MOSAR

Deliverable Reference	:	D3.5
Title	:	Demonstration Procedures
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Lead Partner	:	DLR
Abstract	:	This document presents the specification of the demonstration test procedures covering the WP4 activities. Preliminary procedures are described for the integration and demonstration tests covering WP5
EC Grant N°	:	821996
Project Officer EC	:	Christos Ampatzis (REA)

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1.0.0	16/06/2020	Consortium	All	First release for CDR milestone review
1.1.0	05/08/2020	Space Applications	Section 2.1, test IDCT-A-2 Section 4.2.2, Scenario 2	Add power-off test on the WM, with attached payload, as feedback to RID OG09-117 Add note about generation/detection and action on fault detection, as feedback to RID OG09-119

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1 Introduction

The testing validation campaign will consist of an extended series of tests ranging from components validation to the full setup/demonstration of the five selected scenarios foreseen in the activity. The purpose will be to illustrate all the main functionalities of modular spacecraft, including the ground support tools (design, simulation and planning), the operational concept of manipulator and spacecraft module relocation and resources re-allocation.

1.1 Purpose and Scope

The autonomous transfer and configuration of the SM follow an execution plan prepared and validated off-line, in the Monitoring and Control Centre (MCC), on the ground segment. The MCC includes a satellite design, modelling and validation tool, specifically targeting modular satellites applications. It also allows the automatic planning of the assembly or reconfiguration sequence that can be verified with a multi-physics simulator. All these elements are working iteratively together to prepare a valid execution plan that is finally uploaded to the spacecraft for execution. Based on the monitoring and feedback information received from the spacecraft during the operations (e.g. detected failed module), the MCC can update the execution plan. The MCC finally includes visualisation front-end to support the design, verification and monitoring activities during sequence execution.

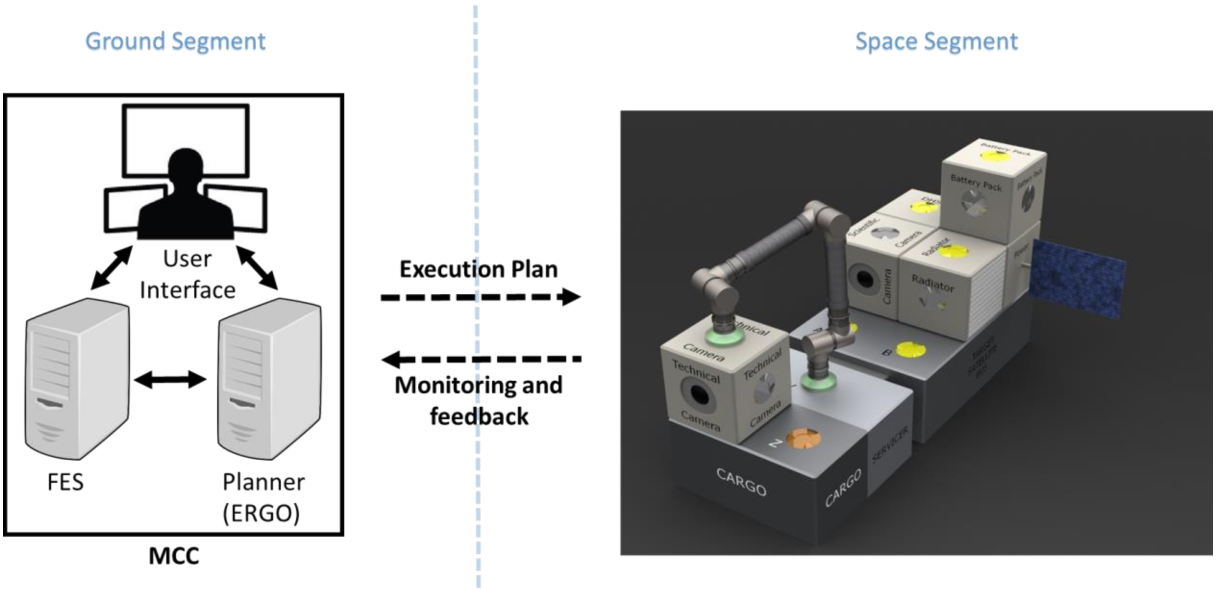


Figure 1-1: MOSAR Demonstrator Global Architecture

The purpose of the ground laboratory demonstrator is to demonstrate the concept of modular spacecraft as presented above. System modularity can be defined at different levels:

- Hardware: with the possibility to re-configure the physical arrangement of the spacecraft and/or providing means to replace/upgrade specific functions.
- Software: with the possibility to re-configure node responsibilities and support the re-configuration operations
- Data: with the possibility to re-route TM/TC and data transmission along the different nodes
- Power: with the possibility to re-route and control the power transmission along the nodes.

The MOSAR demonstrator shall allow verifying and validating the following high level functionalities relevant for future modular spacecraft missions ([VerR_G101], with reference to the MOSAR mission's requirements [AD1]):

Table 1-1: High level functionalities demonstrated in MOSAR

Requirements	High level functionalities
FuncR_S105	Design and creation of a re-configuration execution plan
FuncR_S106	Simulation of the execution plan
FuncR_S101	Manipulation and repositioning of SM
FuncR_S104, FuncR_S107	Control and re-location of the WM
FuncR_S102	Update/upgrade of satellite functionalities
FuncR_S119, FuncR_S121	Data and power transfer between SM
FuncR_S110, FuncR_S120, FuncR_S122	Resources re-allocation, data and power routing
FuncR_S115	Heat management between SM
FuncR_S111	Failure detection and handling

In RD5 a set of tests are described that will be performed on the integrated setup and/or during the final integration. The purpose is on confirming the readiness for the demonstration. These tests imply the availability of multiple components and also multiple partners at one location.

This chapter provides the description of the tests and demonstrations procedures that validate the project requirements, and more particular the ones under testing validation (see RD1). Some of these requirements are related to specific components, other ones to sub-systems or the full setup/demonstration.

1.2 Document Structure

In brief, the document is structured as follows:

Chapter 2 Component Validation Test (Partners site, WP4)

Chapter 3 Integration Tests (On-site, end WP4-WP5)

Chapter 4 Demonstration Scenarios (On-site, WP5)

Chapter 5 Annex

1.3 Applicable Documents

AD1 Strategic Research Cluster "Space Robotics Technologies" – Collaboration Agreement

AD2 MOSAR Consortium Agreement, version 1.0 (7-Nov-2018)

AD3 MOSAR Grant Agreement (821996) (18-Jan-2019)

AD4 MOSAR D1.4 System Requirements Document, MOSAR-WP1-D1.4-SA issue 1.0.0 (1-Sep-2019)

1.4 Reference Documents

RD1 MOSAR D1.4 System Requirements Document, MOSAR-WP1-D1.4-SA, issue 1.1.0

RD2 MOSAR D2.1 OG1-5 Adaptations and Extensions Specifications, MOSAR-WP2-D2.1-GMV issue 1.0.0

RD3 MOSAR D2.2 Non-building block components preliminary design, MOSAR-WP2-D2.2-SA, issue 1.0.0

RD4 MOSAR D2.4 Preliminary Design Document, MOSAR-WP2-D2.4-SA issue 1.0.0

RD5 MOSAR D2.3 Test Demonstration Specification, MOSAR-WP2-D2.3-SA issue 1.1.0

RD6 MOSAR D3.6 Detailed Design Document (DDD), MOSAR-WP3-D3.6-SA issue 1.0.0

1.5 Acronyms

BAT	Battery System
CDR	Critical Design Review
CLT	CLienT (satellite)
cPDU	centralized Power Distribution Unit
EGSE	Electrical Ground Support Equipment
ESA	European Space Agency
FES	Functional Engineering Simulator
FMC	FPGA Mezzanine Card
ICD	Interface Control Document
IDC	Insulation Displacement Connector\
KPI	Key Performance Indicators
DMS	Data Management System
MAIT	Manufacturing, Assembly, Integration and Testing
MCC	Monitoring and Control Center
MGSE	Mechanical Ground Support Equipment
OBC	On-Board Computer
OG	Operational Grant
OSP	Optical Sensor Payload

PDD	Preliminary Design Document
PDR	Preliminary Design Review
PWS	Power System
SI	Standard Interface
SVC	Service (spacecraft)
THS	Thermal System
TM	Telemetry
TC	Telecommand
TCP	Tool Center Point
TRR	Test Readiness Review
TTC	Telemetry and Telecommand
WM	Walking Manipulator

2 Component Validation Test (Partners site, WP4)

This section provides, for each developed component, the list of tests that will be done at the component level during WP4, before the final integration. This can be Unitary (component alone) or Combined (with another component) tests. The tests should focus either on project requirements associated specifically to the component or important characteristics that are required for the integration in the final demonstration. In general, these tests do not require colocations with partners.

2.1 Walking Manipulator

<table>
<tr><td>ID</td><td>CT-A-1</td><td>Title</td><td colspan="2">WM Monitoring and Motion Control</td><td>Lead</td><td>DLR/SpaceApps</td></tr>
<tr><td>Type</td><td>Unitary</td><td colspan="2">Pre-Requisite</td><td colspan="3">N.A.</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">The WM is able to be controlled in the following modes, at 500 Hz:
• Joint Control
• Cartesian Position Control
• Impedance Position Control
and the WM parameters can be monitored (joint angles, current, torques)</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- The WM is fixed on one extremity and free on the other side
- The WM Controller is used to perform the tests

<u>Procedure:</u>
- The operator initiates test sequences for each type of control methodology, by monitoring the physical motion of the arm (or interaction with environment for the impedance), the monitored variables and the update frequency of the control loop</td></tr>
<tr><td colspan="7">Covered Requirements</td></tr>
<tr><td colspan="7">FuncR_B103 (Joint position control)
FuncR_B104 (Cartesian position control)
FuncR_B104bis (Impedance control)</td></tr>
</table>

<table>
<tr><td>ID</td><td>CT-A-2</td><td>Title</td><td colspan="2">WM Power On/Off</td><td>Lead</td><td>DLR/SpaceApps</td></tr>
<tr><td>Type</td><td>Unitary</td><td colspan="2">Pre-Requisite</td><td colspan="3">N.A.</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">The WM is able to be powered on/off, keeping its current position (with use of WM brakes)</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- The WM is fixed on one extremity and free on the other side or with a SM payload (or representative mass dummy)
- The WM power bus is connected to a 48V power supply
- The WM Controller is used to perform the tests

<u>Procedure:</u>
- The operator powers on the WM, through the 48V power supply and validate that the WM is keeping its current position
- The operator monitors the WM TM
- The operator powers OFF the WM
- The operators verifies that the WM keeps its position</td></tr>
</table>

The procedure is repeated with free end and with an SM attached payload
Covered Requirements
FuncR_B106 (Power-on/off)

ID	CT-A-3	**Title**	WM Lifting Capabilities		**Lead**	SpaceApps
Type	Unitary	**Pre-Requisite**		N.A.		
Purpose / Expected Result						
The WM is able to lift up to 10kg at the end-effector, in its workspace						
Procedure						
Configuration: - The WM is fixed on one extremity and free on the other side - A payload of 10kg is fixed at the end-effector - The WM power bus is connected to a 48V power supply - The WM Controller is used to perform the tests Procedure: - The operator powers on the WM, through the 48V - The WM is moved in different positions to validate its capability to move the attached mass in its workspace						
Covered Requirements						
PerfR_B201 (Lifting capability)						

ID	CT-A-4	**Title**	WM Faulty Behaviour Detection		**Lead**	DLR/SpaceApps
Type	Unitary	**Pre-Requisite**		N.A.		
Purpose / Expected Result						
The WM is able to react and provide feedback about faulty behavior of the WM operations						
Procedure						
Configuration: - The WM is fixed on one extremity and free on the other side - The WM power bus is connected to a 48V power supply - The WM Controller is used to perform the tests Procedure: - Different Faulty behaviour are simulated on the WM controller to verify the reaction of the WM as well as the update of the tracking variables - Examples of faulty behaviour: - Joint Drive over-current - Joint over-torque / excess interaction forces - Variable over range - Others TBC						
Covered Requirements						
FuncR_B105 (Fault detection)						
ID	CT-A-5	**Title**	WM Weight		**Lead**	DLR/SpaceApps
Type	Unitary	**Pre-Requisite**		N.A.		

