

The Multi-purpose Crew Vehicle European Service Module: a European Contribution to Human Exploration

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This paper provides an overview of the system and subsystem configuration of the MPCV European Service Module (ESM) at Preliminary Design Review (PDR) stage as well as its perspectives of utilisation within the global space exploration endeavour. The MPCV ESM is a cylindrical module with a diameter of 4500 mm and a total length – main engine excluded – of 2700 mm. It is fitted with four solar array wings with a span of 18.8 m. Its dry mass is 3.5 metric tons and it can carry 8.6 tons of propellant. The main functions of the European Service Module are to bring the structural continuity between the launcher and the crew module, to provide propulsion to the MPCV, to ensure its thermal control as well as electrical power and to store water, oxygen and nitrogen for the mission. The current agreement foresees the development and production by Europe of one flight model, with an option for a second one. This module will be assembled in Europe and delivered to NASA in 2016. It will be used for a flight of the MPCV Orion in December 2017.

Nomenclature

ACS = Auxiliary Control System
ATCS = Active Thermal Control System
BIVP = Bilateral Integration & Verification Plan

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<i>CM</i>	=	Crew Module
<i>CMA</i>	=	Crew Module Adapter
<i>CSM</i>	=	Crew and Service Module
<i>CSS</i>	=	Consumable Storage System
<i>ESA</i>	=	European Space Agency
<i>ESM</i>	=	European Service Module
<i>HDRS</i>	=	Hold Down and Release System
<i>LAS</i>	=	Launch Abort System
<i>MDPS</i>	=	Micrometeoroid/Debris Protection Shield
<i>MMOD</i>	=	Micrometeoroid/Orbital Debris
<i>MPCV</i>	=	Multi-Purpose Crew Vehicle
<i>OMS-E</i>	=	Orbital Manoeuvring System Engine
<i>PIE</i>	=	Propulsion Isolation Equipment
<i>R&R</i>	=	Retention & Release
<i>RCS</i>	=	Reaction Control System
<i>SA</i>	=	Spacecraft Adapter
<i>SADM</i>	=	Solar Array Drive Mechanism
<i>SAJ</i>	=	Spacecraft Adapter Jettisoned panels
<i>SAW</i>	=	Solar Array Wings
<i>SLS</i>	=	Space Launch System
<i>TVC</i>	=	Thrust Vector Control

I. Introduction

Under an agreement between NASA and ESA, ratified in December 2012, NASA's new Orion Multi-Purpose Crew Vehicle (MPCV) for human space exploration missions will include a European Service Module based upon the design and experience of ESA's ATV (Automated Transfer Vehicle), the supply craft for the International Space Station (ISS). ESA's industrial prime contractor for ATV, Astrium Space Transportation of Bremen, Germany, will lead a European industrial consortium to develop this vehicle on behalf of ESA and will work closely with NASA's MPCV Orion US industrial prime contractor Lockheed Martin Space Systems.

ESA will supply an ESM for the initial launch of Orion towards the Moon. During this uncrewed mission, called EM-1, and scheduled for 2017, Orion will be launched by the first Space Launch System (SLS) launcher and perform a mission in the vicinity of the Moon, before landing back on Earth.

The feasibility studies started in 2011 and two reviews, the System Requirements Review (SRR) and the System Definition Review (SDR), have been carried out in 2012. This paper presents the current configuration of this European Service Module at the end of first semester of 2013, i.e. before the Preliminary Design Review of the Module is performed during fall 2013.



Figure 1. Artist impression of the MPCV with the European Service Module attached to the upper stage

II. Objectives and missions of the MPCV

The Orion MPCV is the spacecraft that NASA intends to use to send humans and cargo into space beyond low earth orbit and to return them safely to earth. The first exploration mission is planned as an uncrewed beyond Earth orbit (lunar flyby) mission for system qualification at the end of 2017. The second exploration mission is planned as a crewed beyond Earth orbit mission to a higher lunar orbit no later than the end of 2021.

The MPCV is being developed for crewed missions to cis-lunar space, asteroids, and then to Mars. The capsule is also planned as a backup vehicle for missions to the International Space Station (ISS). It will be launched by the NASA-developed Space Launch System (SLS).

The MPCV resembles its Apollo-era predecessors, but its technology and capability are more advanced. The spacecraft's life support, propulsion, thermal protection, and avionics systems are designed to be upgradeable as new technologies become available.

The MPCV's Crew Module is larger than Apollo's and can support up to four crew members for spaceflight missions. The Service Module fuels and propels the spacecraft as well as stores oxygen and water for astronauts. The Service Module's structure is also being designed to provide locations to mount scientific experiments and cargo.

The MPCV missions are:

- The first test flight is planned for 2014 with a Delta IV launch vehicle that will launch the MPCV CM into a high elliptical orbit to demonstrate high-speed atmospheric Earth re-entry. This flight test does not include the ESM.
- Exploration Mission-1 (EM-1) in 2017 is planned to be an uncrewed lunar flyby mission on a free return trajectory, lasting approximately one week in duration. The trajectory is designed to achieve a high speed atmospheric entry to demonstrate the MPCV entry, descent, and landing systems. This will be the first flight of the ESM.

- Mission description
 - Uncrewed circumlunar flight – free return trajectory
 - Mission duration ~7-10 days
- Mission objectives
 - Demonstrate integrated spacecraft systems performance prior to crewed flight
 - Demonstrate high speed entry (~11 km/s) and TPS prior to crewed flight
- Spacecraft configuration
 - Orion “Block 0 BEO”
- Launch vehicle configuration
 - SLS Block 0
 - Interim Cryo Propulsion Stage
- Launch site
 - KSC LC-39B

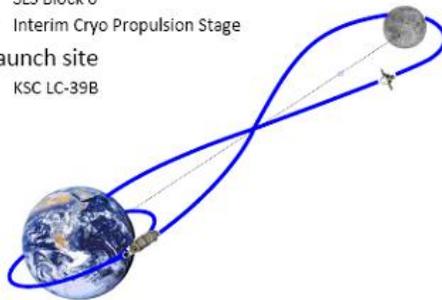


Figure 2. MPCV Exploration Mission EM-1 (Courtesy NASA).

