# Modular System to Enable Extravehicular Activity


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**The ability to perform extravehicular activity (EVA), both human and robotic, has been identified as a key component to space missions to support such operations as assembly and maintenance of space systems (e.g. construction and maintenance of the International Space Station), and unscheduled activities to repair an element of the transportation and habitation systems that can only be accessed externally and via unpressurized areas. In order to make human transportation beyond lower Earth orbit (LEO) practical, efficiencies must be incorporated into the integrated transportation systems to reduce system mass and operational complexity. Affordability is also a key aspect to be considered in space system development; this could be achieved through commonality, modularity and component reuse. Another key aspect identified for the EVA system was the ability to produce flight worthy hardware quickly to support early missions and near Earth technology demonstrations. This paper details a conceptual architecture for a modular EVA system that would meet these stated needs for EVA capability that is affordable, and that could be produced relatively quickly. Operational concepts were developed to elaborate on the defined needs, and to define the key capabilities, operational and design constraints, and general timelines. The operational concept lead to a high level design concept for a module that interfaces with various space transportation elements and contains the hardware and systems required to support human and telerobotic EVA; the module would not be self-propelled and would rely on an interfacing element for consumable resources. The conceptual architecture was then compared to EVA Systems used in the Space Shuttle Orbiter, on the International Space Station to develop high level design concepts that incorporate opportunities for cost savings through hardware reuse, and quick production through the use of existing technologies and hardware designs. An upgrade option was included to make use of the developing suitport technologies.**


## Nomenclature

| | | |
|---|---|---|
| AIA | = | Advanced Inflatable Airlock |
| CDIP | = | Common Docking Interface Plate |
| DSH | = | Deep Space Habitat |
| ECLS | = | Environmental Control and Life Support |
| EET | = | external equipment pallets |
| EVA | = | human extravehicular activity |
| GEO | = | Geosynchronous Earth Orbit |
| GNC | = | Guidance, Navigation, and Control |
| HST | = | Hubble Space Telescope |
| iDSS | = | international Docking System Standard |
| IVA | = | intravehicular activity |
| LEO | = | low-Earth orbit |
| LIDS | = | low-impact docking system |
| MMSEV | = | Multi-Mission Space Exploration Vehicle |
| MPCV | = | Multi-Purpose Crew Vehicle |
| NEA | = | near-Earth ateroid |
| Ops Con | = | Operational Concept |
| ORU | = | On-orbit Replacable Unit |

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|---|---|---|
| PLSS | = | Portable Life Support System |
| REM | = | Robotics and EVA Module |
| SPE | = | solar particle event |
| TRA | = | Telerobotic Activity |

## I. Introduction

Whenever humans have endeavored to explore areas without a breathable environment, whether it be down in the ocean depths or up in the depths of space, extravehicular activity has a role to play; including both telerobotic activities (TRA) and suited human extravehicular activity (EVA).

As NASA looks forward to sending humans farther away from Earth, we will have to develop a transportation architecture that is highly reliable and can be operable without the usual almost constant communication with the ground. These aspects tend to require more mass and volume. Therefore, it is essential to incorporate as much efficiency in the architecture by making use of interoperability, common interfaces, and modularity.

The Robotics and EVA Module (REM) was developed in response to a posed question: what can be done to incorporate EVA capability on a Multi Purpose Crew Vehicle (MPCV) such that a short exploration mission can be performed without a specialized vehicle like the Multi Mission Space Exploration Vehicle (MMSEV).

The REM takes a modular approach to incorporating EVA capability to space transportation elements such as the MPCV or Deep Space Habitat (DSH). This specialized module should allow for optimization of crew interfaces and subsystem reliability. Meanwhile, the overall transportation architecture would be more efficient by making use of this module on various elements.

## II. The Mission

The REM was developed with three operational concepts (Ops Cons) in mind:

1. Satellite repair in a geosynchronous Earth orbit (GEO)
2. EVA excursion at a near Earth asteroid (NEA)
3. EVA troubleshoot and repair while in transit

### A. Satellite Repair

The REM would have to perform basic operations that are common to every mission, such as being launched from Earth. These basic operations are shown in Figure 1. The type of EVA mission is shown as options in the model.

The REM concept was base on a satellite repair mission where crew are transported to and from the Hubble Space Telescope in a single launch to assess repair possibilities and perform maintenance, upgrade and repair activities for Hubble Life Extension. This mission involves telerobotic manipulation of the satellite and servicing equipment as well as extravehicular crewed operations.

On Flight Day 1, the REM is docked to the MPCV, and the crew oversees the checkout of the EVA and TRA systems. These checkouts will be largely autonomous. Data will be transmitted to the crew for review to ensure all parameters are within nominal parameters.