Purpose / Expected Result
Measure the weight of the WM
Procedure
Procedure: - Measure the weight of the WM
Covered Requirements
PhyR_B501 (WM Weight)

ID	CT-A-6	**Title**	WM HOTDOCK Control	**Lead**	SpaceApps
Type	Combined	**Pre-Requisite**	Both WM extremities are equipped with an active HOTDOCK SI		
Purpose / Expected Result					
The WM is able to monitor and control the extremities HOTDOCK SI through the local CAN bus					
Procedure					

Configuration:
- The WM Controller is used to perform the tests, with CAN communication to the HOTDOCK SI
- The WM power bus is connected to a 48V power supply
 	
Procedure:
- The operator verifies the CAN communication availability with both HOTDOCK SI
- The operator verifies the CAN TM from the two HOTDOCK SI
- The operator sends CAN TC to both HOTDOCK SI to validate operation of HOTDOCK:
    - HOTDOCK state update (latching)
    - HOTDOCK power bus switch					

Covered Requirements					
IntR_B305 (WM local CAN network) FuncR_A105 (Components low level control) IntR_B304 bis (WM Interface switch) IntR_B307 (WM mechanical interface to SI)					

ID	CT-A-7	**Title**	WM Power Transfer	**Lead**	SpaceApps
Type	Combined	**Pre-Requisite**	Both WM extremities are equipped with an active HOTDOCK SI, which are connected to a passive SI		
Purpose / Expected Result					
A power of 0.5 kW (TBC) can be transferred through the WM					
Procedure					
Configuration: - The WM Controller is used to perform the tests, with CAN communication to the HOTDOCK SI - The WM power bus is connected to a 48V power supply - The power transfer interface of the passive HOTDOCK-A is connected to a 48V power supply - The power transfer interface of the passive HOTDOCK-B is connected to an electrical load Procedure: - The operator switches on the WM power bus - The operator switches on the 48V power supply					

- The operator enables the power relay of the HOTDOCK and verifies the power transfer through the WM.
Covered Requirements
PerfR_B205 (Power Transfer)

ID	CT-A-8	**Title**	WM Start-Up, Initialization and Communication with OBC-S	**Lead**	SpaceApps
Type	Combined	**Pre-Requisite**	Both WM extremities are equipped with an active HOTDOCK SI, which are connected to a passive SI OBC-S interface to WM controller through SpW/RMAP		
Purpose / Expected Result					
The WM is able to get power, start and initialize automatically after power-on, reaching a state ready for communication and operations. The WM Controller is able to provide TM and get TC to/from the OBC-S, through its HOTDOCK SI.					
Procedure					
Configuration: - The OBC-S is connected by SpW to the WM Controller by the SpW bus through SpW bricks and the HOTDOCK SI - The WM power bus is connected to a 48V power supply Procedure: - The power bus is switched ON - The operator verifies on the OBC-S that the SpW communication with the WM controller is enabled - The operator enables the housekeeping TM for the WM through RMAP TC - The operator verifies that the housekeeping TM for the WM is received on the OBC-S - The operator sends TC to the WM through RMAP TC: - WM control commands - WM configurations commands - WM HOTDOCK SI control - The operator verifies the action of the TC (e.g. TM update) The test is repeated with the second extremity of the WM.					
Covered Requirements					
FuncR_A108 (Monitoring) FuncR_B107 (WM start and initialization) IntR_B301 (WM TM/TC) IntR_B303 (WM Power) FuncR_A104 (SVC high level control) IntR_B306 (WM local control network)					

ID	CT-A-9	**Title**	WM connection to SVC/CLT HOTDOCK SI	**Lead**	SpaceApps
Type	Combined	**Pre-Requisite**	Both WM extremities are equipped with an active HOTDOCK SI Integrated SCV/CLT buses with HOTDOCK SI		
Purpose / Expected Result					
The WM is able to connect to the SI of the spacecraft mockup, independently through one of its own SI					
Procedure					
Configuration: - The WM Controller is used to perform the tests - The WM power bus is connected to a 48V power supply Procedure: - The operator manually aligns one WM HOTDOCK SI to a HOTDOCK SI on the SCV/CLT - The operator commands the WM to connect the WM HOTDOCK SI - The operator validates the good mechanical connection and the continuity connection for the data and power transfer					
Covered Requirements					
FuncR_B101 (SM Connection)					

ID	CT-A-10	**Title**	WM connection to SM SI	**Lead**	SpaceApps
Type	Combined	**Pre-Requisite**	Both WM extremities are equipped with an active HOTDOCK SI Integrated SM with HOTDOCK passive SI and R-ICU OBC-S interface to WM controller through SpW/RMAP		
Purpose / Expected Result					
The WM is able to connect to the SI of a SM, is able to power					
Procedure					
Configuration: - The WM Controller is used to perform the tests - The WM power bus is connected to a 48V power supply Procedure: - The SM SI and the WM SI are aligned - The operator commands the WM to connect the WM HOTDOCK SI - The operator validates the good mechanical connection - The operator commands the WM to switch ON the power transfer of the HOTDOCK SI - The operator validates the start-up of the SM - The operator verifies on the OBC-S that the SpW communication with the SM R-ICU is enabled					
Covered Requirements					
FuncR_B101 (SM Connection) IntR_B302 (WM Data Transfer to SM) IntR_B304 (WM Powers Transfer to SM)					

2.2 B-HOTDOCK Standard Interface

ID	CT-B-1	**Title**	HOTDOCK TM and TC	**Lead**	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
Validate the TM / TC of HOTDOCK with OBC, through CAN					
Procedure					
Configuration: - Active HOTDOCK, powered by 24V power supply and controlled by OBC through CAN Procedure: - Check the reception of the different TM messages (Temperature, encoder position, state, proximity, orientation) - Send the different TC to HOTDOCK and observe reaction (switch state, Emergency stop)					
Covered Requirements					
FuncR_D109 (SI Telemetry)					

ID	CT-B-2	**Title**	HOTDOCK Active to Passive Mechanical Connection, power and SpW Data transfer	**Lead**	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
An active HOTDOCK is able to connect to a passive HOTDOCK, and transfer power and SpW data					
Procedure					
Configuration: - Active HOTDOCK, powered by 24V power supply and controlled by OBC through CAN - Passive HOTDOCK - OBC with CAN and SpW interface (Spw Bricks) Procedure: - The Active HOTDOCK is controlled to connect to the passive HOTDOCK - The operator validates the good mechanical connection and the conductivity between data/power interface lines - The operator measures the connection time - The operator tests and validates SpW data transfer through HOTDOCK, evaluate max data transfer - The operator tests and validates TM / TC (switch ON/OFF) of the power interface, power transfer through HOTDOCK, and evaluation of max power transfer (with or without power switch) - The operator validates the software based over-voltage and over-current protection (through switch off of the power relay of the active interface) - The Active HOTDOCK is controlled to disconnect to the passive HOTDOCK					
Covered Requirements					
FuncR_D103 (Passive coupling) FuncR_D104 (Passive de-coupling) FuncR_D105 (protection) FuncR_D106 (power interface switch) FuncR_D107 (power interface TM) PerfR_D203 (power transfer) PerfR_D204 (data transfer rate) PhyR_D603 (Connection time)					

ID	CT-B-3	Title	HOTDOCK Power Consumption	Lead	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
Measure HOTDOCK power consumption, target <1A under 24V					
Procedure					
Configuration: - Active HOTDOCK, powered by 24V power supply and controlled by OBC through CAN - Passive HOTDOCK - OBC with CAN and SpW interface (Spw Bricks) Procedure: - Measure HOTDOCK power consumption for the different mode of operations					
Covered Requirements					
PhyR_D602 (Power Consumption)					

ID	CT-B-4	Title	HOTDOCK 90deg symmetry	Lead	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
Validate that the HOTODCK can support connection every 90 degrees (mechanical, data and poswer)					
Procedure					
Configuration: - Active HOTDOCK, powered by 24V power supply and controlled by OBC through CAN - Passive HOTDOCK - OBC with CAN and SpW interface (Spw Bricks) Procedure: - Test the mechanical connection, data and power transfer successively for each 90 degree rotation					
Covered Requirements					
DesR_D402 (90deg. Symmetry)					

ID	CT-B-5	Title	HOTDOCK Mechanical Guidance	Lead	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
Validate the capability of HOTDOCK Form-Fit to support the self-alignment, under manipulation of a robotic arm					
Procedure					
Configuration: - HOTDOCK interface connected to robotic arm end-effector (c.f.DLR test) - HOTDOCK interface on fixed structure Procedure:					

- Validate the approach and self-alignment of the two HOTDOCK interfaces, under control of the robotic arm. Evaluate guidance performances (ROA linear, angular) (c.f. DLR tests)					
Covered Requirements					
PerfR_D202 (Mechanical guidance) DesR_D404 (Mechanical guidance)					

ID	CT-B-6	**Title**	HOTDOCK Diagonal Engagement	**Lead**	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
Validate the capability of HOTDOCK to perform diagonal engagement of at least 55 degrees					
Procedure					
<u>Configuration:</u> - HOTDOCK interface connected to robotic arm end-effector (c.f.DLR test) - HOTDOCK interface on fixed structure <u>Procedure:</u> - Validate the diagonal approach and alignment of the two HOTDOCK interfaces, under control of the robotic arm through pre-defined trajectory. Evaluate performances from different approach angles					
Covered Requirements					
DesR_D403 (Diagonal Engagement)					

ID	CT-B-7	**Title**	HOTDOCK Mechanical Loading	**Lead**	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
Validate the mechanical loading performance of HOTDOCK for longitudinal force and bending moment					
Procedure					
<u>Configuration:</u> - Active HOTDOCK mechanically latched to passive HOTDOCK <u>Procedure:</u> - Traction test and bending test on the Active/Passive mechanical connection					
Covered Requirements					
PerfR_D201 (Mechanical loading)					

