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The Second European Service Module (ESM-2) Evolutions, Production and Challenges**Anthony Thirkettle^a, William Hartwell^b, Dirk Schulze-Varnholt^c, Georg Monien^c, Brian Huermann^c,
Siddharth Poornachandran^c, Lori Rauen^d**^a *European Space Agency (ESA), The Netherlands, anthony.charles.thirkettle@esa.int*^b *National Aeronautics and Space Administration (NASA), Johnson Space Center, United States, william.l.hartwell@nasa.gov*^c *Airbus Defence and Space, Germany, dirk.schulze-varnholt@airbus.com, georg.monien@airbus.com, brian.huermann@airbus.com, siddharth.poornachandran@scalian.com*^d *Lockheed Martin Space Systems, United States, lori.a.rauen@lmco.com***Abstract**

This paper presents an overview of the Second European Service Module (ESM-2), the second in a series of European Service Modules produced as part of the Barter agreement between NASA and ESA for the Orion Program. The European Industrial consortium is led by the ESA prime contractor Airbus Defence and Space in Bremen. ESA and Airbus signed the ESM-2 contract on 16 February 2017, for this key element of the Orion Exploration Mission 2 (EM-2). EM-2 is the first crewed mission for Orion and will take astronauts farther into the solar system than humanity has ever travelled. EM-2 will also be a historic mission for Europe, as the ESM-2 will be the first European spacecraft to be part of a human transportation system carrying humans beyond low Earth orbit. ESM-2 is mainly a recurring production following ESM-1. Nevertheless, there are a number of important changes being implemented, for example, to incorporate upgrades to further enhance safety and reliability. The challenging delivery schedule for ESM-2 has driven the need to commence manufacturing prior to completion of the qualification on ESM-1. In addition, some requirement deviations and non-compliances approved for ESM-1 have resulted in modifications for ESM-2. In order to manage the competing constraints effectively, the ESM-2 Team has put in place a number of novel approaches to manage schedule, risk, and technical changes. Airbus has set up multi-functional teams according to an approach known as "Major Spacecraft Deliveries" consisting of quality assurance, engineering and procurement. The risk of starting manufacturing prior to qualification is managed through a special risk share agreement. This agreement necessitates rigorous risk reviews across the board for all manufacturing, assembly, integration and test milestones. The ESM-2 changes are managed by Configuration Management, but Airbus has also introduced the Technical Baseline Matrix to provide a transparent top-level overview of the changes from ESM-1 to ESM-2. The tool provides the basis for ESM-2 design and development needs, decisions, as well as the input for the Orion EM-2 Critical Design Review (CDR). The main technical evolutions, status of the production and the novel management approaches for ESM-2 are presented and discussed in the paper.

Keywords: Orion European Service Module Programme**Acronyms/Abbreviations**

AIT Assembly, Integration and Test

ATV Automated Transfer Vehicle

CDR Critical Design Review

CM Crew Module

CMA Crew Module Adapter

CSS Consumables Storage System

EGS Exploration Ground Systems

EM Exploration Mission

ESA European Space Agency

ESM European Service Module

EUS Exploration Upper Stage

FPGA Field-Programmable Gate Array

HMU Harness Manufacturing Unit

ICPS Interim Cryogenic Stage

ISS International Space Station

KSC Kennedy Space Center

LAS Launch Abort System

MAIT Manufacturing, Assembly, Integration and Test

ML Mobile Launcher

MPCV Multi-Purpose Crew Vehicle

MSD Major Spacecraft Delivery

NASA National Aeronautics and Space Administration

NCR Non-conformance report

NDI Non-Destructive Inspection

OMS Orbital Manoeuvring System

PCA Pressure Control Assembly

PCDU Power Control and Distribution Unit

PDE Propulsion Drive Electronics

PRU Pressure Regulator Unit

PSS Propulsion Sub-System

RCS Reaction Control Thrusters

RFD Request for Deviation

RFW Request for Waiver

SA Spacecraft Adapter

SADM Solar Array Drive Mechanism

SADE	Solar Array Drive Electronics
SAW	Solar Array Wing
SLS	Space Launch System
TBM	Technical Baseline Matrix
TCS	Thermal Control System
TCU	Thermal Control Unit
TLI	Trans Lunar Injection
TVC	Thrust Vector Control