Starting on Flight Day 2, the entire MPCV will be kept at a pressure of 10.2 psi. Doing so will decrease the amount of time required for pre-EVA denitrogenation, or prebreathe, which is needed to mitigate decompression sickness (i.e., the Bends).

The crew will perform functional checks of the TRA systems; this may include movement of the robotic arms and FSS'. The crew will also perform manual checkout of the EVA suits.

The robotic arms will be used to inspect the MPCV exterior surfaces. Imagery experts in Mission Control, Houston, will evaluate the collected data in near real-time, to determine the health of the MPCV.

On flight day three, the MPCV will arrive within at the telescope. One of the robotic arms will be used to capture a grapple fixture on the telescope and then will carefully place Hubble atop its Common Docking Interface Pallet (CDIP), mounted to the side of the PRESM in view of the MPCV crew. NOTE: proximity will be dependent on the reliability and accuracy of the MPCV Guidance, Navigation and Control (GNC) system and the total length of the robotic arm.

On each EVA day, the two designated EVA crewmembers will perform spacewalks to extend the Hubble Space Telescope's life and leave it with new equipment that will improve the data that it is able to send back to scientists here on Earth. The designated IVA crewmember(s) will act as the intravehicular officers, or spacewalk choreographers, for those working outside, and will operate the robotic arms as needed. The robotic arms may also be controlled by the EVA crew.

In previous HST repair missions, crews perform free float worksite tasks. With two arms, the crew can each make use of telerobotic positioning; or a combination of EVA crewmember positioning and ORU/tools retrieval may be performed. The EVA crew will need to rest for 1 day between EVA; but TRA may continue to reposition the HST, preposition ORU's, etc.

Once the mission is complete, the REM is transported and docked to an on-orbit asset, e.g. the ISS. This would preserve the system for a subsequent mission.

### B. NEA Excursion

During a NEA EVA excursion, the MPCV will maneuver close to the NEA. Depending on the movement of the NEA relative to the MPCV, a robotic arm on the REM may be used to anchor the MPCV to the NEA. Another option is to perform proximity operations with the crew on the end of the robot arm. Due to the risk of damage to the MPCV in this scenario due to dust or ejecta form the NEA, it is recommended that separate excursion vehicle, such as the MMSEV, be used for this type of mission.

### C. EVA troubleshoot and repair while in transit

Due to the small size of the MPCV, umbilical based EVA with an EVA compatible flight suits would be the simplest approach to providing EVA contingency EVA capability. However, the REM could be utilized to provide contingency EVA capability if it part of the mission architecture. During deep space missions, the REM could be installed on the deep space habitat (DSH) to provide contingency EVA capability. The same EVA

### D. Requirements

Based on this ops con, the key capabilities of the REM are as follows:

- Provide telerobotic capability
  - Capture and tether/dock to external bodies (e.g. satellite, NEA, etc)
  - Perform science objectives (e.g. deploy science packages, collect samples)
  - Support human extravehicular activity (EVA)
- Provide EVA capability
  - Provide a means for EVA crew to transition between the crew module and space
  - Provide EVA Suit recharge capability
  - Allow for emergency ingress:
    - Retrieval of an incapacitated crewmember
    - Rapid ingress and airlock repress in case of suit failure
    - Rapid ingress and radiation protection in case of solar/electronic particle flare event
- Provide external stowage capability for EVA and telerobotic activity
  - Sample storage
  - EVA tools & equipment
  - Robotic tools & equipment (e.g. varied end effectors)
  - Mission specific payloads (e.g. Satellite ORUs, NEA surface science packages, etc)

### E. Ground Rules and Assumptions

The REM will be attached to a Base Element that will provide GNC, propulsion, life support and recharge consumables, and that will telemeter data to other elements.

The REM receives pressurized consumables from another Element; this may be via a direct line to the Base Element or via rechargeable pressurized oxygen and water containers .

EVA will be performed with autonomous life support, power, data and communications capability: i.e., REM based EVA will not be umbilical based.

The REM will not have the capability to propel itself other than mechanically via the robot arms.

It is assumed that the REM will support all EVA related activities including: donning, pre-breathe, suit checkout, post-EVA doffing and suit clean-up and suit oxygen, water and power recharge. EVA will be performed with autonomous life support, power, data and communications capability (i.e. the REM will not incorporate an umbilical interface).

## III. Concept

The REM provides the infrastructure necessary for extravehicular human and robotic operations to support NEA exploration, transportation system maintenance and repair, transportation of equipment and user payloads about another element, anchoring or tethering of external bodies (e.g. NEA or satellite) to another element, extraction of cargo from another element, and deployment of payloads in Earth orbit for independent entry.