<table>
<tr><td>ID</td><td>CT-B-8</td><td>Title</td><td colspan="2">HOTDOCK Active to Passive thermal connection and thermal transfer by fluid exchange</td><td>Lead</td><td>MAGSOAR / SpaceApps</td></tr>
<tr><td>Type</td><td>Combined</td><td colspan="2">Pre-Requisite</td><td colspan="3">Thermal subsystem</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">An active HOTDOCK is able to connect to a passive HOTDOCK through its thermal interface and transfer thermal power</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- Thermal Active HOTDOCK, powered by 24V power supply and controlled by OBC through CAN
- Thermal Passive HOTDOCK
- OBC with CAN
- Thermal subsystem circuitry connected to each HOTDOCK

<u>Procedure:</u>
- The Active HOTDOCK is controlled to connect to the passive HOTDOCK
- The operator validates the good mechanical connection
- The operator tests and validates the thermal transfer by fluid exchange (through control of the thermal subsystem components), evaluation of the thermal transfer performances</td></tr>
<tr><td colspan="7">Covered Requirements</td></tr>
<tr><td colspan="7">FuncR_D103 (Passive coupling)
FuncR_D104 (Passive de-coupling)
PerfR_D205 (Thermal transfer performance)</td></tr>
</table>

2.3 Spacecraft Modules and Components

<table>
<tr><td>ID</td><td>CT-C-1</td><td>Title</td><td colspan="2">SMs Weight</td><td>Lead</td><td>SITAEL</td></tr>
<tr><td>Type</td><td>Unitary</td><td colspan="2">Pre-Requisite</td><td colspan="3">N.A.</td></tr>
<tr><td colspan="7" align="center">Purpose / Expected Result</td></tr>
<tr><td colspan="7">Measure the weight of the different mobile SMs</td></tr>
<tr><td colspan="7" align="center">Procedure</td></tr>
<tr><td colspan="7"><u>Procedure:</u>
- Measure the weight of the different mobile SMs</td></tr>
<tr><td colspan="7" align="center">Covered Requirements</td></tr>
<tr><td colspan="7">PhyR_C501 (SM Weight)</td></tr>
</table>

2.3.1 cPDU

<table>
<tr><td>ID</td><td>CT-C-2</td><td>Title</td><td colspan="2">cPDU DC/DC conversions</td><td>Lead</td><td>SpaceApps</td></tr>
<tr><td>Type</td><td>Unitary</td><td colspan="2">Pre-Requisite</td><td colspan="3">Thermal subsystem</td></tr>
<tr><td colspan="7" align="center">Purpose / Expected Result</td></tr>
<tr><td colspan="7">The cPDU is able provide required voltage (24V, 12V) from the main 48V bus</td></tr>
<tr><td colspan="7" align="center">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- cPDU, powered by 48V
<u>Procedure:</u>
- The cPDU is powered ON
- The different DC/DC conversion voltages are validated</td></tr>
<tr><td colspan="7" align="center">Covered Requirements</td></tr>
<tr><td colspan="7">Required function</td></tr>
</table>

<table>
<tr><td>ID</td><td>CT-C-3</td><td>Title</td><td colspan="2">cPDU TM and TC, power routing control</td><td>Lead</td><td>SpaceApps</td></tr>
<tr><td>Type</td><td>Unitary</td><td colspan="2">Pre-Requisite</td><td colspan="3">Thermal subsystem</td></tr>
<tr><td colspan="7" align="center">Purpose / Expected Result</td></tr>
<tr><td colspan="7">The cPDU is able to re-route power on different ports</td></tr>
<tr><td colspan="7" align="center">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- cPDU, powered by 48V
- OBC with CAN interface, connected to cPDU
- Power supply connected to one input port of the cPDU
<u>Procedure:</u>
- The cPDU is powered ON and the CAN communication is confirmed with the OBC
- Reception of CAN TM is validated
- CAN messages are sent to switch ON/OFF the other port of the cPDU (power re-distribution)
- CAN messages are sent to switch ON/OFF the DC/DC lines (12V, 24V)</td></tr>
<tr><td colspan="7" align="center">Covered Requirements</td></tr>
<tr><td colspan="7">FuncR_C104 bis (SM Power routing)
FuncR_C106 (SM switch ON/OFF)</td></tr>
</table>

2.3.2 R-ICU / FMC Board

ID	CT-D-1	**Title**	R-ICU SpW Routing	**Lead**	TAS-UK
Type	Unitary	**Pre-Requisite**	R-ICU/FMC Board SpW Brick interfaced to R-ICU		
Purpose / Expected Result					
The R-ICU and FMC board are able to transfer and route SpW data between different nodes					
Procedure					
<u>Configuration:</u> - SpW Brick connected to PC to represent OBC - SpW Brick connected to R-ICU A - R-ICU A connected to R-ICU B via SpW <u>Procedure:</u> -R-ICUs are powered on -R-ICU SpW IDs and router tables initialised to represent the test topology -OBC writes data using RMAP to R-ICU A using SpW path addressing -OBC checks for successful RMAP reply from R-ICU A -OBC writes data using RMAP to R-ICU B using SpW path addressing -OBC checks for successful RMAP reply from R-ICU B -OBC writes data using RMAP to R-ICU A using SpW logical addressing -OBC checks for successful RMAP reply from R-ICU A -OBC writes data using RMAP to R-ICU B using SpW logical addressing -OBC checks for successful RMAP reply from R-ICU B -OBC performs continuous RMAP writes to R-ICU A to determine SpW throughput and RMAP write performance without TMTC handling present on the R-ICU -OBC performs continuous RMAP reads to R-ICU A to determine SpW throughput and RMAP read performance without TMTC handling present on the R-ICU -OBC performs continuous RMAP writes to R-ICU B to verify effect of SpW router latency on RMAP performance					
Covered Requirements					
PerfR_A201 (Sub-systems TM/TC data rate) FuncR_C103 (SM data routing) FuncR_C104 (SM data transmission) FuncR_C105 (SM redundancy) FuncR_D108 (Data Interface Support)					

ID	CT-D-2	**Title**	R-ICU TMTC Handling	**Lead**	TAS-UK
Type	Unitary	**Pre-Requisite**	R-ICU/FMC Board SpW Brick interfaced to R-ICU running OBC RMAP TMTC software		
Purpose / Expected Result					
Validate the RMAP TMTC and evaluate performance. OBC should be able to command R-ICU using RMAP telecommands and read status information using RMAP telemetry					
Procedure					
<u>Configuration:</u> - SpW Brick connected to PC to represent OBC					

- SpW Brick connected to R-ICU A - UART cable connected to R-ICU A Procedure: -R-ICUs are powered on -R-ICU SpW IDs and router tables initialised to represent the test topology -R-ICU TMTC handling task and R-ICU control task are started -OBC issues each R-ICU TC in turn and effects are verified through physical inspection (LEDs) or from UART output -OBC issues each R-ICU TM in turn and returned values are displayed for verification by cross check with the R-ICUs current state (physical inspection or UART output)
Covered Requirements
PerfR_A201 (Sub-systems TM/TC data rate) PerfR_A202 (Sub-systems services data rate) PerfR_C201 (SM data interface rate for TM/TC) PerfR_C202 (SM data interface rate for service data) PerfR_B204 (WMdata interface rate for service data) PerfR_B203 (WMdata interface rate for TM/TC)

ID	CT-D-3	**Title**	R-ICU TMTC Error Handling	**Lead**	TAS-UK
Type	Unitary	**Pre-Requisite**	R-ICU / FMC Board SpW Brick interfaced to R-ICU running OBC RMAP TMTC software		
Purpose / Expected Result					
A corrupted TMTC packet should not cause the TMTC handling to fail in such a way that affects the operation of the R-ICU or OBC TMTC software or stalls the network					
Procedure					
Configuration: - SpW Brick connected to PC to represent OBC - SpW Brick connected to R-ICU A - R-ICU A connected to R-ICU B via SpW Procedure: -R-ICUs are powered on -R-ICU SpW IDs and router tables initialised to represent the test topology -R-ICU TMTC handling task and R-ICU control task are started - R-ICU A is set up to inject faults into RMAP header and data as the RMAP packet is routed. -OBC issues TC requests to R-ICU B. R-ICU A injects a fault into the RMAP header. -OBC should receive RMAP reply indicating CRC error in RMAP header -OBC issues TC requests to R-ICU B. R-ICU A injects a fault into the RMAP data. -OBC should receive RMAP reply indicating CRC error in RMAP data -OBC issues TM requests to R-ICU B. R-ICU A injects a fault into the RMAP reply. -OBC should receive RMAP reply indicating CRC error in RMAP reply -OBC issues TC requests with invalid logical address -R-ICU A should spill the packet and notify R-ICU that invalid SpW logical address was detected					

- R-ICU B locks a TM memory area but does not release the lock -OBC issues TM request to this memory area -After timeout period, OBC should receive RMAP reply indicating NOT AUTHORISED error in RMAP header
Covered Requirements
FuncR_D108 (Data Interface Support)

ID	CT-D-4	**Title**	R-ICU Component SW API	**Lead**	TAS-UK
Type	Unitary	**Pre-Requisite**	R-ICU / FMC Board SpW Brick interfaced to R-ICU running OBC RMAP TMTC software CAN test interface		
Purpose / Expected Result					
R-ICU TMTC handling and CAN drivers need to support multiple R-ICU software drivers using these interface simultaneously					
Procedure					
Configuration: - SpW Brick connected to PC to represent OBC - SpW Brick connected to R-ICU A - R-ICU A connected to R-ICU B via SpW Procedure:					
Covered Requirements					
IntR_C303 (SM R-ICU to SI TM/TC)					

ID	CT-D-5	**Title**	R-ICU Network Discovery and Configuration	**Lead**	TAS-UK
Type	Unitary	**Pre-Requisite**	R-ICU / FMC Board SpW Brick interfaced to R-ICU running OBC RMAP TMTC software		
Purpose / Expected Result					
The OBC is able to read the SpW PnP information fields and this information represents the state of the network. OBC is able to configure the R-ICU routing tables.					
Procedure					
Configuration: - SpW Brick connected to PC to represent OBC - SpW Brick connected to R-ICU A - R-ICU A connected to R-ICU B via SpW Procedure: -R-ICUs are powered on -R-ICU SpW IDs are set as per spacecraft configuration. Routing table entries are reset to NULLs -R-ICU TMTC handling task is started					

-OBC issues SpW PnP: network information read TM request to R-ICU A SpW ID. -OBC should receive network status information of router of R-ICU A -OBC issues SpW PnP: application information read TM request to R-ICU A SpW ID. -OBC should receive information about the components connected to the R-ICU A -OBC uses network information field and SpW path addressing to request SpW PnP TM from R-ICU B -OBC should receive network status information of router of R-ICU B -OBC issues SpW PnP: application information read TM request to R-ICU B SpW ID. -OBC should receive information about the components connected to the R-ICU B -OBC issues routing table set TC to R-ICU A to set up the path to R-ICU B -OBC issues TM request to R-ICU B using SpW logical addressing -OBC should receive R-ICU B TM
Covered Requirements
FuncR_A111 (Modules Plug & Play detection) FuncR_C105 (SM redundancy) FuncR_C108 (Identification Information) FuncR_D108 (Data Interface Support) DesR_A407 (Data Network)