1. Introduction

In March 2011, NASA and ESA decided to partially offset the European obligations deriving from the extension of the International Space Station (ISS) Program until the end of 2020 with a different means than providing services with the Automated Transfer Vehicle (ATV). This change took place following the ATV's fifth mission, ATV-5. The European Service Module (ESM) for Orion (Fig. 1) was selected after studying a number of bartering options. The ESA Ministerial Council gave the approval for the ESM Phase A / B1 activities in November 2011.



Fig. 1. Orion spacecraft

The ESM builds on the European experience of the ATV, which flew five successful resupply missions to the ISS between 2008 and 2015 (Fig. 2). Its mission was to supply pressurized cargo, water, air, and fuel to the ISS, as well as to raise its orbit and perform orbital debris avoidance manoeuvres. The skills and knowledge that European Industry developed from ATV have proven to be valuable for the ESM Project.



Fig. 2. ATV-4 approaching the ISS

The ESA prime contractor Airbus Defence and Space of Bremen, Germany, is leading the European industrial consortium for the development of the ESM and working closely with its customer, ESA, as well as with NASA and Lockheed Martin Space Systems, the Orion prime contractor.

2. The Orion Programme

The ESM is a core part of the Orion spacecraft (Fig. 1), which will be launched on top of NASA's Space Launch System (SLS). When completed, the SLS will be the most powerful rocket ever built. It will enable Orion to take astronauts beyond Low Earth Orbit (LEO) for the first time since Apollo and farther than humans have ever been from Earth.

2.1 Orion Vehicle

The complete Orion vehicle (Fig. 3) consists of the following modules:

- Spacecraft Adapter (SA),
- Spacecraft Adapter Jettisoned Fairings (SAJ),
- European Service Module (ESM),
- Crew Module Adapter (CMA),
- Crew Module (CM), and
- Launch Abort System (LAS).

Before launch, the ESM is mounted on the Orion Spacecraft Adapter and protected by three SAJs. The top of the ESM interfaces with the Crew Module Adapter. The ESM is optimised for mass and performance in-orbit, but also contributes during launch by sharing the loads with the fairing.



Fig. 3. Orion Vehicle

2.2 Space Launch System and Exploration Ground Systems

NASA will launch Orion from Kennedy Space Center (KSC) on the SLS (Fig. 4). After final acceptance testing, the Orion Program turns the Orion spacecraft over to

Exploration Ground Systems (EGS) for fuelling and integration with the SLS. EGS then transports the entire vehicle out to the launch pad on the Mobile Launcher (ML) in preparation for launch.



Fig. 4. Space Launch System on Mobile Launcher

2.3 Exploration Mission 1 (EM-1)

The Exploration Mission 1 (EM-1) is an uncrewed mission to test Orion's capabilities in deep space. EM-1 is the first flight of the ESM and also Orion's first flight on the new SLS. During the mission, the Crew Module guidance navigation and control system will command the ESM propulsion system to place the spacecraft into a Distant Retrograde Orbit around the moon. The nominal mission duration is 25 days, but will be adjusted between 21 and 43 days in order to ensure a landing under daylight conditions.

2.4 Exploration Mission 2 (EM-2)

Exploration Mission 2 (EM-2) (Fig. 5) is the first crewed mission for Orion and will take astronauts farther into the solar system than humanity has ever travelled. EM-2 will also be a historic mission for Europe, as the ESM-2 will be the first European spacecraft to be part of a human transportation system carrying humans beyond low Earth orbit.

After launch, the SLS and the Interim Cryogenic Propulsion Stage (ICPS) will place the Orion spacecraft into a high Earth orbit, where the astronauts will remain for 24 hours to check out the spacecraft's systems. When Mission Control gives the approval to initiate trans-lunar injection, the ESM-2's Orion Orbital Manoeuvring System (OMS) will fire and send the spacecraft on a free-return trajectory out toward and around the Moon. The ESM-2's Auxiliary (AUX) thrusters will be used to make any needed trajectory corrections along the way.