The REM serves as the primary structural interface for robotic and robotically assisted EVA. It functions mechanically as a passive vehicle to dock with an iDSS interface. The Platform includes the structural interface to the Robotic Arm, foot restraints for platform EVA, and power and data interfaces. The Platform also provides a capability to release payload in low-Earth orbit (LEO) to enable independent Earth entry. The Platform integrates tether interfaces strong enough to keep the docked element (e.g. MPCV or DSH) tethered to another body (e.g. NEA or satellite).

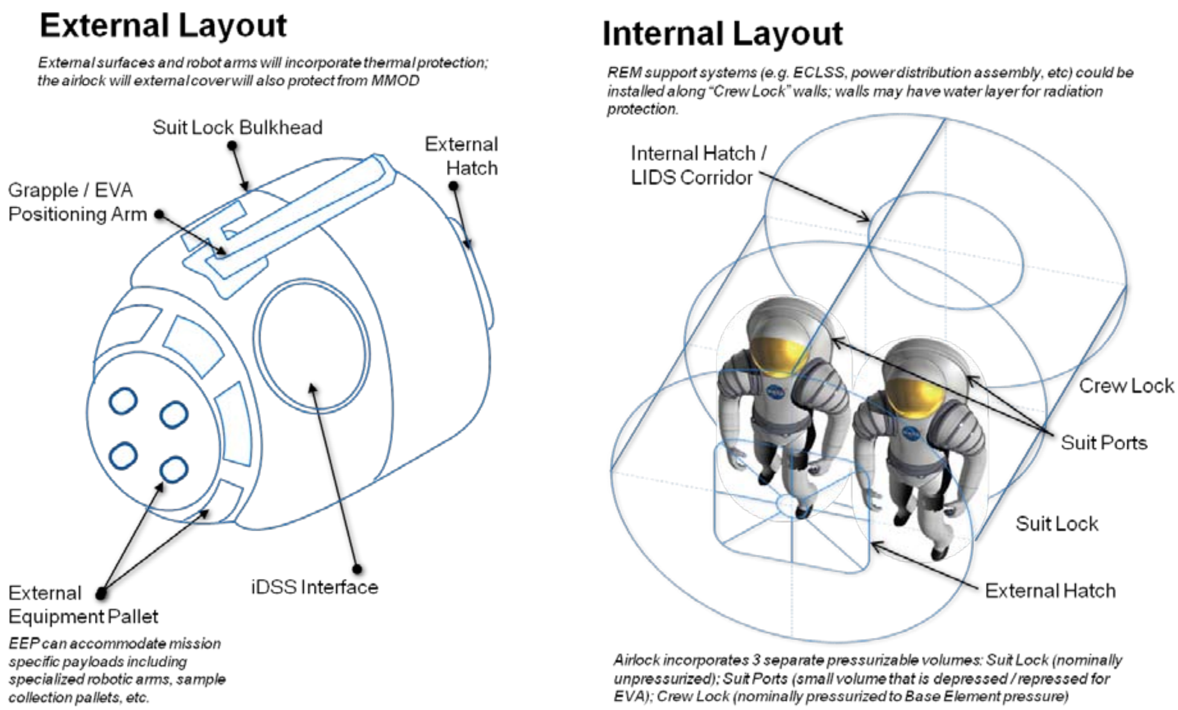


**Figure 1. REM Physical Layout.** The REM concept considers a spheroid structure with an iDSS interface hatch, an external equipment pallet, a couple of robotic arms (1 not included in visualization) and an external hatch for EVA crew egress/ingress. The internal layout shows an option to incorporate a suitport bulkhead.

### A. Telerobotics System

The Telerobotics System will see extensive action throughout the mission to perform telerobotic inspection and reconfiguration operations and to support EVA operations.

#### *1. Robotic Arms*

The length of the robotic arms will determined by the mission. The robotic arms will provide maneuvering capability. For example, the robotic arm may be used to capture and dock a satellite to the integrated REM/MPCV at the Common Docking Pallet (CDP) or, with integrated footrestraints, the the robotic arm may be used to position spacewalkers and tools in close proximity to worksites. The arms may also be used to survey the outside surfaces of the MPCV for signs of damage that may have occurred during the launch and climb to orbit; or survey a NEA prior to EVA.