ID	CT-D-6	**Title**	Camera Rendering through SpW to OBC-C	**Lead**	TAS-UK
Type	Combined	**Pre-Requisite**	R-ICU / FMC Board I3DS Framework ZED Camera OBC-C interfaced to R-ICU through SpW/RMAP		
Purpose / Expected Result					
The R-ICU is able to interface the ZED Camera and transmit picture data to the OBC-C					
Procedure					
<u>Configuration:</u> - SpW Brick connected to PC to represent OBC - SpW Brick connected to R-ICU -ZED Camera attached to R-ICU -UART cable connected to R-ICU <u>Procedure:</u> -R-ICUs are powered on -R-ICU SpW IDs and router tables initialised to represent the test topology -R-ICU TMTC handling task and R-ICU control task are started -I3DS framework initialises and connects to Zed Camera -OBC issues TC to configure Zed camera. -Confirmation of Zed camera settings should be present on R-ICU UART -OBC issues TM to read Zed camera frame. -OBC should receive the image data					

-OBC polls Zed camera status TM and fetches frame TM if available -Optical payload maximum rate over the SpW network can be established
Covered Requirements
DesR_A404 (OG4 Reuse) PerfR_A202 (Sub-systems services data rate) PerfR_C202 (SM data interface rate for service data)

ID	CT-D-7	**Title**	SM Power On and TM to OBC-S	**Lead**	TAS-UK
Type	Combined	**Pre-Requisite**	R-ICU / FMC Board cPDU OBC-S interfaced to R-ICU through SpW/RMAP		
Purpose / Expected Result					
The SM is able to start and initialize automatically after power-on, reaching a state ready for communication and operations'					
Procedure					
<u>Configuration:</u> - cPDU, connected to switchable 48V power supply - cPDU connected to R-ICU by CAN - R-ICU connected to OBC-S through SpW / RMAP <u>Procedure:</u> - The cPDU is powered ON from power supply - The start-up of the cPDU, R-ICU and good initialization are confirmed on the OBC-S via TM - The reception of TM from R-ICU is validated on OBC-S					
Covered Requirements					
FuncR_C107 (SM Sstart and initialization) FuncR_C108 (Identification information) FuncR_C109 (Status and fault detection)					

2.3.3 Battery Subsystem

ID	CT-E-1	**Title**	Battery subsystem TM / TC	**Lead**	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
The battery subsystem can be interfaced to OBC through CAN communication					
Procedure					
<u>Configuration:</u> - Battery subsystem powered by 24V/48V power supply - OBC with CAN interface, connected to battery subsystem controller <u>Procedure:</u> - The battery subsystem is powered ON - The CAN communication between the battery subsystem and the OBC is confirmed - Validation of TM and TC with the battery subsystem, from the OBC					
Covered Requirements					

Required function

ID	CT-E-2	**Title**	Battery subsystem charging / discharging	**Lead**	SpaceApps
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
The battery subsystem can be charged and discharged					
Procedure					
Configuration: - Battery subsystem powered by 24V/48V power supply - Power supply to charge and electrical load to discharge, connected to the battery subsystem - OBC with CAN interface, connected to battery subsystem controller Procedure: - The battery subsystem is powered ON - The CAN communication between the battery subsystem and the OBC is confirmed - Control of the battery subsystem through CAN command to charge/discharge the battery, validation by TM					
Covered Requirements					
Required function					

2.3.4 Thermal Subsystem

ID	CT-F-1	**Title**	Thermal IF performance	**Lead**	MAG SOAR
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
○ The standard interface shall provide a thermal interface to allow active transfer of thermal flow between two Spacecraft Modules ○ The thermal interface shall allow a thermal flow rating of 2500 W ○ The thermal interface shall enable thermal connection to the thermal module sub-system ○ The pressure drop of the thermal IF will be quantified for different liquid flows					
Procedure					
Configuration: - Hot site connected to thermal IF - Cold site connected to thermal IF Procedure: - The thermal IFs are mechanically linked - Temperature sensors are implemented on input and output of the hot site - Temperature sensors are implemented on input and output of the cold site - Pressure sensors are implemented in the hydraulic circuit **These tests will be carried out at MAG SOAR facilities**					
Covered Requirements					
FuncR_D102 PerfR_D205 IntR_D303					

ID	CT-F-2	Title	Demonstration of heat transfer in the thermal subsystem (250 W)	Lead	MAG SOAR
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
○ Demonstrate the capability of the thermal subsystem to transfer 250 W					
Procedure					
Configuration: - The thermal subsystem is closed and allow close loop circulation Procedure: - The thermal IFs are mechanically linked - Temperature sensors are located in the input and output of the fan pipes - Temperature sensors are located in the input and output of the heat generator - Pressure sensors are implemented in the hydraulic circuit					
Covered Requirements					
PerfR_D205					

ID	CT-F-3	Title	Demonstration of non-leakage strategy	Lead	MAG SOAR
Type	Unitary	**Pre-Requisite**	N.A.		
Purpose / Expected Result					
○ Demonstrate the non-leakage control strategy proposed for the thermal subsystem					
Procedure					
Configuration: - The thermal subsystem is closed and allow close loop circulation Procedure: - The thermal IFs are mechanically linked - Temperature sensors are implemented on input and output of the heat exchanger - Temperature sensors are implemented on input and output of the cooler - Pressure sensors are implemented in the hydraulic circuit - Transparent pipes will allow visual inspection of the fluid along the line					
Covered Requirements					
Required function					

ID	CT-F-4	Title	Orbital pump failure operation	Lead	MAG SOAR
Type	Unitary	**Pre-Requisite**	N.A.		
	Purpose / Expected Result				
	Demonstrate that after a hypothetical pump failure on orbit, the redundant pump can manage the power transferred				
	Procedure				
	Configuration:				

	- The thermal subsystem is closed and allow close loop circulation Procedure: - The thermal IFs are mechanically linked - Temperature sensors are implemented on input and output of the heat exchanger - Temperature sensors are implemented on input and output of the cooler - Pressure sensors are implemented in the hydraulic circuit - Transparent pipes will allow visual inspection of the fluid along the line
	Covered Requirements
	Required function

2.4 Design and Simulator Tools

<table>
<tr><td>ID</td><td>CT-G-1</td><td>Title</td><td colspan="2">Design and Simulation tool procedure</td><td>Lead</td><td>DLR</td></tr>
<tr><td>Type</td><td>Pre-integrated</td><td colspan="2">Pre-Requisite</td><td colspan="3">- Full parameter files for scenario and components
-WM controller and trajectory planner.</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">The Design tool will check the scenario and important parameters for validity. The FES simulator will simulate the whole scenario and generate data plots and data results for further analysis.</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- Set parameter files for components and scenario
- Initialize full setup of FES, WM controller and Trajectory planner

<u>Procedure:</u>
- Start design toll form MATLAB/ Simulink
- Wait until analysis is finished.
- Check Design Toll log file for warnings and errors
-If everything is ok run full FES simulation, otherwise adjust parameters and/or scenario
- Run trajectory planner with the desired trajectory it will send commands to the WM controller which will communicate with the FES
- Wait until simulation is finished.
- Run evaluation Matlab script to generate data files and plots for the simulation
- Analyse the simulator outputs and plots,</td></tr>
<tr><td colspan="7">Covered Requirements</td></tr>
<tr><td colspan="7">FuncR_E104 (Task Planning and Simulation)
FuncR_E106 (Simulation of Reconfiguration)
FuncR_E109 (Manipulator Dynamics Simulation)
PerfR_E201 (Simulation Real-Time Performance)
PerfR_E202 (Number of SM in Simulation)
IntR_E301(Simulator Input Interfaces)
IntR_E302 (Simulator Output Interfaces)
IntR_E303 (Simulator Communication Interface)
IntR_E304 (Generation of plan for onboard execution)</td></tr>
</table>

2.5 Planner and Agent

<table>
<tr><td>ID</td><td>CT-H-1</td><td>Title</td><td colspan="2">On-ground plan calculation (display driver)</td><td>Lead</td><td>GMV</td></tr>
<tr><td>Type</td><td>Pre-integrated</td><td colspan="2">Pre-Requisite</td><td colspan="3">- Agent CFG files (agent and timelines).
- Planner PDDL model (problem and domain).</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">ERGO Agent will run perform a plan in E4 autonomy level using PUS Console and display driver. This plan will be saved and re-run using E3 autonomy level.</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- Initialize PUS Console
- Initialize Agent in E4 autonomy level with Functional compiled with the Display RARM driver

<u>Procedure:</u>
- Send planner goal using PUS Service 200.
- An E4 plan is generated and executed.
- Wait until plan is finished.
- Reinitialize all the components to repeat with the generated goal in E3.
- Configure Agent to run in E3 autonomy level using Service 200.
- Send E3 plan goal using Service 23 and 200. Uploads and run previous plan.
- Wait until the same plan finishes.
- Check that same plan is executed following the same operation order.</td></tr>
<tr><td colspan="7">Covered Requirements</td></tr>
<tr><td colspan="7">FuncR_A103
DesR_A401
DesR_A402
IntR_E304
FuncR_F105
FuncR_F106
IntR_F301
DesR_F401
ConfR_F801</td></tr>
</table>

2.6 MCC and PUS Service

ID	CT-I-1	**Title**	SW Reconfiguration	**Lead**	GMV
Type	Pre-integrated	**Pre-Requisite**	N/A		
Purpose / Expected Result					
OBC shall be able to enable and disable come on-board functions from SMs doing a re-configuration process.					
Procedure					
Configuration: - Initialize PUS Console - Define several reconfiguration modes enabling/disabling different SMs Procedure: - Use PUS Service 220 to set a reconfiguration mode. - Using dummy “prints” to show the enable/disable status of each SM-XX. - Check housekeeping parameters values for each SM to check the status flags.					
Covered Requirements					
FuncR_A111 IntR_A304 DesR_A401 FuncR_F101 ConfR_F801 ConfR_F802					

ID	CT-I-2	**Title**	PUS-RMAP commanding chain	**Lead**	GMV
Type	Pre-integrated	**Pre-Requisite**	N/A		
Purpose / Expected Result					
PUS to command via RMAP and get TMs from dummy R-ICU functionality.					
Procedure					
Configuration: - Initialize Image viewer - TASTE simplified module Procedure: - Use PUS Service 210 to send TCs via RMAP to p.e. turn on a LED - Check via Housekeeping (Service 3) different parameters requested to R-ICU are shown in PUS Console - Check in PUS console that parameters acquired via RMAP are as expected					
Covered Requirements					
FuncR_A112 DesR_A401 FuncR_F102 FuncR_F103 IntR_F301					

<table>
<tr><td>ID</td><td>CT-I-3</td><td>Title</td><td colspan="2">Camera acquisition</td><td>Lead</td><td>GMV</td></tr>
<tr><td>Type</td><td>Pre-integrated</td><td colspan="2">Pre-Requisite</td><td colspan="3">N/A</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">SM-OSP using SPW driver is able to get a dummy image from the R-ICU and send it to ground via ZeroMQ using I3DS framework.</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- Initialize Image viewer
- TASTE simplified module
- Launch an I3DS address server in the MCC and the Client.