- EM-2 is planned to be a crewed lunar orbital mission, spending several days in lunar orbit before performing a Trans-Earth Injection (TEI) burn to begin the return to Earth.

- EM-2 mission design is tailored to fit within Orion design capabilities provided by ISS and Lunar Surface functional and performance requirements

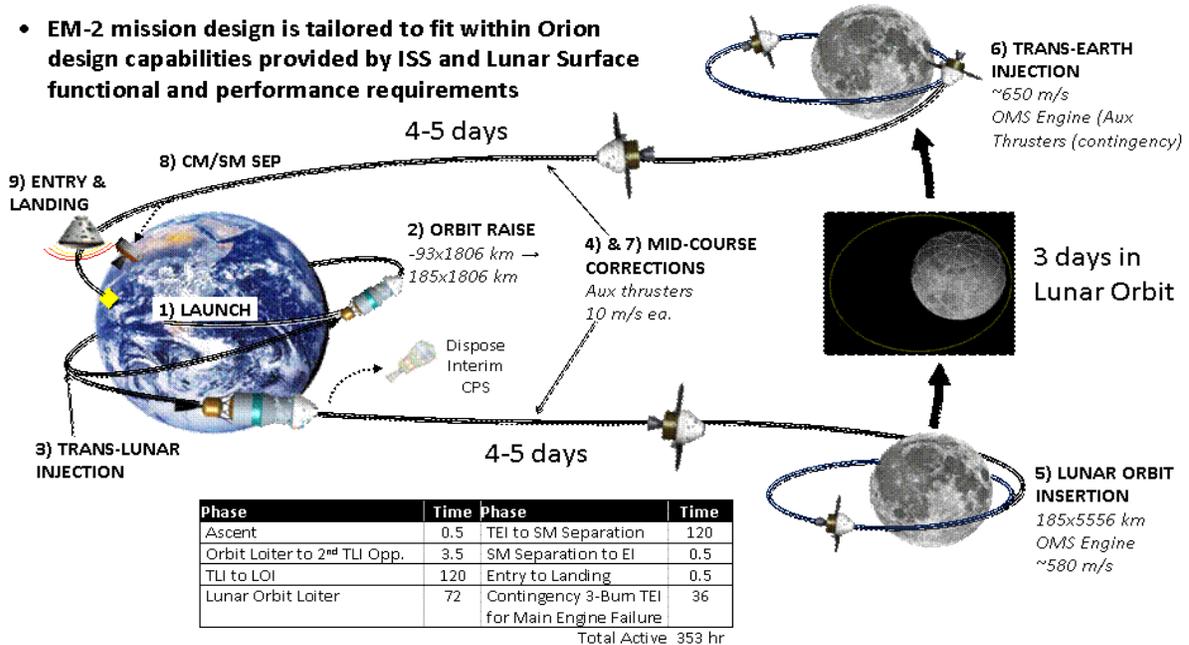


Figure 3. MPCV Exploration Mission EM-2 (Courtesy NASA).

III. Description of the MPCV

The MPCV configuration consists of:

- Crew Module (CM)
 - European Service Module (ESM)
 - Crew Module Adapter (CMA)
 - Spacecraft Adapter (SA)
 - Spacecraft Adapter Jettisoned Fairings (SAJ)
 - Launch Abort System (LAS).
- The Service Module (SM) refers to the combined CMA + ESM + SA + SAJ

The Crew Module and European Service Module will physically interface via an interface ring called the Crew Module Adapter (CMA). The ESM is attached to the CMA for the duration of the mission. Just prior to the Earth's orbit entry, the CMA separates from the CM for CMA/ESM disposal and the CM performs final re-entry and landing operations.

NASA is responsible for development of the CM, CMA, SA, SAJ, and LAS elements of the MPCV. The CMA provides the structural, mechanical, electrical, and fluid interface between the CM and ESM. In addition, the CMA houses communication equipment, sublimators for thermal heat rejection, and power and data control/interface electronics. NASA will also be responsible for the spacecraft adapter (SA) and the spacecraft adapter jettisoned fairings (SAJ). The SM is enclosed by three spacecraft adapter fairing panels which provide a partial load path from the CMA to SA but also protect the solar arrays, radiators, and thrusters from launch and ascent loads. The fairings may be jettisoned during the ascent phase or following main engine cut-off of the launch vehicle.

The Spacecraft Adapter (SA) provides the interface to the launch vehicle during launch. During launch and ascent, the ESM and SA will be enclosed by the SAJ. The SA attaches to the aft end of the ESM to the Launch Vehicle and includes the structural interface, separation mechanisms, and umbilical connectors for communication between the launch vehicle and the MPCV Spacecraft. At launch vehicle burnout, the MPCV Spacecraft separates from the SA at the ESM/SA separation plane.

Figure 4 presents the overall MPCV vehicle elements including the ESA-provided ESM. All other elements are provided by NASA.

IV. Overall technical concept of the MPCV ESM

The ESM, as an integral part of the MPCV that provides five major system functionalities to the MPCV.

These are:

- 1) Provide structural continuity between the launcher and the Crew Module
- 2) Provide thrust after upper stage/launch vehicle separation;
- 3) Generate electrical power;
- 4) Regulate heat for the life support and avionics equipment;
- 5) Store potable water, oxygen, and nitrogen and deliver them to the Crew Module.

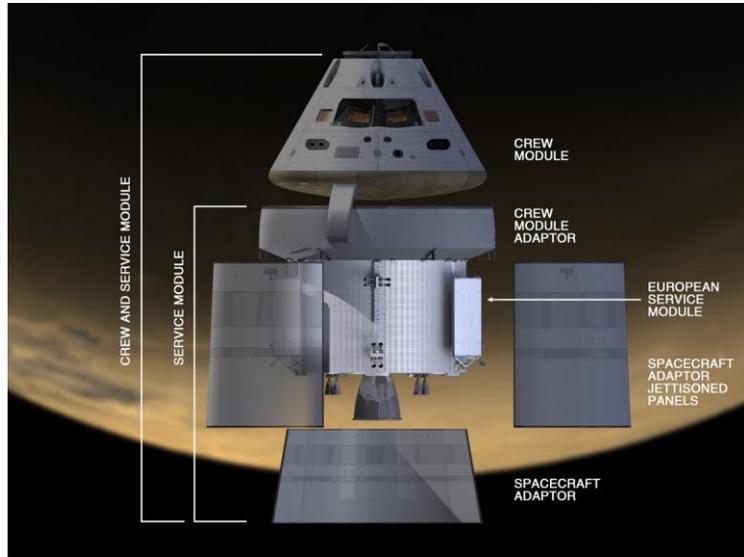


Figure 4. MPCV Vehicle Elements (Courtesy NASA).