NASA and Lockheed Martin will conduct the EM-2 Critical Design Review (CDR) in late 2018. In 2015, NASA and LM completed the Orion CDR evaluating the common aspects of the spacecraft for EM-1 and the spacecraft for EM-2. The EM-2 CDR will confirm that the EM-2 unique systems also meet the necessary requirements and that the upgrades to the ESM design from ESM-1 to ESM-2 are appropriately integrated into the overall spacecraft design.

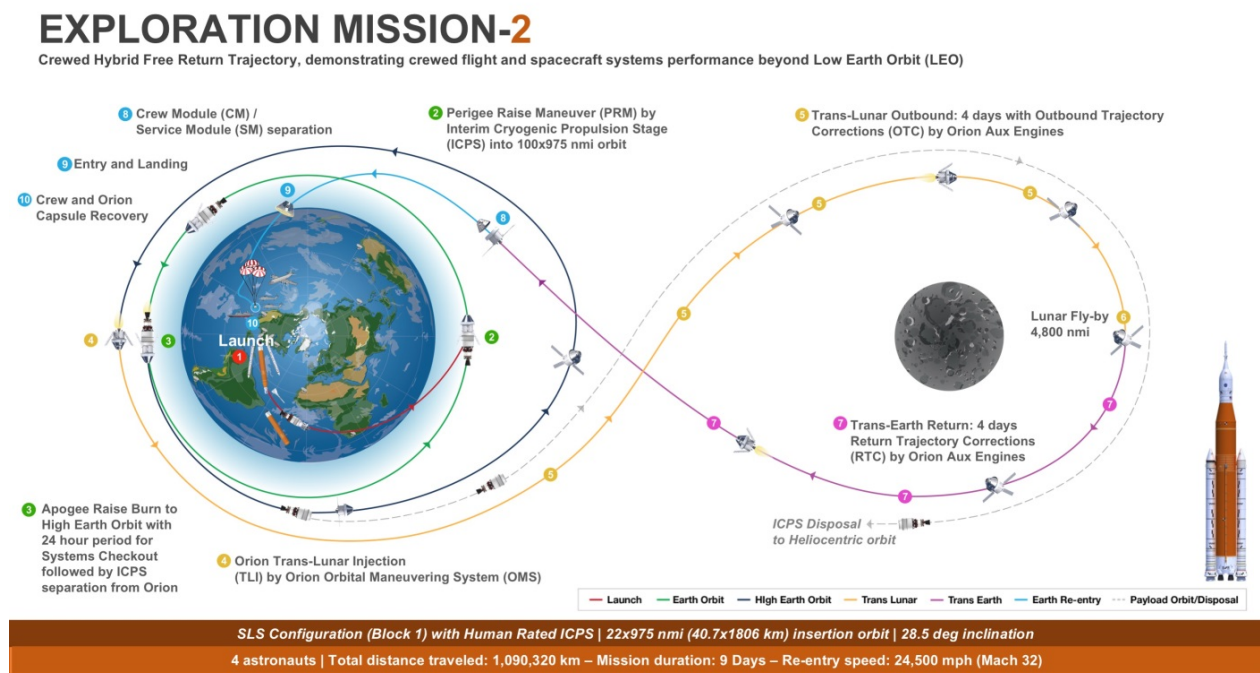


Fig. 5. Exploration Mission-2

3. Overview of the ESM design

The ESM provides the propulsion, power, water, oxygen and nitrogen for the Orion spacecraft as well as providing thermal control and protection from micrometeorite and orbital debris (Fig. 6). The main characteristics of the ESM are:

- Launch mass of 13580 kg for Lunar Missions, including 8600 kg of usable propellant, 240 kg of potable water, 30 kg of nitrogen and 90 kg of oxygen;
- Unpressurised cargo accommodation with a maximum volume and mass of 0.57 m³ and 380 kg respectively;
- Height of around 2 m considering the primary structure only, but reaches up to 4 m adding the protrusions of the main engine toward SA and the propellant / gas tanks toward CMA;
- Diameter of approximately 5.2 m when solar arrays are stowed under the fairing and a wing span in the order of 19 m on-orbit;