<u>Procedure:</u>
- R-ICU will generate dummy images
- Use PUS Service 210 to request an image. Via RMAP a dummy image will be read from R-ICU
- Requested image will be sent to ground using a publisher integrated in a I3ds node deployed in the Client trough ZeroMQ protocol and received by a subscriber instantiated in ground and showed in a viewer tool</td></tr>
<tr><td colspan="7">Covered Requirements</td></tr>
<tr><td colspan="7">FuncR_A108
FuncR_F102
FuncR_F103
FuncR_F104
IntR_F301</td></tr>
</table>

2.7 Visual Subsystem

ID	VSA1.1	**Title**	Detection of simple cube object	**Lead**	USTRATH
Type	Software Integration	**Pre-Requisite**	The source stereo camera has been calibrated and camera calibration parameters are known, The disparity computation has been calibrated and good reconstruction parameters are known. Good algorithm parameters are known as result of previous experimentation.		
Purpose / Expected Result					
A 3D reconstruction of the camera observed scene is visible in the output. If there are modules in the scene, these are detected and their models are visible in the output. Any damage is also detected and is visible in the output by means of bounding boxes around the region of anomaly. For each detected area of anomaly, a measure of the anomaly as average point-to-model distance is available; this is close to the real predicted damage. Processing time is also available.					
Procedure					
<u>Configuration:</u> <u>- Print two 3D cubes (about same size as the spacecraft module), a undamaged ideal one, and a damaged one, with 1cm average surface error on one face;</u> - Take two pictures from the stereo camera; - Write down a DFPC configuration file. Procedure: - Execute a step-by-step integration test for DFPC instance 1.1 using a single model in input. - Advance through the software steps until the final output is displayed. - Take note of the detected anomaly, and the reported measured error. Inputs VSA1.1.1. Picture of a scene which does not contain any cube object; VSA1.1.2 Pictures of a scene which contains the 3D printed undamaged cube within the shared view of the cameras; VSA1.1.3 Pictures of a scene which contains the 3D printed damaged cube within the shared view of the cameras.					
Covered Requirements					
Surface Anomaly Detection of Spacecraft Modules Surface Anomaly Detection of Walking Manipulator					

ID	VSA1.2	**Title**	Detection of simple cube objects	**Lead**	USTRATH
Type	Pre-integrated	**Pre-Requisite**	The source stereo camera has been calibrated and camera calibration parameters are known, The disparity computation has been calibrated and good reconstruction parameters are known. Good algorithm parameters are known as result of previous experimentation.		
Purpose / Expected Result					
A 3D reconstruction of the camera observed scene is visible in the output. If there are modules in the scene, these are detected and their models are visible in the output. Any damage is also detected and is visible in the output by means of bounding boxes around the region of anomaly. For each detected area of anomaly, a measure of the anomaly as average point-to-model distance is available, this is close to the real predicted damage. Processing time is also available.					
Procedure					
<u>Configuration:</u> <u>- Print two 3D cubes (about same size as the spacecraft module),, a undamaged ideal one, and a damaged one, with 1cm average surface error on one face;</u>					

- Take two pictures from the stereo camera; - Write down a DFPC configuration file. Procedure: - Execute a step-by-step integration test for DFPC instance 1.2 using a single model in input. - Advance through the software steps until the final output is displayed. - Take note of the detected anomaly, and the reported measured error. Inputs VSA1.2.1 Pictures of a scene which contains both 3D printed cubes within the shared view of the cameras.
Covered Requirements
Surface Anomaly Detection of Spacecraft Modules Surface Anomaly Detection of Walking Manipulator

ID	VSA1.3	**Title**	Detection of simple cube-like objects	**Lead**	USTRATH
Type	Pre-integrated	**Pre-Requisite**	The source stereo camera has been calibrated and camera calibration parameters are known, The disparity computation has been calibrated and good reconstruction parameters are known. Good algorithm parameters are known as result of previous experimentation.		
Purpose / Expected Result					
A 3D reconstruction of the camera observed scene is visible in the output. If there are modules in the scene, these are detected and their models are visible in the output. Any damage is also detected and is visible in the output by means of bounding boxes around the region of anomaly. For each detected area of anomaly, a measure of the anomaly as average point-to-model distance is available. Processing time is also available.					
Procedure					
<u>Configuration:</u> <u>- Print two 3D cubes and two 3D parallelepiped (about same size as the walking manipulator parts), one cube and one parallelepiped should be undamaged, and one cube and one parallelepiped should be damaged with 1cm average surface error on on side;</u> - Take two pictures from the stereo camera; - Write down a DFPC configuration file. Procedure: - Execute a step-by-step integration test for DFPC instance 1.3 using the two printed models in input; - Advance through the software steps until the final output is displayed. - Take note of the detected anomaly, and the reported measured error. Inputs; VSA1.3.1. Picture of a scene which does not contain any object; VSA1.3.2 Pictures of a scene which contains the 3D printed undamaged cube and the 3D printed undamaged parallelepiped within the shared view of the cameras; VSA1.3.3 Pictures of a scene which contains the 3D printed damaged cube and the 3D printed damaged parallelepiped within the shared view of the cameras.					
Covered Requirements					
Surface Anomaly Detection of Spacecraft Modules Surface Anomaly Detection of Walking Manipulator					

<table>
<tr><td>ID</td><td>VSA1.4</td><td>Title</td><td colspan="2">Detection of small cube objects</td><td>Lead</td><td>USTRATH</td></tr>
<tr><td>Type</td><td>Software Integration</td><td colspan="2">Pre-Requisite</td><td colspan="3">The source stereo camera has been calibrated and camera calibration parameters are known,
The disparity computation has been calibrated and good reconstruction parameters are known.
Good algorithm parameters are known as result of previous experimentation.</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">A 3D reconstruction of the camera observed scene is visible in the output. If there are modules in the scene, these are detected and their models are visible in the output. Any damage is also detected and is visible in the output by means of bounding boxes around the region of anomaly. For each detected area of anomaly, a measure of the anomaly as average point-to-model distance is available, this is close to the real predicted damage. Processing time is also available.</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
<u>- Print two 3D cubes (about same size as the interfaces), a undamaged ideal one, and a damaged one, with 5mm average surface error on one face;</u>
- Take two pictures from the stereo camera;
- Write down a DFPC configuration file.

Procedure:
- Execute a step-by-step integration test for DFPC instance 1.4 using a single model in input.
- Advance through the software steps until the final output is displayed.
- Take note of the detected anomaly, and the reported measured error.

Inputs:
VSA1.1.1. Picture of a scene which does not contain any cube object;
VSA1.1.2 Pictures of a scene which contains the 3D printed undamaged cube within the shared view of the cameras;
VSA1.1.3 Pictures of a scene which contains the 3D printed damaged cube within the shared view of the cameras.</td></tr>
<tr><td colspan="7">Covered Requirements</td></tr>
<tr><td colspan="7">Surface Anomaly Detection of Spacecraft Interfaces
Surface Anomaly Detection of Walking Manipulator Interfaces
Surface Anomaly Detection of Walking Manipulator</td></tr>
</table>

<table>
<tr><td>ID</td><td>VSA2.1</td><td>Title</td><td colspan="2">Detection of a simple cube and its components</td><td>Lead</td><td>USTRATH</td></tr>
<tr><td>Type</td><td>Software Integration</td><td colspan="2">Pre-Requisite</td><td colspan="3">The source stereo camera has been calibrated and camera calibration parameters are known,
The disparity computation has been calibrated and good reconstruction parameters are known.
Good algorithm parameters are known as result of previous experimentation.</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">A 3D reconstruction of the camera observed scene is visible in the output. If there are modules in the scene, these are detected and their models are visible in the output. Any damage is also detected and is visible in the output by means of bounding boxes around the region of anomaly. For each detected area of anomaly, a measure of the anomaly as average point-to-model distance is available, this is close to the real predicted damage. Processing time is also available.</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
<u>- Print two 3D almost-cubes (about same size as the interfaces). The cube should have a smaller cube attached to one face (about the same size as the interfaces). One almost-cube should be an undamaged ideal one, the second almost-cube should be a damaged one, with 1mm average surface error on one free face, and 5mm error on one free face of the smaller attached cube;</u></td></tr>
</table>

- Take two pictures from the stereo camera; - Write down a DFPC configuration file. Procedure: - Execute a step-by-step integration test for DFPC instance 2.1 using a single model in input. - Advance through the software steps until the final output is displayed. - Take note of the detected anomaly, and the reported measured error. Inputs: VSA1.1.1. Picture of a scene which does not contain the almost-cube object; VSA1.1.2 Pictures of a scene which contains the 3D printed undamaged cube within the shared view of the cameras; VSA1.1.3 Pictures of a scene which contains the 3D printed damaged cube within the shared view of the cameras.
Covered Requirements
Surface Anomaly Detection of Spacecraft Modules and their Interfaces. Surface Anomaly Detection of Walking Manipulator and its Interfaces.

ID	VSA2.2	**Title**	Detection of simple cube objects and their components	**Lead**	USTRATH
Type	Software Integration	**Pre-Requisite**	The source stereo camera has been calibrated and camera calibration parameters are known, The disparity computation has been calibrated and good reconstruction parameters are known. Good algorithm parameters are known as result of previous experimentation.		
Purpose / Expected Result					
The source stereo camera has been calibrated and camera calibration parameters are known, The disparity computation has been calibrated and good reconstruction parameters are known. Good algorithm parameters are known as result of previous experimentation.					
Procedure					
<u>Configuration:</u> <u>- Print two 3D almost-cubes (about same size as the interfaces). The cube should have a smaller cube attached to one face (about the same size as the interfaces). One almost-cube should be an undamaged ideal one, the second almost-cube should be a damaged one, with 1mm average surface error on one free face, and 5mm error on one free face of the smaller attached cube;</u> - Take two pictures from the stereo camera; - Write down a DFPC configuration file. Procedure: - Execute a step-by-step integration test for DFPC instance 2.2 using a single model in input. - Advance through the software steps until the final output is displayed. - Take note of the detected anomaly, and the reported measured error. Inputs: VSA1.2.1 Pictures of a scene which contains both 3D printed cubes within the shared view of the cameras.					
Covered Requirements					
Surface Anomaly Detection of Spacecraft Modules and their Interfaces. Surface Anomaly Detection of Walking Manipulator and its Interfaces.					

<table>
<tr><td>ID</td><td>VSA2.3</td><td>Title</td><td colspan="2">Detection of simple cube-like objects and their components</td><td>Lead</td><td>USTRATH</td></tr>
<tr><td>Type</td><td>Software Integration</td><td colspan="2">Pre-Requisite</td><td colspan="3">The source stereo camera has been calibrated and camera calibration parameters are known,
The disparity computation has been calibrated and good reconstruction parameters are known.
Good algorithm parameters are known as result of previous experimentation.</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">A 3D reconstruction of the camera observed scene is visible in the output. If there are modules in the scene, these are detected and their models are visible in the output. Any damage is also detected and is visible in the output by means of bounding boxes around the region of anomaly. For each detected area of anomaly, a measure of the anomaly as average point-to-model distance is available. Processing time is also available.</td></tr>
<tr><td colspan="7">Procedure</td></tr>
<tr><td colspan="7"><u>Configuration:</u>
- Print two 3D almost-cubes (about same size as a walking manipulator component) and 3D almost-parallelepiped (about the same size as the walking manipulator component). The cube and the parallelepiped should have a smaller cube attached to one face (about the same size as the interfaces), One almost-cube and one almost-parallelepiped should be an undamaged ideal one, the second almost-cube and the second almost-parallelepiped should be a damaged one, with 1mm average surface error on one free face, and 5mm error on one free face of the smaller attached cube;
- Take two pictures from the stereo camera
- Write down a DFPC configuration file.