The solar arrays and their respective gimbal control assemblies are attached to the ESM. The ESM houses the main engine and engine thrust vector control, the Reaction Control System (RCS) and auxiliary thrusters, and the fuel, oxidizer, and pressurant tanks for the propulsion system. Thermal radiators surround the propulsion tanks and are attached to the ESM structure. Like the (CM and CMA, the ESM's passive thermal control design incorporates multi-layer insulation (MLI) blankets, thermal coatings, and micrometeoroid/orbital debris (MMOD) shielding.

The ESM may provide additional unpressurized cargo volume (0.57 m³/382 kg for Lunar mission and 2.92m³/600 kg for ISS mission) and other resources on select missions to accommodate science, engineering demonstrations, development test objectives, and to deploy lunar infrastructure equipment during the cruise and orbital phases of its missions. This volume provides electrical power distribution, network access for command and control interfaces, as well as supporting structures and retention mechanisms.

The functions of the ESM are controlled and monitored by specific electronic units. These controller units are connected via the On-board Data Network (ODN) to the Vehicle Management Computer (VMC) and the Back-up Flight Control Unit (BFCU) residing in the Crew Module.

The specified maximum mass budget for the ESM is 12848 kg at lift-off for a lunar mission (7077 kg for LEO mission), a figure which includes the capacity to carry 8602.4 kg of usable propellant for the same lunar mission (3521 kg for LEO mission).

A. Physical architecture

The ESM is a cylindrical unpressurized module which interfaces at its bottom to the SA and at its top to the CMA. The Orbital Manoeuvring System Engine (OMS-E) main engine protrudes into the SA. Equipment on the tank platform is also allowed to protrude into the CMA. The total height of the ESM is 4.0 meters. The diameter of the main body is 4.086 m (5.228 m with external equipment). The Solar Array Wings (SAW) give the module a total span of 18.8 m.

The cylindrical shape is defined by the external radiators which enclose the body of the ESM. The function of the radiators is twofold, i.e. to radiate heat, and to serve as the first barrier of the Micrometeoroid/Debris Protection Shield (MDPS). Mounted to the back side of the radiators are Nextel and Kevlar blankets which serve as the second

barrier. The externally mounted Reaction Control System Pods and Solar Arrays must be designed such that these respect the MPCV SAJ geometrical interface.

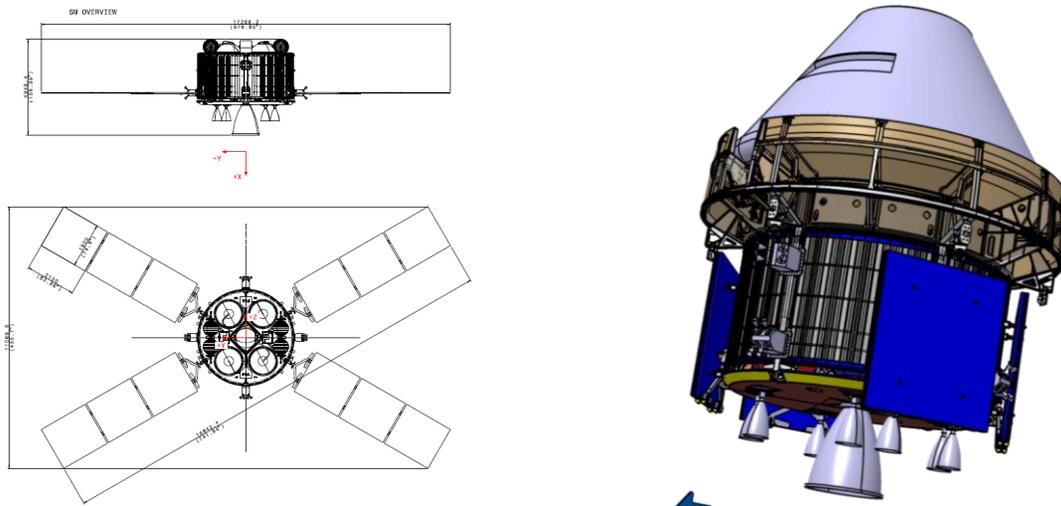
The internal accommodation of the ESM sub-system equipment is highly dependent to the primary structure. Together with the SAJ, the primary structure transfers the loads between the launcher and the launch stack made of the ESM, CMA, CM, and LAS.

The structure consists of six longerons located at 60 degree spacing which are aligned with the CMA longerons and the CM Retention and Release (R&R) mechanisms. These longerons are connected to each other via the tank platform, the lower platform, and the internal shear web assembly. The Shear Web Assembly provides for seven separate bays for accommodation, six located circumferentially about the central bay.

The pressurant tanks are accommodated in the center bay. The central bay is also used to provide a channel to pass the major fluid lines between upstream and downstream tanks, as well as harness elements which pass undisturbed from the top of the ESM to the base. This eliminates the need for many cut outs in the shear panel assembly. The four largest bays are used for the accommodation of the propellant tanks which dominate the available volume. The remaining volume provides accommodation to the avionics equipment, consumable storage system (CSS) water tanks, harnessing and tubing.

The top surface of the ESM is dominated by the protruding tank domes for the propellant systems, one of the helium pressure tanks, the four tanks for Oxygen and Nitrogen, and the pump packages for the active cooling system. These elements protrude into the CMA, while maintaining a specific minimum distance to the CM Heat Shield. For these elements above the tank platform, the CMA provides the MDPS protection.

The lower surface is dominated by the OMS-E, which serves as the main engine of the ESM, and the eight auxiliary thrusters. The remaining surface area is covered by a metallic MDPS bumper shield. Within the lower platform, a panel will be incorporated through which the Unpressurized Cargo (UPC) is installed, and optionally ejected.