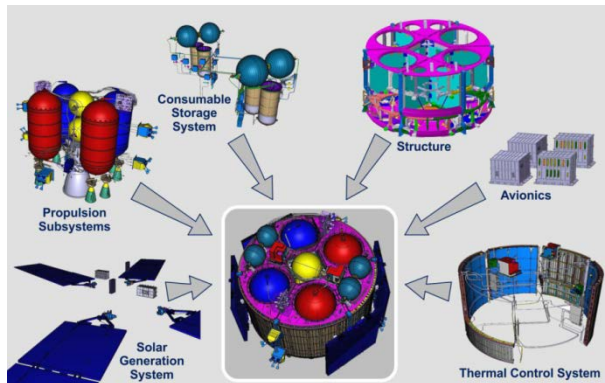


Fig. 6. European Service Module components

3.1 Propulsion system

The propulsion system consists of three different types of engines. The main engine is a heritage engine from the Shuttle, known as the OMS-E. The OMS-E engine can be gimbaled with an amplitude of $\pm 7^\circ$ around both axes (pitch and yaw) using the Thrust Vector Control (TVC) system. It provides 27.7 kN of thrust. There are eight 490 N auxiliary engines which are used during spacecraft separation and during ascent abort, as well as functioning as a backup for the main engine in case they are called upon to perform trans-earth injection and for trajectory correction manoeuvres. Translation and attitude control manoeuvres are performed by 24 RCS thrusters, which are mounted on six RCS pods.

All of the engines are supplied with MON-3 oxidiser and MMH fuel. These are housed in four propellant tanks that are fed with Helium from two pressurant tanks located in the central tube of the ESM.

The propulsion subsystem is controlled by the Propulsion Drive Electronics (PDE), the Pressure Regulation Unit (PRU), the Pressure Control Assembly

(PCA) and isolation valves for the main lines, auxiliary thruster lines and RCS lines.

3.2 Power system

Electrical power for Orion is provided by four Solar Array Wings (SAWs). Each wing is 7375 mm long and made of three panels (2130 by 1920 mm), providing a total power output of 11.2 kW. The wings are orientated by a dual axis Solar Array Drive Mechanism (SADM). The SADM can swing between -35° and $+25^\circ$ on the inner axis and the outer axis can rotate the full 360° . The solar arrays are controlled by the Solar Array Drive Electronics (SADE), and the Power Conditioning and Distribution Unit (PCDU) regulates and distributes the power to the ESM and Orion equipment.

3.3 Consumable Storage System

The Consumable Storage System (CSS) provides potable water, oxygen and nitrogen to the CM. There are four water tanks (with metal bellows), three gas tanks for the oxygen, one gas tank for the nitrogen, water and gas on/off valves, gas pressure regulators, gas relief valves, filters and temperature, pressure and quantity sensors.

The crewed EM-2 mission will fly the full CSS system, whereas the uncrewed EM-1 mission will have a reduced CSS configuration without the oxygen tanks.

3.4 Thermal Control System

The Thermal Control System (TCS) consists of active and passive thermal control.

The active thermal control subsystem uses cold plates to collect heat from the CM and ESM equipment and dissipates it via the radiators. The Fluid Control Assembly controls the flow of HFE-7200 coolant in the two independent loops.

The passive thermal control system is comprised of heaters, thermistors and insulation blankets. The Thermal Control Unit (TCU) manages the thermal environment as well as the CSS, keeping temperatures within the defined thresholds and commanding the CSS water and gas valves to open and close when needed.

3.5 Structure system

The structure subsystem carries the loads during launch and supports all of the ESM equipment through the primary and secondary structures. It also provides protection against meteoroids and orbital debris using gap covers, Kevlar blankets mounted behind the radiators, and a spider net on the bottom of the ESM.

4. The Second European Service Module (ESM-2)

ESM-2 is the second service module and will have the full set of capabilities to support EM-2 and the first Orion crew on their journey around the Moon. The main differences with respect to ESM-1 are the addition of the oxygen tanks which were unnecessary for the first mission and a number of upgrades to enhance safety, reliability and performance. Suppliers are currently working hard to deliver the components for ESM-2 and the structure is already at the Airbus facility in Bremen, where system integration activities have started.