Procedure:
- Execute a step-by-step integration test for DFPC instance 2.3 using the two printed models in input;
- Advance through the software steps until the final output is displayed.
- Take note of the detected anomaly, and the reported measured error.

Inputs:
VSA2.3.1. Picture of a scene which does not contain any object;
VSA2.3.2 Pictures of a scene which contains the 3D printed undamaged cube and the 3D printed undamaged parallelepiped within the shared view of the cameras;
VSA2.3.3 Pictures of a scene which contains the 3D printed damaged cube and the 3D printed damaged parallelepiped within the shared view of the cameras.</td></tr>
<tr><td colspan="7">Covered Requirements</td></tr>
<tr><td colspan="7">Surface Anomaly Detection of Spacecraft Modules
Surface Anomaly Detection of Walking Manipulator</td></tr>
</table>

<table>
<tr><td>ID</td><td>VSA3.1</td><td>Title</td><td colspan="2">Detection of reconfiguration anomalies</td><td>Lead</td><td>USTRATH</td></tr>
<tr><td>Type</td><td>Software Integration</td><td colspan="2">Pre-Requisite</td><td colspan="3">The source stereo camera has been calibrated and camera calibration parameters are known,
The disparity computation has been calibrated and good reconstruction parameters are known.
Good algorithm parameters are known as result of previous experimentation.</td></tr>
<tr><td colspan="7">Purpose / Expected Result</td></tr>
<tr><td colspan="7">A 3D reconstruction of the camera observed scene is visible in the output. If at least two cubes are present and their relative position is possible in the reconfiguration pattern, the the full reconfiguration pattern is displayed as an ideal model in the scene. Represented pattern modules will have different colors. Green modules represent correctly detected modules in the correct pattern position. Red modules represent correctly detected but their pattern position is within a tolerable error range from the detected position. Blue modules represented non-detected modules.</td></tr>
</table>

Procedure
Configuration: - Print three 3D undamaged cubes (about same size as the spacecraft modules); - Prepare a configuration pattern of the cubes (positions of the cube in a 3D coordinate system); - Take two pictures from the stereo camera; - Write down a DFPC configuration file. Procedure: - Execute a step-by-step integration test for DFPC instance 3.1 using a single model in input. - Advance through the software steps until the final output is displayed. - Take note of the detected anomaly, and the reported measured error. Inputs: VSA3.1.1: Pictures of a scene with one module; VSA3.1.2: Pictures of a scene with two modules in an incorrect relative position according to the pattern, all modules should stay within the field of view all both cameras; VSA3.1.3: Pictures of a scene with two modules in a correct relative position according to the pattern, all modules should stay within the field of view all both cameras; VSA3.1.4: Pictures of a scene with three modules, two modules are in a correct position, the third is in an incorrect position (above the tolerance threshold), all modules should stay within the field of view all both cameras; VSA3.1.5: Pictures of a scene with three modules, two modules are in a correct position, the third is in an incorrect position (within the tolerance threshold), all modules should stay within the field of view all both cameras; VSA3.1.6: Pictures of a scene with the three modules in the correct pattern position, all modules should stay within the field of view all both cameras.
Covered Requirements
Reconfiguration Anomaly Detection

3 Integration Tests (On-site, end WP4-WP5)

We describe our testing strategy for the integration phase in the final demonstrator. This is based on the assumption that all individual components have been tested in the previous phases.

3.1 Sub-Systems Validation Tests

The full demonstration scenarios are built from a sequence of autonomous operations managed by the different components of the MOSAR setup. Before demonstrating these scenarios, the purpose of the sub-systems validation tests is to validate and verify the good operations of the individual sub-systems. Whenever possible, these tests are done before integrating in the final set-up. The sub-system tests include: The design and simulation tool

- The monitoring and control centre
- The design and Simulation tool
- The planner and the simulation interface
- The Servicer Spacecraft Bus (SVC)
- The client satellite bus (CLT)
- The spacecraft modules
- The walking manipulator
- The visual processing system

3.1.1 ST1 - Monitoring and Control Centre

The purpose of the tests on the Monitoring and Control Centre is to validate the possibility for the operator to control and monitor the other components of MOSAR through the Monitoring and Control console. This section will be limited to the initial configuration of the MCC setup, while the TM/TC of the other sub-subsystems will be described in the corresponding sections.

The tests include the following steps:

Step	Description and Goal	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.
Setup for on-ground plan computation		
ST1-1	**Start the Monitoring and Control Console** The operator can visualize the GUI of the PUS Console application.	• Launch the PUS Console GUI application (instance for on-ground plan computation) in the MMC computer • The application waits for the start-up of the OBC-S and OBC-C SW
ST1-2	**Start the Simulator** The operator can visualize the GUI of the Simulator.	• Launch the Simulator in the MMC computer
ST1-3	**Start the MCC instance of the Agent SW** The operator runs the MCC instance of the Agent SW, and verifies that the connections between components are established.	• Launch the application in the MCC computer • Verify in the terminal output of the Agent SW that the connection to the PUS Console has been established, and vice versa • Verify in the terminal output of the Agent SW that the connection with the Simulator has been established • Verify that the PUS Console displays TM data produced by the Simulator
Setup for plan execution		
ST1-4	**Start the Monitoring and Control Console**	• Launch the PUS Console GUI application (instance for on-plan execution) in the MMC computer

	The operator can visualize the GUI of the PUS Console application.	• The application waits for the start-up of the OBC-S and OBC-C SW
ST1-5	**Start the OBC-C SW** The operator runs the OBC-C application.	• Launch the OBC-C application (note: the OBC-C can be accessed via SSH from the MCC)
ST1-6	**Start the OBC-S SW** The operator runs the OBC-S application, and verifies that the connections between components are established.	• Launch the OBC-S application (note: the OBC-S can be accessed via SSH from the MCC) • Verify in the terminal output of each OBC-S, OBC-C and PUS Console that the connections have been established • Verify that the PUS Console displays TM data produced by the OBC-C and OBC-S

These tests (and correlated ones after) address the following demonstration requirements (in integrated state):

Requirements
IntR_F301 (PUS services)

3.1.2 ST2 - Design and Simulation Tool

The purpose of the tests on the Design and Simulation tool is to validate the possibility for the analyst to define the configuration of a spacecraft and to check this configuration regarding assembly constraints, resources utilization and steady state operations of the spacecraft.

The tests include the following steps:

Step	Description and Goal	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.
ST2-1	**Build spacecraft configuration** The analyst is able to describe the spacecraft configuration (text based structure) and the design tool can validate the syntax of the description (structure, components references, naming….).	• Set scenario and component parameters in configuration files • Initialize Design Tool in Matlab/Simulink • Check output of Design Tool on screen or in log file
ST2-2	**Visualize spacecraft configuration** The spacecraft configuration can be loaded in the Simulator and the analyst can visualize the spacecraft state (support to the design phase)	• Set scenario and component parameters in configuration files • Start FES with required sub components (WM controller) • Simplified visualization directly in Matlab Simulink using FES • Advanced visualization requires SIMvis
ST2-3	**Validate spacecraft design step 1 – Design Tool** The design tool can perform initial check of the spacecraft configuration regarding assembly constraints (SM positions/orientations, SI mating…)	• Set scenario and component parameters in configuration files • Initialize Design Tool in Matlab/Simulink • Check output of Design Tool on screen or in log file
ST2-4	**Validate spacecraft design step 2 – Simulation Tool** The simulation tool can validate the spacecraft configuration performance, with multi-physics simulation, regarding steady state operations (power, thermal, data resources and management) (The test can be performed for different environmental conditions, e.g. LEO, Lab)	• Set scenario and component parameters in configuration files • Start FES with required sub components (WM controller, trajectory planner) • Run full FES simulation • Run scripts for output analysis and plotting of data • Analyze data and plots

ST2-5	**Generate goal description for the Planner** The desired spacecraft configuration is saved for input to the Planner.	• The user runs Matlab script to create a TC file that can be sent to the Agent SW for execution (JSON file with embedded macros).

These tests address the following demonstration requirements (in integrated state):

Requirements
FuncR_E101 (Design and Simulation Tool Purpose) FuncR_E102 (Design Software) FuncR_E105 (Simulation Topics) FuncR_E108 (Environnemental Conditions Simulation)

3.1.3 ST3 – Planner and Simulation Tool

The purpose of the tests on the planner and simulation tool is to validate the possibility for the system to build a valid and verified plan that can be uploaded to the Space Segment for operations.

The tests include the following steps:

Step	Description and Goal	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.

ST3-1	**Load spacecraft configuration**
	The analyst can load a spacecraft configuration description in the Planner tool
		• Prerequisites:
		  ○ The on-ground setup has been started following ST1-1 to 3
		  ○ The TC file describing the goal spacecraft configuration has been created following ST2
		• The analyst loads the TC file in the PUS Console GUI; this launches the calculation and execution of the plan against the Simulator, with re-planning enabled

ST3-2	**Build reconfiguration plan** Based on the description of two spacecraft configurations, the Planner can build a reconfiguration plan with a sequence of WM, SM relocation (simple case description). The plan can be visualized by the analyst.	• The analyst verifies that an initial plan has been computed, by observing the PUS 200 TM emitted by the Agent and visualized in the PUS Console

ST3-3	**Test reconfiguration and feedback**
	The FES can simulate the system reconfiguration in closed loop interaction with the ground instance of ERGO (plan decomposition) and the Functional Layer (ground versions of controllers and drivers). The FES can provide feedback to the Planner about the success or not of the plan execution
		• Prerequisites::
		  ○ Set parameter files for components and scenario
		  ○ Initialize full setup of FES, WM controller and Trajectory planner
		• Procedure:
		○ Start design toll form MATLAB/ Simulink
		○ Wait until analysis is finished.
		○ Check Design Toll log file for warnings and errors
		○ -If everything is ok run full FES simulation, otherwise adjust parameters and/or scenario
		○ Run trajectory planner with the desired trajectory it will send commands to the WM controller which will communicate with the FES
		○ Wait until simulation is finished.
		○ c to generate data files and plots for the simulation
		• Analyse the simulator outputs and plots,

ST3-4	**Reconfiguration Visualization** The analyst can visualize the spacecraft reconfiguration operations on the Simulator	• Prerequisites ○ Full simulation run with FES, trajectory planner and WM controller • Procedure:

		○ Adjust FES evaluation script in MATLAB for times at which the configuration should be visualized ○ Run FES evaluation script in MATLAB. It will generate a plot for each of the configured time steps. • Full continuous visualization (optional) requires SimVIS and all geometry data files and is generated directly while simulating using the FES.
ST3-5	**Reconfiguration Monitoring** The analyst can visualize the spacecraft components and simulation state parameters through the GUI of the MCC during the spacecraft reconfiguration	• The analyst monitors the evolution of the system parameters through the PUS service 3 (housekeeping TM) • The analyst monitors the plan execution and re-planning events through the PUS service 200 (Agent management)
ST3-6	**Iteration** The above sequence from ST2-1 to ST2-4 is repeated with a more complex example, leading to a failure of the plan execution in the simulation. The Planner can iterate with the FES to find a valid plan execution	• The analyst monitors the failure of plan execution, the re-planning and the attempt to execute the new plan through the PUS service 200 (re-planning starts from the current state of the system, not from the initial state)
ST3-7	**Plan Saving** Following a successful plan execution, the Planner can save the valid plan for future uploading to the onboard Autonomy Agent of the OBC-S. The analyst can have access to the file	• The analyst retrieves the successful plan execution record from the Agent output files • The successful plan execution record is transformed into a plan TC file for execution at E3 autonomy level by the on-board system

These tests address the following demonstration requirements (in integrated state):

Requirements
FuncR_E104 (Task Planning and Simulation) FuncR_E106 (Simulation of Reconfiguration) FuncR_E109 (Manipulator Dynamics Simulation) PerfR_E201 (Simulation Real-Time Performance) PerfR_E202 (Number of SM in Simulation) IntR_E301(Simulator Input Interfaces) IntR_E302 (Simulator Output Interfaces) IntR_E303 (Simulator Communication Interface) IntR_E304 (Generation of plan for onboard execution)

3.1.4 ST4 - Servicer Spacecraft Bus (SVC)

The purpose of the tests on the SVC is to validate the connection to and the operations of its components that include the OBC-S, the R-ICU and the cPDU, respectively for the data and power transfer management through the passive HOTDOCK interfaces.