V. MPCV ESM Subsystems

A. Structure

The functions of the structure subsystem are:

- For the primary structure: transmit the SLS launch loads to the upper composite composed of the CMA, the CM, and the LAS, then support ESM inertial loads generated by ESM-loaded equipment, mainly the propulsive ones.
- For the secondary structures: transmit the SLS launch loads to the ESM equipment from primary structure, and then support the dynamic inertial loads generated by the ESM loaded equipment and transmit the in-orbit loads.

The primary architecture must be designed to ensure correct and adequate sharing of SLS launch loads coming from upper composite between the SM and the SAJ external structure. The objective is to minimize the loads applied on the ESM mechanical structure in order to minimize its structural dry mass which is propelled all along the mission, while the SAJ capability is sized to the extent possible by the main launch phase, since the SAJ mass is jettisoned early in the flight. The ESM minimum stiffness requirements are based on vehicle level analyses and were defined by making the assumption that the loads are shared between both load paths, through the ESM and through the SAJ.

The separation system is provided by the SA.

The baseline architecture is the following:

The primary structure is composed of:

- 6 longerons linked to the CMA frame and six SA pyronut separation systems, directly supporting external equipment such as the reaction control system pods, and the power supply system solar array wings.
- Tank bulkhead supporting the four propellant tanks, as well as the gas delivery CSS tanks, ensuring the main link between the CMA lower interface ring and the rest of ESM structure
- "Radial" shear webs and internal "square" webs assembly, housing most of the ESM equipment and propulsion high pressure system and constituting the ESM structure core attached to tank bulkhead, longerons and closure lower platform. To the "central square", the main engine is attached via a specific platform. The shear webs assembly which is the central frame of the architecture is also supporting the dynamic lateral loads of the propellant tanks by means of specific struts attached to them. The water delivery system is mainly implemented on two intermediate platforms linked to shear webs accommodated in the two free volumes, each side of the tankage sectors assembly.
- Lower Platform on which the main propulsion equipment is connected: OMS-E main engine, Auxiliary thrusters, ACS, and Propulsion Isolation Equipment (PIE)
- MDPS aft closure panels to protect the aft face from MMOD environment

The lateral closure panels are provided by the Active Thermal Control System (ATCS) radiators and are not structural parts (isostatic assembly), indeed, they are part of the TCS subsystem. These panels also ensure the lateral MMOD protection of the ESM, acting as a MDPS.

The secondary structures support the following equipment:

- Solar Array Wings (SAW) via 4 support brackets and one Solar Array Drive Mechanism (SADM) per wing attached to the longerons and shear webs
- Reaction Control System (RCS) clusters
- Water Delivery and Gas Delivery system attachment to shear webs and tank bulkhead

The rest of the ESM equipment is directly linked to the primary structure: OMS-E, auxiliary engines, harness lines of the avionics, OMS-E Thrust Vector Control (TVC), TCS radiators, TCS equipment, MLI, heaters, etc.

The Baseline structure concept is composed of:

- Integral machined aluminum tank bulkhead and water tank panels, to minimize the mass of this main structural part

- Carbon sheets/ alu sandwich for webs panel and lower bulkhead, with specific equipment attachment by inserts and local reinforcement when needed to optimize the mass /stiffness needs
- Integral machined aluminum longerons connected to SA separation pyronuts and CMA frame by means of splices attachment connected to CMA by specific splice adjustment.

B. Thermal Control System

The Thermal Control Subsystem (TCS) includes an ATCS interfacing with the CM. The heat will be rejected into space via surface mounted radiators. A passive part will control the ESM internal environment via heater circuits and MLI. The Thermal Control Unit (TCU) controls the TCS as well as the CSS equipment (valves, heater zones, water pump package for active TCS).

1. Active Thermal Control System

The ATCS has been designed to collect the thermal loads from the CM and from the ESM powered equipment and to reject them toward the space radiative sink. The ATCS Baseline architecture is based on a Single-phase Fluid Loop Architecture using a HFE-7200 series as coolant fluid to collect and to transfer the heat loads from both ESM avionics (via cold plates) and CM (via Inter-Loop Heat Exchanger) and to reject them through specific body mounted radiators. The ATCS is composed of two fully independent loops working simultaneously (hot redundancy approach). The schematic of the ATCS architecture is presented in Figure 7.

Each of both ATCS cooling loops is composed by the following main Components:

- Six Body Mounted Radiators (common for both loops)
- One 3-Way Modulating Valve
- Four Cold Plates
- Two On/Off valves
- Four Pressure Sensor Blocks,
- Three Wet Temperature Sensor Blocks
- One Fluid Pump Package (FPP) with relevant passive accumulator
- Hard/flex hoses, tees, couplings and restrictors