#### *2. External Equipment Pallet (EET)*

This REM concept includes two external equipment pallets (EET). The EET will be outfitted with satellite capture mechanisms, EVA tools and equipment, handrails, unpressurized storage, foot restraints, etc. The EET functions similarly to the Shuttle Flight Support System, serving as a high-tech "lazy Susan" that can be rotated and tilted to present the desired part of the interfacing systems forward for easy access by spacewalkers, and to offer the best viewing angles for cameras and crew members inside the MPCV. It also provides all electrical and mechanical interfaces between the vehicle and the interfacing systems.

One EET will be outfitted with the system required to attach to an external body. For HST repair, a Common Docking Interface Plate (CDIP) will interface with the HST Soft-Capture Mechanism to mate the HST to the integrated REM/MPCV. A special capture device may be mounted for GEO satellite repair. For NEA exploration, a device will be mounted that will allow the REM to auger into the NEA ground and anchor the REM/Base Element to the NEA.

The other EET will be used to store EVA tools and equipment, science payloads, ORUs, areas for storing samples, or any items required for the specific EVA sequence.

*3. Avionics*

The Telerobotic systems will be outfitted with several cameras and sensors to monitor TRA operations. Telemetry will be sent to the intravehicular activity (IVA) crew and the ground for evaluation of system health and to ensure that no damage is incurred on any system. Video imagery of the HST TRA and EVA operations will also be collected to support public affairs communications; a camera will be installed on each robotic arm.

An option to control the REM robotics from the suit should be considered; though EVA operation could also be implemented with manual controls either mounted on or tethered to these systems.

## B. Extravehicular Activity Systems

Many HST repair operations will be performed manually by astronauts through a series of spacewalks, or EVA. The EVA System includes the elements necessary to protect crewmembers and allow them to work effectively in the pressure and thermal environments that exceed the human capability. The EVA System includes the pressure suits, autonomous life support systems, umbilicals, EVA tools and mobility aids, EVA-specific vehicle interfaces, EVA servicing equipment, suit avionics, and the EVA transition airlock.

*1. Airlock*

The airlock mechanically interfaces the REM to the MPCV via an iDSS interface. This interface provides all consumables interfaces between the REM and the MPCV, including oxygen, water, power, data/telemetry and communications.

The airlock is sized to accommodate two fully suited flight crew members simultaneously (approximately 1.5m (5 ft) in diameter by 2.1m (7 ft) in length). Support functions include airlock depressurization and repressurization, extravehicular activity equipment recharge, liquid-cooled garment water cooling, EVA equipment checkout, donning and communications. The EVA gear, checkout panel and recharge stations are located on the internal walls of the airlock.

Two hatches are mounted on the airlock. The inner hatch isolates the airlock from the MPCV crew cabin. The outer hatch isolates the airlock from space when closed and permits the EVA crew members to exit from the airlock when open. The two airlock hatches open toward the primary pressure source, the orbiter crew cabin, to achieve pressure-assist sealing when closed.

The Airlock includes Eenvironmental Controls and Life Support (ECLS) functionality, including depressurization, repressurization and air circulation. An EVA Suit Servicing Panel will be included in the airlock. This panel provides recharge capability to the spacesuit with high-pressure oxygen, cooling water and power. It is assumed that the consumables needed to support these functions will be received from the MPCV.

To assist the crew member before and after EVA operations, the airlock incorporates handrails and foot restraints to assist the crew before and after EVA operations.

The internal layout visualized in Figure 1 shows use of suitport technology. This would provide an opportunity for incorporating two pressurizable volumes within the REM. Having two pressurizable volumes allows for redundant ingress capabilities, which increases the overall safety of EVA. This would also simplify suit and system maintenance activities. The suitport manifold would however increase the mass and volume of the REM as compared to a single chamber airlock. A trade study would have to be performed to determine the optimal layout.

*2. Extravehicular Activity Tools and Equipment*

EVA tools and equipment will include such things as tethers, vice grips, mobility aids, and probes. These tools will be a mix of legacy and customized tools. Generic tools that could be used to perform tasks such as turning a bolt or cutting the wire are straightforward and can be largely reused from legacy programs. Other specialized tools, such as a rigidizable tether or foot restraints customized for the next generation suit or task specific tools may be developed.

## IV. Resource Utilization Estimates

A prototype Advanced Inflatable Airlock (AIA) was developed as part of the Reusable Launch Vehicle technology program, This airlock would provide 226 ft3 of internal volume when erected, a 50% increase over the shuttle airlock. The developers projected the basic mass of the airlock was projected by the developers to be 483 kg (1064 lbs), including a 20% mass margin.

The Exploration Systems Architecture Study (ESAS) baseline involved the use of the low impact docking system (LIDS), with a design mass of 138 kg (304 lbs) (again with a 20% margin.)