The tests include the following steps:

Step	Description and Goal	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.
ST4-1	**SVC Start-up** The operator can have remote access to the OBC-S (e.g. SSH) and confirm the connection to the R-ICU (from the OBC-S) and the start of the TTC service.	• The SVC is powered-on from EGSE • The operator launches the OBC-S SW on the terminal (SSH)
ST4-2	**MCC Monitoring** The operator can visualize and monitor on the MCC the parameters of the SVC that includes the OBC-S, the R-ICU and the cPDU (through the TTC service of the OBC-S)	• The operator visualizes enables the generation of housekeeping TM reports using the PUS 3 service; note that only when the counterpart applications at the MCC and OBC-C are started, the OBC-S SW initialization will complete and TM will be generated
ST4-3	**MCC Commanding** The operator can send telecommands from the MCC and validate the control of the SVC components that includes the OBC-S, the R-ICU and the cPDU (through the TTC service of the OBC-S)	• The operator uses the PUS Console GUI and PUS service 210 (mission-specific) to issue component TCs; the APID for OBC-S is used as TC destination
ST4-4	**Execution Plan Loading** The operator can upload an execution plan from the MCC to the OBC-C	• The operator loads the TC file generated in ST3-9; this file contains a set of TC[200,3] telecommands that represent the plan to be executed at E3 autonomy level

These tests address the following demonstration requirements (in integrated state):

Requirements
IntR_E304 (Generation of plan for onboard execution) FuncR_A104 (SVC high level control) FuncR_A105 (Components low level control) FuncR_A108 (Monitoring)

3.1.5 ST5 - Client Satellite Bus (CLT)

The purpose of the tests on the CLT is to validate the connection to and the operations of its components that include the R-ICU, the cPDU, respectively for the data and power transfer management through the CLT HOTDOCK interfaces, from which one is active. The R-ICU is connected to the OBC-S (SVC) spW network, which represent the docking data interface between the SVC and the CLT (considered as permanent in the MOSAR demonstrator).

The tests include the following steps:

Step	Description and Goal	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.
	Initial Condition The SVC is powered on with TM/TC with the MCC and spW data connection to the CLT SpW network (data docking interface)	
ST5-1	**CLT Start-up** The CLT is powered on and the operator can confirm the connection to the CLT R-ICU, by remote access to the OBC-S	• The operator launches the OBC-C SW on the terminal
ST5-2	**MCC Monitoring** The operator can visualize and monitor on the MCC the parameters of the CLT that includes the the R-ICU, the cPDU and the active HOTDOCK SI (through the TTC service of the OBC-S)	• The operator visualizes enables the generation of housekeeping TM reports using the PUS 3 service; note that only when the counterpart applications at the MCC and OBC-S are started, the OBC-C SW initialization will complete and TM will be generated
ST5-3	**MCC Commanding** The operator can send telecommands from the MCC and validate the control of the CLT components that includes the R-ICU, the cPDU and the active HOTDOCK SI (through the TTC service of the OBC-S)	• The operator uses the PUS Console GUI and PUS service 210 (mission-specific) to issue component TCs; the APID for OBC-C is used as TC destination

These tests address the following demonstration requirements (in integrated state):

Requirements
FuncR_A104 (SVC high level control) FuncR_A105 (Components low level control) FuncR_A108 (Monitoring)

3.1.6 ST6 - Spacecraft Modules (SM)

The purpose of the validation tests on the SM is to validate, for each SM, the correct operation of the internal components, that includes the generic elements as the R-ICU, cPDU and SI, and the specific payloads (as available on each SM), in order to be usable for the other validation tests (c.f. WM) and the demonstration.

There is two configurations of SM in the system. Two SM (SM1-DMS and SM2-PWS) are permanently fixed on the CLT structure with data and power connections between them and with the CLT components. The other SM are movable and can be interfaced with the spacecraft through the HOTDOCK SI. For this set of tests, the mobile SM will be manipulated manually by the operator for alignment with the active HOTDOCK SI of the CLT, before initiating their connection.

The tests are split between the generic components validation (described once here, but applied on all SM) and the specific payload validation (except the thermal fluid transfer, covered by the demonstration scenarios).

The generic tests include the following steps:

Step	Description and Goal	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.
	Initial Condition For mobile SM, the SM is connected through the active HOTDOCK of the CLT (powered-off), with the possibility to transfer power and data	
ST6-1	**SM Start-up** The SM is powered on by activating the corresponding power line from the CLT cPDU. The internal SM R-ICU shall automatically power on and establish a SpW link with the CLT R-ICU. The operator can confirm the availability of the SM R-ICU by monitoring the CLT R-ICU parameters (connected ports) on the MCC.	• The operator issues the TC[210,X] to enable power to the SM • the presence in the network of the new SM is detected and the SW is automatically reconfigured • the operator to command the reconfiguration of the SW to enable the TM using the PUS TC[2X0,Y]
ST6-2	**CLT R-ICU Routing** The operator can send a TC to the OBC-S (with the MCC or through remote access) and configure the data routing of the CLT R-ICU (enabling routing of packets from SM R-ICU).	• The operator issues the TC[210,X] to configure the routing table of the CLT-R-ICU [depending on automatic reconfiguration]
ST6-3	**SM R-ICU Configuration** The operator can send a TC to the OBC-S (with the MCC or through remote access) and configure the SM R-ICU (service exposition and logical address allocation)	• The operator issues the TC[210,X] to configure the routing table of the SM [depending on automatic reconfiguration]
ST6-4	**MCC Monitoring** The operator can visualize and monitor on the MCC the parameters of the SM that includes the the R-ICU, the cPDU and the active HOTDOCK SI (through the TTC service of the OBC-S)	• The operator visualizes and enables the generation of housekeeping TM reports using the PUS 3 service
ST6-5	**MCC Commanding** The operator can send telecommands from the MCC and validate the control of the SM components that includes the R-	• The operator uses the PUS Console GUI and PUS service 210 (mission-specific) to issue component TCs; the APID for OBC-C is used as TC destination, and SM and HOTDOCK IDs are passed as parameters.

	ICU, the cPDU and the active HOTDOCK SI (through the TTC service of the OBC-C)	

The sub-system tests will use the OBC-S of the SVC to ensure the TM/TC link with the MCC. However, during the scenarios, it is the client satellite OBC-C (located in the SM1-DMS) that will perform the TM/TC during nominal operations. This will require the switching of the SpW network management between the reconfiguration and nominal operation phase. Tests related to the SM1-DMS are covered in section 3.2.5. The specific payload tests include the following steps:

Step	**Description and Goal**	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.
	Initial Condition For each test, it is expected that the SM is connected and powered-on. It has a TM/TC connection with the MCC, through the OBC-S TTC service	
ST6-6	**SM2-PWS Thermal Payload MCC Monitoring (Part 1)** The operator can visualize and monitor on the MCC the parameters of the SM2-PWS Thermal payload (through the TTC service of the OBC-S). This test doesn't cover fluid transfer to another module (covered by scenario 3)	See ST6-4. List of parameters to observe is TBD.
ST6-7	**SM2-PWS Thermal Payload MCC Control (Part 1)** The operator can send telecommands from the MCC and validate the control of SM2-PWS Thermal payload (through the TTC service of the OBC-S). This test doesn't cover fluid transfer to another module (covered by scenario 3) Note: The power TC functions are managed by the cPDU, covered in the generic SM tests	See ST6-5. List of commands to issue is TBD.
ST6-8	**SM3-BAT Battery Payload MCC Monitoring** The operator can visualize and monitor on the MCC the parameters of the SM3-BAT Thermal payload (through the TTC service of the OBC-S).	See ST6-4. List of parameters to observe is TBD.
ST6-9	**SM3-BAT Battery Payload MCC Control** The operator can send telecommands from the MCC and validate the control of SM3-BAT Thermal payload (through the TTC service of the OBC-S).	See ST6-5. List of commands to issue is TBD.
ST6-9	**SM4-THS Thermal Payload MCC Monitoring (Part 2)** The operator can visualize and monitor on the MCC the parameters of the SM4-THS Thermal payload (through the TTC service of the OBC-S). This test doesn't cover fluid transfer to another module (covered by scenario 3)	See ST6-4. List of parameters to observe is TBD.
ST6-10	**SM4-THS Thermal Payload MCC Control (Part 2)**	See ST6-5. List of commands to issue is TBD.

	The operator can send telecommands from the MCC and validate the control of SM4-THS Thermal payload (through the TTC service of the OBC-S). This test doesn't cover fluid transfer to another module (covered by scenario 3)	
ST6-11	**SM5/6 Optical Payload MCC Monitoring** The operator can visualize and monitor on the MCC the parameters of the SM5/6 Optical payload	See ST6-4. List of parameters to observe is TBD.
ST6-12	**SM5/6 Optical Payload MCC Control** The operator can send telecommands from the MCC and validate the control of SM5/6-OSP Optical payload (through the TTC service of the OBC-S).	See ST6-5. List of commands to issue is TBD.
ST6-13	**SM5/6 Optical Payload Data** The operator can visualize on the MCC the image frames coming from the OSP5/6 Optical payload (through the Payload Relay service of the OBC-S).	• The operator launches the image visualization tool in the MCC, and checks the output to verify that the connection to the image relay in the OBC-C is established • The operator commands the camera to capture an image using TC[210,X] • The operator visualizes the images captured

These tests address the following demonstration requirements (in integrated state):

Requirements
FuncR_A104 (SVC high level control) FuncR_A105 (Components low level control) FuncR_A108 (Monitoring) FuncR_A111 (Modules Plug & Play detection) FuncR_C104 (SM data transmission) FuncR_C104 bis (SM power routing configuration) FuncR_C106 (SM power-on/off) FuncR_C107 (SM start and initialization) FuncR_C108 (Identification information) FuncR_C109 (Fault detection) IntR_C301 (SM power) IntR_C302 (SM R-ICU power Up) IntR_C303 (SM R-ICU to SI TM/TC) ConfR_C801 (Demonstrator SM Configurations) FuncR_F104 (Large data transfer over SpaceWire)

3.1.7 ST7 - Walking Manipulator

The purpose of the validation tests on the WM is to validate its correct operation, its interfaces with the OBC and MCC for TM/TC, to ensure it is ready for the demonstrations.