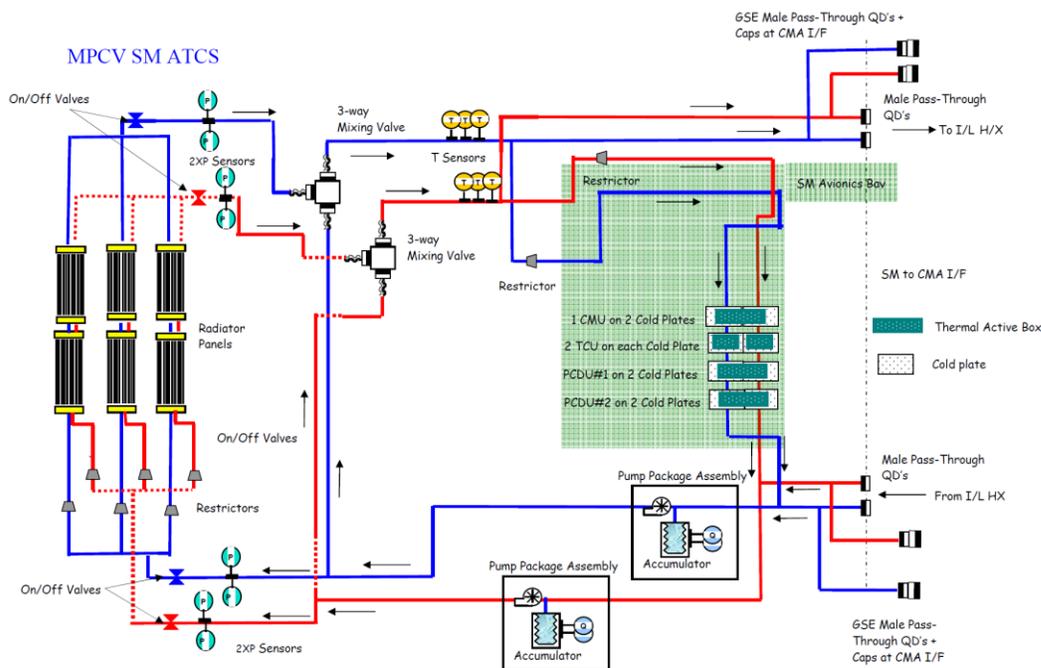


Figure 7. ATCS Block Diagram.

The FPP is controlled by the TCU to provide temperature constant mass flow rate inside the loop. In particular two flow rate set points are foreseen, one at 600 [kg/h] for nominal operation and one at 800 [kg/h] for contingency (with only one loop operative). The FPP is capable of a maximum flow rate of 1200 [kg/hr] at a fluid temperature range of 0 - 80°C and a max pressure rise of 4 bar.

The external surface of the Radiator Panels is coated with a specific paint characterized by the following thermal-optical characteristics:

- Alpha (α) = 0.2
- Emissivity (ϵ) = 0.8

The Cold Plates are devoted to collect the entire thermal load from the following ESM avionics boxes: PCDU (2 boxes), CMU (2 boxes) and TCU (2 boxes). The Cold Plate design is constituted by a stainless steel channelling enclosed in an aluminum casting acting as a plate in direct contact with the thermally active unit. Different Cold plate sizes, to satisfy the different configuration needs, are foreseen.

2. *Passive Thermal Control System*

The Passive Thermal Control System (PTCS) provides the Thermal control of ESM hardware (propulsion, CSS, power and avionic items) and reduces the temperature gradients and minimize heat flows through the internal elements.

The PTCS has two main components, heaters (thermistors and wire heaters for the propulsion and CSS lines) and insulation (MLI Thermal Blankets, including some specific High Temperature MLI blankets, for thrusters and engine nozzle thermal impingement protection).

The MLI protects the internal parts against the external environment and heater lines to compensate the heat leaks toward space. Different MLI typologies, in terms of composition, have been identified for the different applications on the ESM. The MLI composition mainly depends on exposure or not to the space, geometry & fixation interfaces and exposure to thrusters plume flux and nozzle radiation.

The Heater lines assure thermal control and temperature uniformity in the MPCV internals and for the local thermal control of the CSS Propulsion lines items and tanks, in addition heater lines are foreseen for the EPS SADM. On each thermal homogeneous zone or item, two Heaters Lines are working in cold redundancy.

3. *Thermal Control Unit (TCU)*

The TCU is designed to perform the tasks of management of the TCS and of the CSS.

For the Active Thermal Control System (ATCS) the TCU will acquire the various parameters from the ATCS sensors (Pressure, Temperature and Quantity of fluid within the the Pump Package Assembly), monitor and control the ATCS valves, and issue commands to the Pump Package.

For the Passive Thermal Control System (PTCS) the TCU will control the heater chains and monitor the signals coming from the thermistors. It will define and modify any independent heaters chains activation and de-activation thresholds, while ensuring bus interface and power supply logic.

For the Gas Delivery System of the CSS, the TCU will command the valves and monitor their position, monitor pressure levels for the O₂ and N₂ distribution lines (high and low pressure) as well as the temperature levels on the tanks. It will command the heaters and have a current/voltage monitoring to identify heater failures.

Likewise, for the Water Delivery System of the CSS, the TCU will command the valves and monitor their position, monitor flow rate for the water distribution lines as well as the temperature levels on the tank. It will have a current/voltage monitoring to identify heater failures.

- Turn on/off line heaters based on gas distribution request from CM and on on-off-valve position
- Current/Voltage monitoring to identify failures on heaters

C. **Consumable Storage System**

The Consumable Storage System (CSS) provides potable water for the CM crew as well as water for the sublimator located in the CMA. In addition it provides oxygen and nitrogen to the CM.

The Water Delivery Section of the CSS includes six potable water metallic bellow tanks, each with a storage capability nominally of 46.7 kg for a total storage capability of 280 kg of water. Furthermore the architecture can be reconfigured with only three tanks to perform a mission towards the ISS. A double distribution line of potable water connects to tanks to the CMA interface to supply both the CM and the Water Sublimator Assembly (WSA) in the CMA, while a single distribution line is connecting the tanks to the CMA for the GSE. Each branch of the distribution line towards the CMA can be isolated via a specific on/off valve.

The Water Delivery Section is connected with the Gas Delivery System for pressurization of the gas side of the tanks to overtake distribution back-pressure and allow water distribution at proper interface flow rate and pressures. The water tanks can be isolated on the gas side (two tanks at a time) and on the water side.

The Gas Delivery section includes four ATV-like gas tanks each with a storage capability of 33 kg at 275 bar, two of which are for oxygen storage, one for nitrogen and the fourth for either nitrogen or oxygen storage depending on the type of mission (ISS or Lunar). O₂ and N₂ are distributed towards the CMA via two independent distribution lines for each gas. Each branch of the O₂ and N₂ distribution lines towards the CMA can be isolated via a specific on/off valve. The tanks are filled by the GSE via the CMA.