ESM-2 is primarily a recurring production vehicle, therefore the main activities are manufacturing, integration, acceptance, delivery, post-delivery activities at KSC and operations support to the EM-2 mission. The industrial consortium must complete verifications waived on ESM-1 and implement corrective measures for requirement deviations or waivers only approved for the first uncrewed mission. In addition, there are a number of changes emanating from recommendations of the safety panels and from the need to increase performance for on-orbit manoeuvres, reduce mass, as well as changes to optimize the integration flow.

Implementing these modifications, enhancing safety and performance, manufacturing and integrating the ESM-2, whilst keeping it all within a tight schedule represents a challenge in itself. It becomes especially challenging when considering ESM-1 is in the final stages before delivery to KSC, ESM-2 manufacturing had to begin prior to completion of the ESM design qualification, and Industry are preparing proposals for the next two flight units, ESM-3 and ESM-4.

4.1 ESM-2 Modifications

There are a number of specific changes for ESM-2 in order to enhance the on-orbit manoeuvring capability, reduce mass, and to further increase safety for the crewed mission.

At the time ESA and Airbus signed the contract for ESM-2, the EM-2 mission was intended to use the new Exploration Upper Stage (EUS), therefore EUS mechanical loads were incorporated into the ESM-2 design. The loads mainly affect the solar array wings and solar array drive mechanism. The solar array hinges and the housing of the solar array drive mechanism have been reinforced to support the increased bending loads during the trans-lunar injection manoeuvre (Fig. 7).



Fig. 7. ICPS TLI burn with wings canted backwards

The on-orbit loads from OMS-E, AUX and RCS manoeuvres have resulted in additional heaters on the SADM and a SADE. These changes result in additional power to the SADM and better control of the thermal environment, both of which contribute to an important improvement in the capability of the solar array wings to track the sun during on-orbit manoeuvres.

Mass is a very important factor for the overall ESM and Orion performance, and the mass requirement levied on the ESM has been a challenge since the beginning of the project. Strict mass management is applied and mass threats and opportunities are continuously monitored and controlled. For schedule reasons there were a number of mass-saving opportunities that were deferred to ESM-2. Optimisation of the secondary structures, optimisation of the brackets for piping and harnesses, and a reduction of the number of Kevlar layers for the blankets which provide protection against micrometeorites and orbital debris, have resulted in significant mass savings for ESM-2.

The majority of ESM-2 changes however, are to enhance safety. The main changes in this category are the:

- upgrade of the CSS redundancy,
- adding secondary containment for the PSS pressure transducers in the high-pressure lines,
- application of advanced measures of robustness for the zero fault tolerant bellows of the PSS isolation valves,
- PSS localized leak detection,
- a modification of the SAW latch indicator, and
- a modification of the SADE FPGA design.

An additional source of modifications are non-compliances or non-conformances uncovered during the ESM design qualification campaign. The main changes resulting from this category are:

- modifications to the CSS gas and water isolation valves and pressure regulator,
- an improved seal design for the water tanks,

- local design modifications for the PSS high pressure valves, pyro valves and fill and drain valves,
- improved harness design,
- replacement of the pressure transducers for the RCS thrusters,
- and upgrades of the TCU FPGA design.

4.2 ESM-2 Production

A large number of suppliers throughout Europe and the US provide equipment and subsystems for the ESM (Fig. 8). The ESM-2 production consists of two main phases: the equipment manufacturing at subcontractor level and the final Assembly, Integration and Test (AIT) activities at system level, which starts with the reception of the primary structure in Bremen.

In 2016, Airbus initiated procurement of the long lead items, including structural materials and forgings for propellant and pressurant tanks. Industry began manufacturing activities in earnest at the end of 2016, starting with components of the primary structure. During 2017, the equipment suppliers began initiating manufacturing step by step for all other equipment and the sub-systems via dedicated Manufacturing Readiness Reviews (MRRs). The primary structure was delivered from TAS-I in Turin to Bremen in April 2018, which marked the start of the system level AIT activities.



