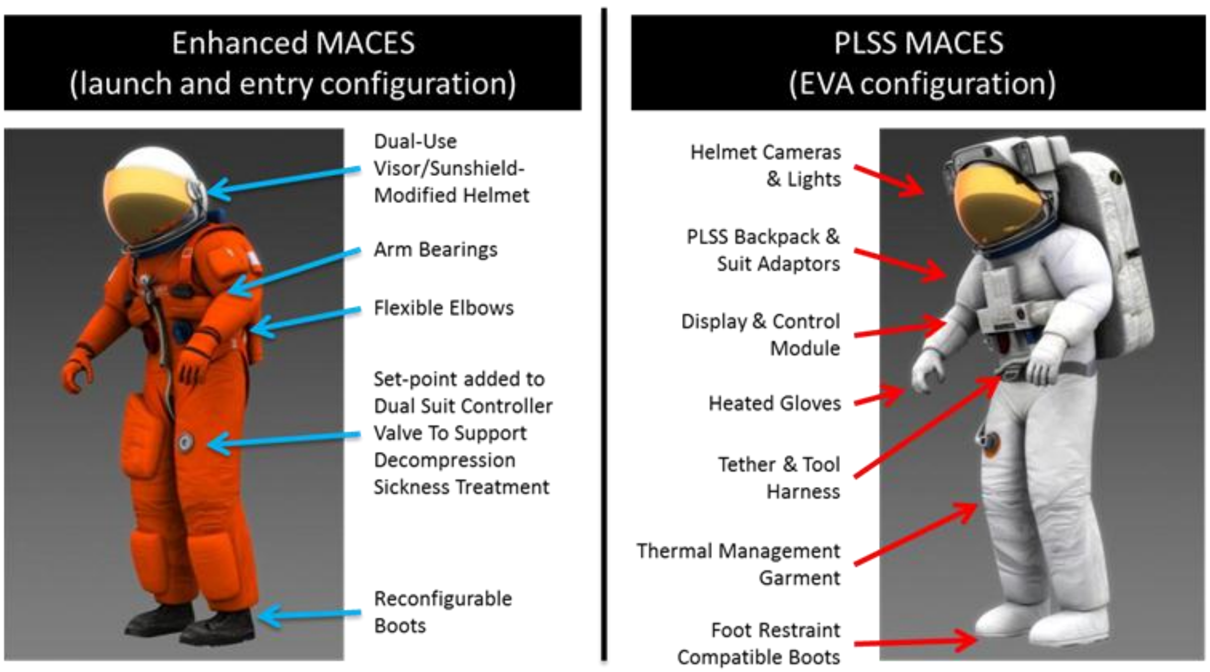

Figure 9. Side-by-side comparison of MACES configurations.

A. EVA Suit Kit

ARCM EVAs will use the Orion Baseline Modified Advanced Crew Escape Suit (MACES) enhanced to support 4-hour EVA operations. Some of the enhancements to the MACES will improve mobility and reduce fatigue to allow 4-hour EVAs. Figure 9 shows the differences between the launch & entry configuration and the EVA configuration of the MACES. Testing of the MACES has been conducted in the Neutral Buoyancy Laboratory (NBL) during 2013. These runs accomplished integration of a new suit into the underwater facility. Continued testing in 2014 is focusing on the feasibility of the MACES system to provide the necessary mobility for EVA operations. Included in this assessment are potential design modifications to improve the suit fit and mobility as well as prototype EVA Tools and Equipment enabling micro-gravity Geology Tasks. Reference AIAA-2014-TBD[5], "Asteroid Redirect Crewed Mission Space Suit and EVA System Architecture Trade Study" paper for further discussion of the EVA life support, pressure garment, and EVA Tools and Equipment. Initial NBL testing results suggest that the MACES suit is capable of performing representative tasks for asteroid missions for four hour duration EVAs (Figure 10).

Figure 10. NBL test of MACES feasibility.