This system, comprising the manipulator, end effector capable of using RMS grapple fixtures, and launch restraints on the EVA pallet would have a mass of 363 kg (800 lbs).

Addition of a pair of Ranger-class dexterous manipulators and associated support equipment will add 209 kg (460 lbs).

The entire gas consumables systems to support Six 2-crew EVA (gas plus bottles plus 20% design margin) would then have a total mass of 198 kg (437 lbs).

LSS Airlock Module – 1000 kg

| Item | Mass | Source |
|---|---|---|
| EVA Suits | 220 kg (485 lbs) | AIAA 2006-7390 |
| Airlock | 1000 kg (2205 lbs) | SARDv4.2 |
| LIDS | 130 kg (287 lbs) | AIAA 2006-7390 |
| Two dexterous manipulators | 200 kg (441 lbs) | AIAA 2006-7390 |
| One large manipulator | 350 kg (772l bs) | AIAA 2006-7390 |
| Two equipment pallets | 300 kg (662 lbs) | (about 2 x LIDS i/f) |
| | 2200 kg (4850 lbs) | |

## V. Key Trades:

### A. Radiation Protection

The REM must provide the EVA crew quick access to radiation protection in case event notification is received during an EVA. It may be that all Base Elements will have built-in radiation protection and the integrated stack must all for quick ingress. The REM may also be outfitted with radiation protection. A trade should be performed to determine the best means of radiation protection for both IVA and EVA crew given the following options:

- REM airlock as a common radiation haven for both IVA and EVA crew
- REM airlock as a radiation haven for only EVA crew
- A deployable device that can shield crew at the EVA worksite
- Quick ingress capability to the Base Element with integrated radiation protection

### B. Cross-Architecture Use

This Element was developed to establish EVA and robotics capability on the MPCV to support DRMs that do not include an MMSEV. It is assumed that each vehicle will have to incorporate some level of contingency EVA capability; this would require, at a minimum: a means of egress, suit interfaces, and portable life support (whether autonomous as with a portable life support system (PLSS) or via an umbilical). A trade study should be performed to determine whether use of the REM to provide tele-Robotic and EVA capability across the architecture (e.g. for DSH and SEV) would be beneficial from a safety, cost, and mass perspective.

### C. Use of Inflatable Structures

The structural design of this element is still to be determined. Inflatable rigidizable structures are being studied due to the possible of greatly reducing mission mass and volume. A trade should be performed to determine where inflatable structure technology can be integrated into the REM design given the following options:

- Building the suit-lock as an inflatable structure could help minimize up-mass and volume; the suit-lock does not have to be as robust as the crew-lock as it will not see as many pressure cycles and will not have to support load bearing structures like the robotics elements and the vehicle interface
- Adding an inflatable element prior to the bulkhead could be a means of establishing a habitable volume for prolonged pre-breathe or radiation event campout
- Robotics platform, vehicle interface and suit port bulkhead are load bearing structures and may, therefore, have to be metal/rigid structures

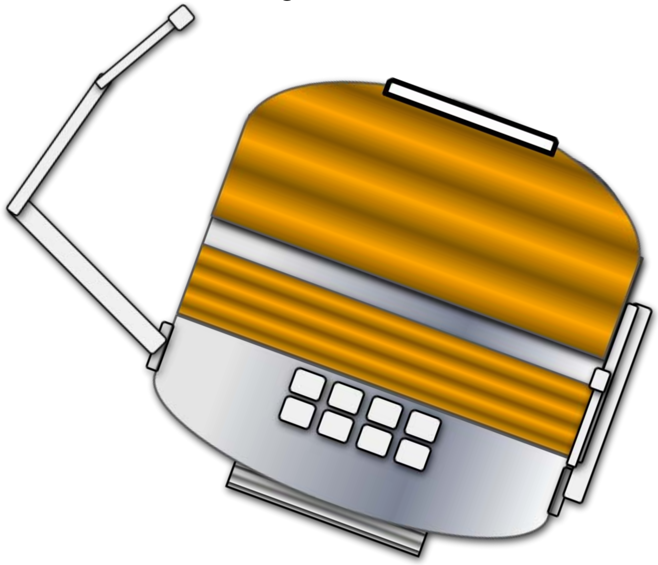

**Figure 2. Use of Inflatables in REM Construction.** Notional figure showing inflatable technology used to provide the majority of the REM structure with rigid metal structure used to support the robotic elements.

## VI. Conclusion

{Words on applicability}. MMSEV allows for more flexible mission objectives. REM is tied to a primary vehicle and is better suited to contingency EVA and short local EVA, including in-space assembly and repair. {Restate benefits of "EVA in a can" and discuss forward work}

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## References