Fig. 8. ESM Industrial Consortium

The assembly and integration sequence is driven by the design of the ESM. Due to the high density of components and equipment within the ESM, accessibility is key. The ESM design naturally provides the opportunity to schedule some assembly tasks in parallel, because it is comprised of zones between the web panels. Four zones house the propellant tanks, two zones contain the water tanks, and the central tube zone holds the Helium pressurant tanks. In addition, large subassemblies are preassembled and tested in separate areas in the clean room adjacent to the main ESM assembly.

The overall AIT logic can be broken down into several phases: mechanical integration of ty-bases and brackets, harness integration, PSS piping and subassembly integration (including propellant tank and

thrusters), the avionics integration, and finally, the functional testing. Parallel to these activities, the TAS-I TCS and CSS subsystems are integrated.

Mechanical dummies serve as interface simulators to allow the start of harness integration prior to the final mating once the avionic boxes are delivered. The harnesses are delivered as pre-fabricated bundles called Harness Manufacturing Units (HMUs).

Teams work on four PSS subassemblies simultaneously to speed up PSS piping integration, all in parallel to the integration activities on the main vehicle. Pipe sections are delivered pre-shaped, but with spare length at the ends. The ends are then cut to fit in their final position before being cleaned, welded and inspected. The weld inspection and verification process consists of X-ray and eddy current inspection, followed by a proof pressure test subassembly by subassembly, followed by a second set of X-ray and eddy current inspections. The welding sequence is optimized in such a way that the required proof pressure tests are grouped in sections. When ready, the subassemblies are integrated on the primary structure and the last piping interfaces are joined.

Step by step the major components are integrated – the first is the PSS pressurant tank. As a precondition, all ty-base, brackets, harness and piping integration tasks need to be finalized for the specific area in question which will no longer be accessible.

In parallel to the PSS piping integration and its related equipment, TAS-I integrates the subsystems for TCS and CSS. TAS-I pre-assembles the CSS and TCS valves and piping in Turin before delivery and installation in Bremen.

Before starting the system level functional tests, AIT personnel must successfully perform all integration tests and subsystems acceptance tests, including harness mapping and isolation tests; initial power on and inrush current measurements on the avionics boxes; and leak and proof pressure tests for the PSS, CSS and TCS, including functional verification and any special Non-Destructive Inspection (NDI).

Once these tasks are completed successfully, the final system level functional tests can be performed. This is when the full vehicle is activated, including the power subsystem.

The functional tests in Bremen are the first set of system-level acceptance tests. After its successful testing, the ESM is packed and transported to KSC in the US where a health check is performed before the final mating with the Crew Module Adapter (CMA). The ESM is an integral part of Orion, and Airbus will be actively involved in the US AIT activities and joint verification tests, which can only be performed on the full Orion vehicle. Once the ESM acceptance is complete, Airbus and ESA transfer ESM ownership to NASA.

4.3 ESM-2 Schedule

Airbus and their subcontractors developed the ESM-2 schedule based on the generic logic as described in Section 4.2. The schedule consists of Manufacturing, Assembly, Integration and Testing (MAIT) phases, with sub-system and system-level AIT activities performed in Bremen. Manufacturing refers to the equipment manufacturing by suppliers and subcontractors whose key milestones and deliveries Airbus has incorporated into the schedule and whose progress they closely monitor. Airbus has adapted the AIT schedule based on ESM-1 lessons learnt and actual task durations. Furthermore, they have incorporated new tasks not performed on ESM-1 due to waived requirements on ESM-1 for PSS Helium cross feed, second NDI of PSS welds after proof-pressure testing, and the complete installation of the CSS to include the oxygen tanks for the crew. Finally, certain changes to further enhance safety for a crewed exploration mission have been implemented.

The development of the ESM-2 schedule provided an opportunity for a schedule balancing. Special attention was paid in order to avoid issues encountered during ESM-1 integration. This leads to the optimal deployment of personnel, ensures accessibility for the maximum number of teams to carry out parallel work during integration, and increases shop-floor productivity.