B. EVA Servicing Kit

EVA operations require servicing equipment and consumables to support two planned EVAs. The servicing and checkout equipment will include the hardware required to recharge the suit and tool batteries, clean the suit interior, replace biomed sensors, and checkout Exploration PLSS components.

C. EVA Tool Kit

EVA tools will be launched on both the Orion and the ARV. The ARV will launch with as many EVA tools as feasible in the ARV EVA toolbox in order to preserve up-mass on the Orion. The EVA tools needed for contingency Orion EVAs, egress from Orion, translation from the Orion to ARV, and tools with thermal constraints that preclude long durations in the ARV EVA toolbox will be launched in the Orion. Specific EVA objectives defined after the science community has evaluated the data from the ARV capture survey will likely require unique geological tools that will be added to the Orion EVA Tool Kit.

The anticipated EVA Tools list is captured in Table 1; these tools are launched in the MPCV. The EVA Tools Kit mass is additional mass to the Orion baseline. ISS EVA Tools are the basis of estimate for the tethers, bags and thermal cover. Tools developed in support of Near Earth Asteroid analog testing provide the basis for estimates of the geological tools and the boom.

Table 1. MPCV stowed EVA Tools.

Suit-Worn EVA Tools (per crew member)
85-foot Safety Tether
2 Waist Tethers
2 Adjustable Equipment Tethers
4 Retractable Equipment Tethers
Mission EVA Tools (MPCV-Stowed)
Boom mounting bracket
Boom
Geological Tools Allocation
ORU Bags
EVA Hatch thermal cover
EVA Digital Camera (repurposed MPCV camera)

D. EVA Communication Kit

The EVA Communications Kit consists of a suit radio and a deployable antenna. The antenna may be standalone hardware or integrated into the translation boom launched in Orion. If the antenna is a standalone, deployable design, it will be placed outside the Orion hatch by the EVA crew members at the start of each EVA. The purpose of either antenna type is to relay the biometric, suit health & status, and voice & video data from the Exploration PLSS radio to the ground via the Orion S-Band system. The communication kit will include a bi-directional serial data connection to Orion and this study assumes a single relay antenna will be sufficient for EVA communication.

E. Sample Container Kit

The Sample Container Kit will provide stowage of the asteroid samples during the EVA, and both stowage and containment of samples for transport to the Earth-based curation site. The Sample Container Kit will be sized by the mass constraints on the Orion parachutes for abort/landing and the volume of samples the EVA crew is likely to collect in the time available.

The current approach is to provide the EVA crew the ability to collect surface samples using multiple small sample bags and core samples using core sample tubes. The sample bags and tubes will be collected in a single stowage bag during the EVA, and then the contents of the stowage bag will be transferred into the sample container box upon return to the Orion cabin. The sample container box will remain in the Orion cabin for return, maintaining segregation and containment of samples and protection against contamination of the samples by the IVA atmospheric environment both during landing and post-landing processing. Current assessments do not include temperature (cryogenic) accommodations for volatile management; contamination control would be addressed by sealed-vessel only and contain gasses as they evolve while the samples warm up.

IV. ARV design accommodations for EVA

The Asteroid Redirect Vehicle (ARV) will be outfitted to enable EVA. Features are necessary on the ARV to allow the Orion crew to access the ARV from Orion, to translate along the ARV toward the capture system, to store EVA tools, to translate from the ARV to the capture system and to access the asteroid within the capture mechanism. EVA translation and handling aids will be incorporated into the hardware prior to launch. EVA tools associated with asteroid sample retrieval will be pre-installed on the ARV. Stowing EVA Tools on the ARV reduces the mass impact to Orion, and locating the EVA tools in close proximity to the asteroid EVA worksites creates efficiencies in the EVA timeline.

Figure 11. Notional EVA transfer boom.

A. Booms and Attach Points

EVA crew members are assumed to access the ARV via a “Gap Spanner” translation boom launched on Orion. The ARV will host a mechanism to attach the telescoping boom carried on the Orion. The crew will place the boom out of the Orion hatch and guide the boom into the attach mechanism. A notional example of an EVA translation boom is shown in Figure 11. The EVA crew member will then attach the boom to the Orion. Once in place, the EVA crew member will translate across the boom and secure it to a locking mount device.