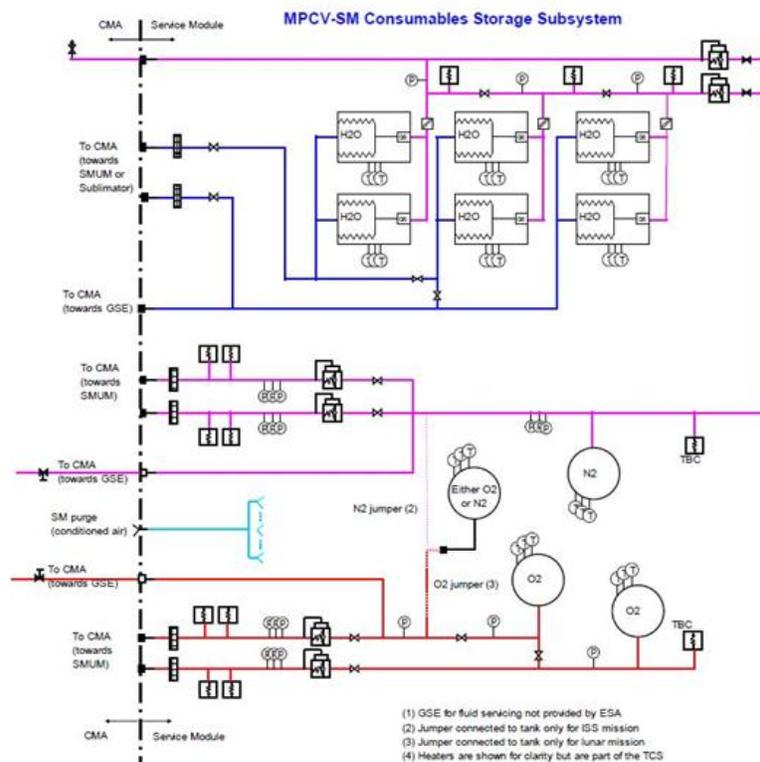


Figure 8. ESM Consumables Storage System.

D. Propulsion

The propulsion subsystem includes three different types of engines / thrusters. Each of these thrusters utilises the same propellants which are: MON-3 as oxidiser and MMH as fuel. In addition they all have the same nominal mixture ratio of 1.65:

- The single Main Engine which is one of the Shuttle OMS-E engines (27.7 kN) delivered by NASA as Government Furnished Item (GFI) and will be used during ascent abort and trans-earth injection manoeuvres as well as orbit change manoeuvres. This engine is gimballed with an amplitude of $\pm 6^\circ$ around both axes (pitch and yaw). The actuation is performed by the Thrust Vector Control (TVC).
- The 8 auxiliary thrusters which are similar to those used on ATV (490 N) are used during ascent abort and launcher separation as back-up to the main engine for trans-earth injection and for trajectory correction manoeuvres.
- The 24 RCS thrusters which are the same as used on ATV (220 N) provide the impulse necessary for translation and attitude control manoeuvres. These thrusters are accommodated into 8 pods. Four pods are composed of two roll thrusters, placed along the ESM lateral surface under the CMA, while four other pods are composed of four thrusters, placed along the ESM lateral surface under the level of the first four pods. The pods are aligned two by two and placed in the four directions of the main axes of the vehicle.

Each propellant type is stored in two propellant tanks, both sets of propellant tanks being arranged in a series configuration.

The propellant distribution comprises several electro-mechanical valves for propellant isolation and pressure transducers interconnected via pipes. The assembly ensures isolation of the engine / thrusters from the propellant tanks during launch, docked phase to the ISS and other mission events where it becomes necessary to isolate the engine / thrusters from the propellant storage.

The propellant distribution network provides the connections between the propellant tanks and the isolation valves and then onwards to the thruster assemblies.

Fill and Drain Valves and the related access lines are used during ground testing and for loading and unloading of the propellant and pressurized tanks. They are located in the CMA to enable access even after the SAJ around the service module has been installed.

The propulsion system will be controlled by the Propulsion Drive Electronics (PDE) which handles all nominal Propulsion related commands issued by the CM and provides feedback via the CMA Power Distribution Units (PDUs) and the PDUs to Vehicle Management Computer interface and the ESM network.

The PDE controls:

- RCS Thrusters
- Auxiliary Thrusters
- OMS-E Main Engine
- I/F to TVC

and all associated valves, instrumentation and leakage detection of the RCS thrusters.

E. Power

The Electrical Power System (EPS) has the function to generate the power for all modules of the MPCV vehicle i.e. the European Service Module, the Crew Module Adapter and the Crew Module. It manages the power provided by its 4 Solar Array wings. The Power Control and Distribution Unit (PCDU) provides the power I/F to the SAW and CMA, distributes electrical power to ESM users and protects the power lines. The electrical power will be

transferred from the Solar Array Wings to the PCDU via the Solar Array Drive Assembly (SADA). The Solar Array Drive Electronic (SADE) controls the Solar Array deployment and rotation.

The Power Generation part of the ESM EPS consists of four (4x) Solar Array Wings (SAW). Each wing is composed of three deployable CFRP rigid panels covered with triple junction GaAs solar cells forming nine (9x) sections of solar cells strings. In nominal condition the SAW can supply a total 11.1 kW. Each SAW is linked to the ESM structure by a two degrees of freedom SADA. The SADA ensures the power and signal transfer from the SAW to the PCDU. It is composed of a mechanism (SADM) and a drive electronics (SADE). The SADM allows orienting the SAW in two independent axes.

The EPS distributes the generated power to the ESM, but distributes part of the generated power to the CMA PDUs. This function is fulfilled by the PCDUs. The power is transferred through four independent 120 V busses rated at 30 A each. The power interfaces of the PCDU protect each unregulated bus from overload or short circuit failures on feeder busses outside the PCDU. They are implemented with Power Devices connected in parallel and independently operated for power flow from PCDU to CMA PDU, plus a number of Power Diodes for power flow from CMA PDU to PCDU.

The SADM allows Sun-tracking by the SAW in two independent axes. In the Sun-tracking mode the inner axis can swivel between -35 and +25 deg., while the outer axis has a continuous rotation capability [0; +360 deg.].

The SADM also allows repositioning (canting) of the SAW to reduce the loads on the SAW and SADM during the different MPCV orbital maneuvers. At Trans-Lunar Injection (TLI) a 0.5 g acceleration is generated by the iCPS engine and at Lunar Orbit Insertion (LOI) and Trans-Earth Injection (TEI) a 0.3 g deceleration is generated by the OMS-E engine.