Engineering teams review the schedule, for example a PSS workshop was held during which ESM integration was reassessed and opportunities were identified for performing further bench work besides the main ESM integration, enabling more decoupling whilst solving some accessibility challenges encountered on ESM-1. The prime, the agencies and Lockheed Martin perform very thorough reviews of the schedule. This process involving all of the subsystem and AIT experts, the so-called deep dive review, helps to provide a transparent, optimum and robust schedule.

That said, the ESM integration is largely driven by equipment deliveries which are under the responsibility of the subcontractors. The delivery dates and interdependencies between various sub-systems are very complex, therefore the critical path is driven by a combination of equipment deliveries, interdependencies across the various sub-systems and the overall ESM AIT logic.

Due to the demanding schedule for ESM-2, the release of manufacturing was required prior to the completion of the equipment and system qualification, otherwise it would have been impossible to meet the required KSC on dock date.

The main risks to equipment deliveries are unexpected anomalies and mishaps in the nominal manufacturing and test flow, but also potential problems identified during the ongoing qualification activities. In some cases 'use-as-is' proved to be acceptable for the

uncrewed ESM-1 mission, whereas ESM-2 being the first crewed exploration mission required corrective measures to be applied to the hardware itself. Such decisions are taken jointly with the involvement of all parties, the agencies, prime and subcontractor.

The ESM-2 schedule provides as much flexibility as possible in order to manage the dynamic ESM environment, to ensure activities remain on track and to incorporate schedule robustness measures identified by the industrial procurement, engineering and AIT teams.

4.4 ESM-2 Management approach

In order to manage the competing constraints effectively the ESM-2 team is applying a number of novel approaches, including

- the risk sharing scheme,
- schedule robustness measures
- multi-functional teams aligned along a "Major Spacecraft Delivery (MSD)" structure, and
- the Technical Baseline Matrix (TBM).

4.4.1 The risk sharing scheme

As described, the demanding schedule resulted in the need to start manufacturing of flight units prior to the completion of the qualification campaign. This was not only relevant for the flight units of ESM-1 but also affects the ESM-2 flight units. This fact was already known at the time of the contract signature and a dedicated risk sharing scheme was established to cover this challenge. The risk sharing scheme includes a rigorous screening and management of all risks prior to the equipment milestones.

4.4.2 Schedule robustness measures

Due to the strong dependency of the AIT flow on subcontractor deliveries and the difficulty to rearrange the nominal AIT flow to accommodate delays, it was decided quite early on in the development that specific measures were necessary to stabilize the ESM2 schedule and the delivery date to the US. As a consequence the AIT flow at system level was analysed and reviewed to identify opportunities, and the subcontractors were challenged to find schedule acceleration or robustness measures for their schedule critical equipment.

The AIT schedule analysis is based on the ESM-1 as-run schedule with review of anomalies and the collection of lessons learned. In general the main improvements on system level are achieved by a further parallelization and removing of constraints in the integration and test logic. That could be realized by different methods, e.g.

- implementation of dummies to releases tasks before delivery of the final flight hardware,
- piping deliveries from the suppliers already cut according to the final design,

- increased offline activities such as welding more pipe sections in advance,
- implementation of test rims to reduce proof testing durations,
- additional shift work and weekends, and
- the use of a rolling spare concept.

On equipment level a standard catalogue of recovery and robustness measures were defined. It was presented to the subcontractors with the request to investigate if part of these measures would improve the delivery schedule. These measures are subdivided into the following categories:

- Human resources (shift work, increased team size),
- Production measures (enhanced GSE & Facilities, prioritization, staggered delivery)
- Management measures (incentives, on-site residents to improve communications and decision making), and
- Equipment specific measures.

All of the schedule measures identified by this process are recorded in the ESM database. The actual delivery status of equipment is monitored and drives the prioritization of measures. The measures are then implemented, following agency approval of the associated benefits, costs and priorities.