Two telescoping booms will be stowed on the ARV prior to launch. The booms will enable the EVA crew member to reach desired asteroid sample retrieval worksites without translating directly on the capture mechanism or the asteroid. The booms will be designed to be used independently or joined together in series. The end interface of the booms will be structurally compatible with each other, the ARV bus mounting location, and the EVA foot restraint. Rotational joints will be incorporated into the boom interfaces to allow access to multiple asteroid sample retrieval worksites from a single bus mounting point. Multiple boom mounting points will be attached to the ARV bus structure around the interface plane to the capture mechanism enabling access to multiple locations around the asteroid. Representative EVA worksites are shown in Figures 7 and 8.

B. Handrails

EVA equipment enables translation, handling, and EVA worksite access. Handrails will be mounted on the ARV to create a translation path beginning at the Orion access point, along the ARV bus toward the asteroid capture bag and EVA toolbox. The handrails could either be 24 inches long and spaced 24 inches apart, or continuous along a given translation path. Another set of handrails will be placed around the circumference of the ARV bus at the closest point to the capture system. Several boom attach points will be mounted near this ring of handrails, like the one shown in Figure 12. The two ARV launched booms will be installed to these attach points to allow crew accessibility to the asteroid.

Figure 12. EVA handrail and boom attach point.

C. Tool Stowage

Several items will be pre-positioned on the ARV in order to offload Orion mass. The pre-positioned items consist of two telescoping booms and a toolbox containing several EVA tools as detailed in Table 2.

The Telescoping booms are mounted on the outside of the ARV near the EVA Toolbox and proposed EVA worksites. An EVA Toolbox mounted on the ARV bus will be used as a stowage location for the EVA tools. Mounting the EVA toolbox along the primary translation path also serves to streamline the EVA timeline, shown in Figure 1. The Toolbox will have sufficient handling aids to allow the crew member access, and sufficient volume to allow independent retrieval and stowage of each tool independently from the others. Asteroid tools may include a hammer, core sampler or other sample retrieval devices. Other EVA tools may include equipment tethers used to restrain the asteroid tools and worksite restraint aids such as local tethers and foot restraints.

Table 2. EVA Tools Stowed on the ARV.

Geological Tools
Asteroid Sample Caddy
Gap Spanner
Boom
ORU Bags
Adjustable Equipment Tethers
Fish Stringer tether
Retractable Equipment Tethers
Boot Plate
Ascenders
Carabiners
Tent Flaps

IV. Conclusion

Initial assessments, as well as NBL MACES testing, demonstrate that an Orion vehicle, MACES suit, Exploration PLSS, and functionality kits are feasible for conducting EVA objectives on a captured asteroid.

As the Asteroid Redirect Mission (ARM) program continues in development, EVA operations will evolve. The potential addition of a habitable module with airlock capability will enable longer docked crewed missions (30-90 days) with more frequent, longer duration EVAs (i.e. multiple EVAs/week). An Exploration EVA suit could be worn by the crew, replacing the MACES worn for the first ARCM EVAs. Additional EVA worksites on the asteroid are anticipated to provide a diversity of samples to the scientific community. There is the potential that EV1 and EV2 will work simultaneously at separate worksites.

The ARM is sequenced as a strategic stepping stone within the NASA Capability Driven Framework. The Exploration EVA systems implemented for this mission will be designed to function for any other deep space, microgravity destinations, such as other Near Earth Asteroids and the moons of Mars. Asteroid EVA sampling and exploration techniques developed for ARM will benefit these same microgravity destinations.

References

[5]Blanco, R.A., Bowie, J.T., Watson, R.D., Kelly, C., Buffington, J., and Sipila, S.A., “Asteroid Redirect Crewed Mission Space Suit and EVA System Architecture Trade Study,” SpaceOps 2014, AIAA Pasadena, California (submitted for publication).