As shown in [Figure 9](#)~~Figure-10~~ below, in order to reduce these loads to an acceptable level, the SAWs need to be repositioned by the SADM. In TLI the SAWs are thus canted during the maneuver to inner axis = - 60 deg. / outer axis = 0 deg. In LOI/TEI the SAWs are canted to inner axis = +55 deg. / outer axis = 0 deg.

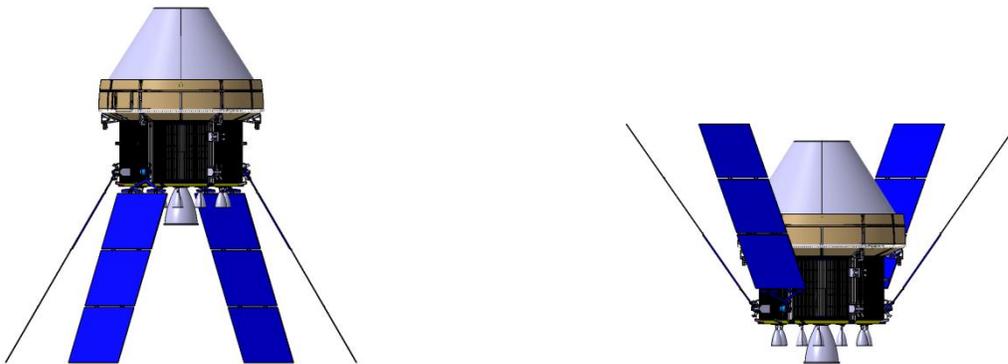


Figure 9~~10~~. ESM SAW canting angles (-60 deg./0 deg. @ TLI, +55 deg./0 deg. @ LOI/TEI).

F. Avionics

The high-level management of the vehicle and its functions will be performed at the level of the Orion Vehicle Management Computer (VMC). The MPCV-ESM will be controlled and monitored by specific electronic controller units:

- PCDU - Power Control and Distribution Unit
- SADE - Solar Array Drive Electronics
- PDE - Propulsion Drive Electronics
- TCU - Thermal Control Unit
- CMU - Command and Monitoring Unit

All units are connected via the Onboard Data Network (ODN) to the VMC and the Backup Flight Control Unit (BFCU). All vehicle control and management software resides in the VMC. The ODN is a three plane Time Triggered Gigabit Ethernet (TTGbE) (1000Base-CX) according to standard SAE AS6802.

Time-Triggered Gigabit Ethernet ODN provides a set of time-triggered services implemented on top of standard IEEE802.3 Ethernet. It provides the capability for deterministic, synchronous, and congestion-free communication, unaffected by any asynchronous Ethernet traffic load. This occurs via a fault-tolerant, self-stabilizing synchronization strategy, which helps to establish temporal partitioning and ensures isolation of the synchronous time-critical dataflow from other asynchronous Ethernet dataflow. By implementing this standard in network devices (network switches and network interface cards), Ethernet becomes a deterministic network which can be shared by low-latency, low-jitter, and non-time-critical applications. This means that distributed applications with mixed time-criticality requirements (e.g., real-time command and control, audio, video, voice, data) can be integrated and coexist on one Ethernet network.

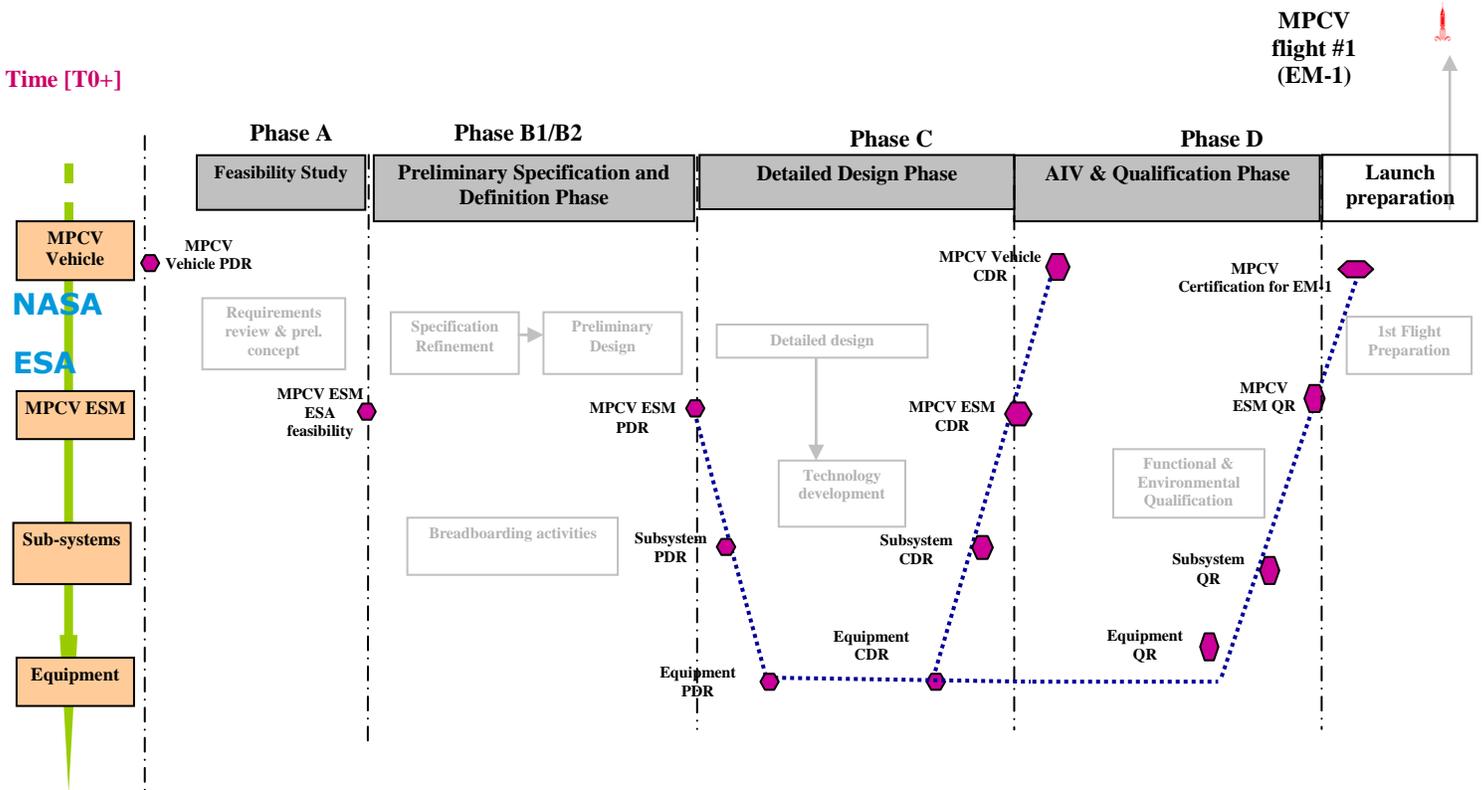
Each of the ESM controller units is connected via a Standard integrity Network-Interface Card (SNIC, according to Honeywell ICD8273722) to the LAN switch located in the CMA-PDU. The SNICs have three ports for two failure-tolerant communication on three network redundancy planes.