4.4.3 Major Spacecraft Delivery (MSD) structure

Airbus has set up multi-functional teams according to an approach known as “Major Spacecraft Deliveries” (MSD) consisting of quality assurance, engineering and procurement. The main aim of the MSDs is to focus a small, highly qualified and dedicated team on the timely delivery of the equipment. The equipment is grouped in logical entities (MSDs) to allow synergies in regard to the technical expertise required as well as the supplier structure. The grouping as well as the focused multi-functional team allows a close monitoring and control of the equipment evolution and speeds up the decision-making process.

Based on this concept, Airbus has established improved internal processes with clear responsibilities and accountabilities allowing a detailed, stringent and highly visible internal and external reporting on the progress of the major spacecraft deliveries.

A final benefit is also the increased reactivity needed to cope with competing constraints of the program.

4.4.4 Technical baseline matrix

Configuration management plays a major role for any spacecraft project. The high demands on safety and reliability further emphasises the importance of good configuration control to clearly manage and document the configuration status of each component in the spacecraft.

Although ESM-2 is primarily a recurring production the need to increase robustness and safety has resulted in several modifications as already described. In order to clearly monitor the differences between the vehicles Airbus DS has established a technical baseline matrix.

In order to fully appreciate the significance of the technical baseline matrix, it is important to understand the general logic for managing the baseline. Fig 9. shows a top-level schematic of a typical spacecraft development on the left-hand side, in this case, for ESM-1. On the right-hand side it shows a how evolutions for ESM-2 are managed.

Based on the set of customer requirements, a detailed design is established. This design is qualified in a dedicated qualification campaign and any deviations to the customer requirements are tracked in dedicated RFD/RFWs. Anomalies occurring during the manufacturing and acceptance of the flight units are tracked as NCRs.

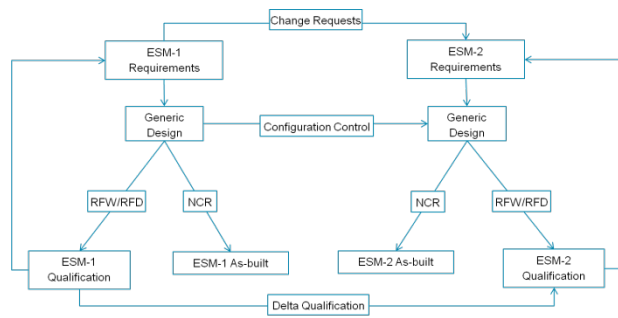


Fig. 9 General baseline management logic

If a second flight unit is built and changes have to be implemented they generally result from a change in the customer requirements, the need to optimize the design due to an approved deviation, a non-conformance, or an obsolescence. Independent from the reason for a change, it is important to ensure clear tracking of the design modification between the flight models and to perform a critical evaluation of the potential need for a delta qualification. This concept is also illustrated in Fig. 9.

Airbus tracks all modifications using standard configuration control methodologies and tools, but there was a need to increase visibility and provide a concise overview of all changes. Therefore, Airbus created the Technical Baseline Matrix (TBM) for the ESM-2 program. The TBM is a tool aligned along the ESM product tree to track all elements that are changed as well as potential risks of items that might change. This provides a very quick overview of the changes between ESM-1 and ESM-2. The tool is further used to track the overall progress of the modifications, as well as the risk elements and provides closure plans for monitoring and controlling the activities. One novelty of this tool is that it is accessible to the customer at all times to provide a clear status of the ESM-2 configuration.

The TBM provides an overview for management and it has proven to be a valuable tool. It also serves as the key input to the Orion EM-2 System CDR. Nevertheless, it has to be stressed that this tool is not replacing the standard configuration methods, it is rather a technical management tool to control the baseline evolution between different flight models.

5. Conclusions

The EM-2 mission will be a historic event in many ways. It will be the first crewed mission to return to cislunar space in the last 50 years, since the famous Apollo missions. It will be the first human spaceflight mission to go beyond Earth involving an international collaboration, between ESA and NASA. And last but not least, the ESM-2 will be the first human spacecraft in Europe to launch and fly astronauts around the Moon as a key element of the Orion vehicle.

With these existing capabilities and the plans for future missions to the Lunar Orbiting Platform - Gateway, to explore cislunar space and beyond, it is an exciting time to be part of the human space exploration programme.

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