For the first MPCV flight EM-1 mission, a Demonstration Flight Instrumentation (DFI) will be implemented on MPCV SM (Data Acquisition Unit (DAU) provided by NASA) to acquire engineering data for this first demonstration flight.

VI. Testing and integration process

The goal of the development of the ESM is to make it ready for the initial flight of the SLS in 2017.

The development of the ESM will rely on a series of standard test models (Qualification models (QM) for an equipment prototype approach), in addition to the EM-1 proto-flight model (PFM).



MPCV-ESM Program Planning objective

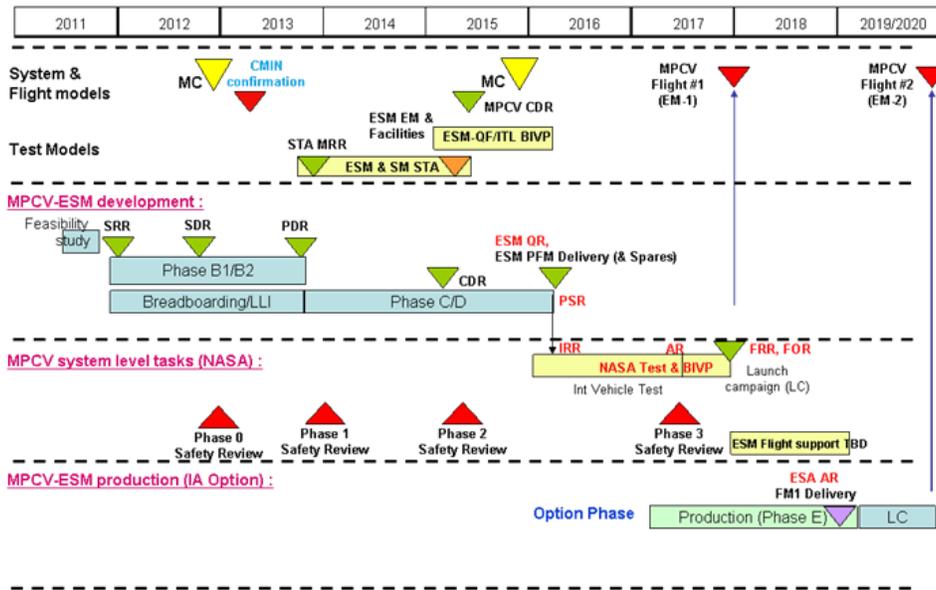


Figure 10. MPCV-ESM Development Logic

For functional tests, an ESM-QF (ESM Qualification Facility) will be created in Europe to provide simulation models, front-end equipment as well as EM/QM equipment in order to perform the ESM element level qualification tests. This will support the functional testing and qualification of the ESM hardware and software, and allow testing the interface between the ESM and the CMA/CM and verification of the performance requirements of the ESM functional chains (BIVP Tests). The ESM-QF will allow nominal and non-nominal operations testing and will be an essential tool for the performance of the verification activities. It will prepare the PFM integration and support trouble shooting activities related to this integration and to the MPCV tests on NASA side. The ESM-QF will consist of laboratory racks since there is no need for a geometrical representation of the flight configuration for these functional and performance tests (BIVP tests).

The ESM-ITL (ESM Integrated Test Laboratory) supports the NASA MPCV test campaign in the United States. This self-standing facility will serve as a functional representation of the ESM, containing Engineering Model units for the PCDUs and the PDEs with the other components of the ESM being simulated. The ESM-ITL and its ancillaries will be delivered to NASA and remain at NASA for the whole CM and MPCV flight configuration test campaign.

The Structural Test Article (STA) will be used for stiffness and static tests and assembly tests in Europe, and will be afterwards shipped to the U.S. to undergo dynamic, acoustic, pyro shock and mechanisms deployment tests in the NASA Plum Brook Station test facility. NASA will then use the STA for the MPCV level STA Campaign after refurbishment. These tests will be performed in 2014-15.

The ESM flight model for EM-1 will be delivered to KSC for integration with the SA, CMA and CM and undergo there some static and functional tests. Then the stack will be transported to Plum Brook to perform another series of tests (acoustics, modal, functional, thermal, EMI/EMC) and then will be shipped back to KSC for launch processing.

VII. Conclusion

The inclusion of an International Partner in the development of the MPCV will be a benefit to both NASA and ESA and will provide a significant International contribution towards NASA's exploration program. The ESA provided ESM will be part of the first flight of the Orion MPCV beyond Low Earth Orbit and will allow the US contractors to concentrate on the development of the Crew Module and Launch Abort System.

In addition, the ESM provides ESA an opportunity for cooperation that builds on existing ATV Service Module technology, leveraging skills and knowledge created for ATV. The ESM will also benefit ESA in the development of additional capability for use toward future ESA missions, creation of long term cooperation on future programs and strengthen the strategic partnership with NASA. The NASA and ESA teams including their respective contractors are now working together and making swift progress towards the Preliminary Design Review (PDR) and initiation of the Phase C/D of the project.

Acknowledgments

The work performed was initiated and guided by the NASA - ESA ISS / MPCV program management, namely Mike Suffredini and Mark Geyer from NASA and Bernardo Patti, Nico Dettmann and Philippe Deloo from ESA.

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