The tests include the following steps:

Step	Description and Goal	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.
	Initial Condition The WM is connected through an HOTDOCK of the CLT or SVC and powered-off, with the possibility to transfer power and data	
ST6-1	**WM Start-up** The WM is powered on by activating the corresponding power line from the CLT cPDU (with the MCC). The internal WM Controller shall automatically power on and establish a SpW link with the CLT R-ICU. The operator can confirm the availability of the SM R-ICU by monitoring the CLT R-ICU parameters (connected ports) on the MCC	• The operator enables power transfer to the WM using a TC[210,X] TC • [TBC depending on automatic network reconfiguration] The operator configures the SpW routing table of the SVC and CLT R-ICU using TC[210,X] • The operator enables the housekeeping TM for the WM using PUS service 3 • The operator verifies that the housekeeping TM for the WM is received and displayed in the PUS console

ST6-2	**WM Configuration**
	The operator can send a TC to the OBC-S (with the MCC or through remote access) and configure the WM Controller (service exposition and logical address allocation)
		• By an external command the WM Controller (WM OBC) is activated and put in operational mode.
		  ○ Activates interface to ERGO/Planner
		  ○ Activates interface to EtherCAT
		  ○ TBD

ST6-4	**WM Monitoring** The operator can visualize and monitor on the MCC the parameters of the WM that includes its own parameters and the two active HOTDOCK SI (through the TTC service of the OBC-S)	• The operator visualizes the housekeeping TM for the WM and the rest of the components in the PUS Console

ST6-5	**WM Low-Level Commands**
	The operator can send telecommands and validate the control of the WM, that includes:
	• Cartesian position command
	• Impedance mode control
	• Mode of operation
	• Administrative commands
	• Operations of the two HOTDOCK SI (requiring a switch of the robot base)
		• start action; stop action
		• command counter to detect a new command
		• command id to select the desired action:
		  ○ Power
		  ○ Controller
		  ○ joint trajectory list
		  ○ Cartesian motion
		  ○ interface command
		• command control mode
		  ○ Torque control
		  ○ Position control
		• List of joint configurations for transfer motion
		• Goal pose for approach/docking operation
		• HOTDOCK commanding is through the same TCs than the SM HOTDOCKS

ST6-6	**OBC-S WM High-Level Commands** The operator can send telecommands from the MCC to the OBC-S to initiate the high-level trajectory commands implemented during the spacecraft reconfiguration operations and validate the behavior of the WM, that includes:	• The WM is moving based on given a series of joint position sets • The WM is moving impedance controlled based on on a Cartesian goal pose.

	• Move Cartesian Position • Move Cartesian Impedance	

These tests address the following demonstration requirements (in integrated state):

Requirements
FuncR_A104 (SVC high level control)
FuncR_A105 (Components low level control)
FuncR_A108 (Monitoring)
FuncR_B101 (SM connection)
FuncR_B103 (Joint position control)
FuncR_B104 (Cartesian position control)
FuncR_B104 bis (Impedance control)
FuncR_B105 (Fault detection)
FuncR_B106 (Power-on/off)
FuncR_B107 (WM start and initialization)
IntR_B301 (WM TM/TC)
IntR_B303 (WM power)
IntR_B305 (WM local CAN network)
IntR_B306 (WM local control network)
IntR_B307 (WM mechanical interface to SI)

3.1.8 ST10-Visual Processing System

The test purpose is to verify whether the vision processing system is able to validate the shape of the spacecraft modules, hardware interfaces and walking manipulator, and to highlight any deviation from the expected ideal surface model. Processing time will be monitored in order to validate usability requirement. We will also evaluate whether some common defects are detectable.

The tests include the following steps:

Step	Description and Goal	**Procedure** Short description / reference of test set-up (EGSE/MGSE) and the procedure to execute the test.
	Initial Condition The walking manipulator is ready to start operating on the satellite. There is a damaged spacecraft module with a damaged interface. The damaged interface is visible from the camera.	
Steps 7.1-7.4	**3D Reconstruction** The vision system is activated, the camera starts recording images and the software outputs initial results. A partial representation of the scene is available on the output screen throughout the whole demonstration. The output changes if and only if there is actually some movement occurring on the demonstrator. Any detected object will be highlighted by showing its model within the reconstructed cloud. Any detected defect will be highlighted in an image or a point cloud. damaged area will be highlighted with a bounding box in the point cloud. The processing frequency is visible on the output screen..	If you are using the PTC camera bring the cameras to maximum zoom level. Start either instance 1.2 or instance 1.3 of Module Anomaly Detection Program, or Instance 2.2 or Instance 2.3 of Interface Anomaly Detection Program. Depending on the instance you started observe whether the following is true: Instance 1.2: spacecraft modules and related damaged should be detected; Instance 1.3: walking manipulator modules and related damage should be detected Instance 2.2: spacecraft modules, their interfaces and related damage should be detected; Instance 2.3 walking manipulator modules their interfaces and related damage should be detected. Repeat four times, once for each program instance.
Steps 7.5-7.6 (only for PTC cameras)	**Selective Zooming** A partial representation of the scene is available on the output screen throughout the demonstration. The output changes if and only if there is actually some movement occurring on the scenario. An interface will be highlighted by showing its model within the reconstructed cloud. Damaged areas will be highlighted with a bounding box in the point cloud. The processing frequency is visible on the output screen.	Halt the current software instance. Control the camera to focus on a visible interface. Start Instance 1.4 Module Anomaly Detection for Selective Zooming Program. Observe the interface and related damage is correctly detected Repeat twice once with a non-damaged interface and once with a damaged interface.
Steps 7.7-7.8	**Reconfiguration Validation** A partial representation of the scene is available on the output screen throughout the demonstration. The output changes if and only if there is actually some movement occurring on the demonstrator. If at least two spacecraft modules are in the expected configuration, the final expected demonstration will be visible in the point cloud, and any difference with the real configuration will be highlighted. Specifically, spacecraft modules detected in the right position will be in green,	Halt the current software instance. If you are using the PTC camera bring the cameras to maximum zoom level. Start instance 3.1 Reconfiguration Anomaly Detection Program. Repeat twice once mid-way through the configuration, once at the end of the reconfiguration.

	spacecraft module detected in a wrong position will be in red, and missing modules will be in blue.	

Tests do not exhaust the set of all possible detects, due to the limitation on the number of components that can be manufactured. We will test whether some defects are reliably detectable, but we will not be able to assess what the smallest detectable defect is.

These tests address the following demonstration requirements:

ID	Title	Description
	Validation of Module Shape and Interfaces	[DEVIATION] Detect modules, their interfaces and highlight surface defects.
	Validation of Walking Manipulator Shape and Interfaces	[DEVIATION] Detect walking manipulator components, their interfaces and highlight surface defects
	Validation of module configuration	[DEVIATION] Detect modules and highlight final configuration defects
	Selective Zooming	[DEVIATION] Detect interface defects with higher accuracy.

There are some deviations on demonstrator requirements. Originally, the specified validation / demonstration tests were linked to the demonstrator testing requirements, as defined in AD1. During the preliminary design phases, some of these requirements have been reviewed / descoped.

3.2 Integration Validation Tests

Following the sub-systems validation, the next phase will target to validate integrated systems. This will cover the main routine of operation, as defined in the DDD [RD6], which are recurrent sequences of actions requested by the planner. It will also address other operations that implicate several components of the system and relevant for the final demonstration.

During the tests, the operator can observe the telemetry of the components implemented on the MCC.

3.2.1 IT1 – WM Re-localization

The purpose of this test is to validate the possibility for the WM to re-localize itself along the structure of the spacecraft, as illustrated in Figure 3-1. This is a routine defined in RD6.

The following initial conditions need to be full-filed to start the sequence:

- The WM SI-A is connected to the Initial SI, with power and data transmission
- The WM is powered on, is able to communicate with the OBC-S by SpW and is ready for operations
- The Target SI is able to provide power and data communication with the OBC-S
- The Target SI can be reached by the WM SI-B (following the required trajectory)

The test is successful if, at the end of the sequence, the WM is connected to the other SI and able to be interfaced with the MCC for TM/TC.

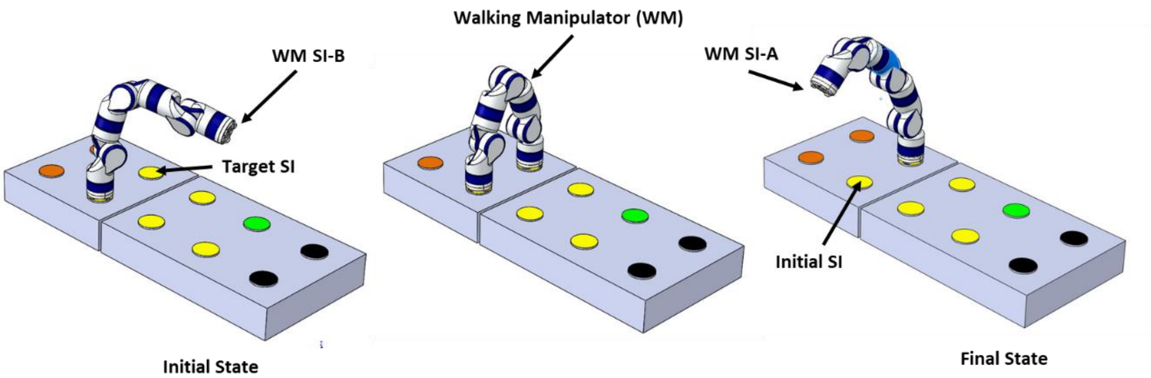


Figure 3-1: Routine 1 – WM re-localization between initial SI and Target SI

On top of the requirements presented in section 3.1, this test address the following demonstration requirements:

ID	Title	Description
FuncR_A107	WM relocation	The WM shall be able to reposition itself by using the SI of the functional modules or the platform
IntR_B304 bis	WM interface switch	The WM shall be able to switch power and data interface between the two SI extremities

3.2.2 **IT2 – SM Re-localization**

The purpose of this test is to validate the possibility for the WM to re-localize as SM between two different position/orientations on the SVC or CLT, as illustrated in Figure 3-2. This is a routine defined in RD6.

The following initial conditions need to be full-filed to start the sequence:

- SM powered-off
- The WM SI-A is connected to another SI (spacecraft or module), with power and data transmission
- The WM is powered on, is able to communicate with the OBC-S by SpW and is ready for operations
- The position of the WM and SM allow performing the desired trajectory between the initial and final position of the SM.

The test is successful if, at the end of the sequence, the SM has been moved to another connection point and is able to be monitored/commanded from the MCC.

The test can be repeated for different configuration of the SMs, including configuration with two and three simultaneous HOTDOCK connections.

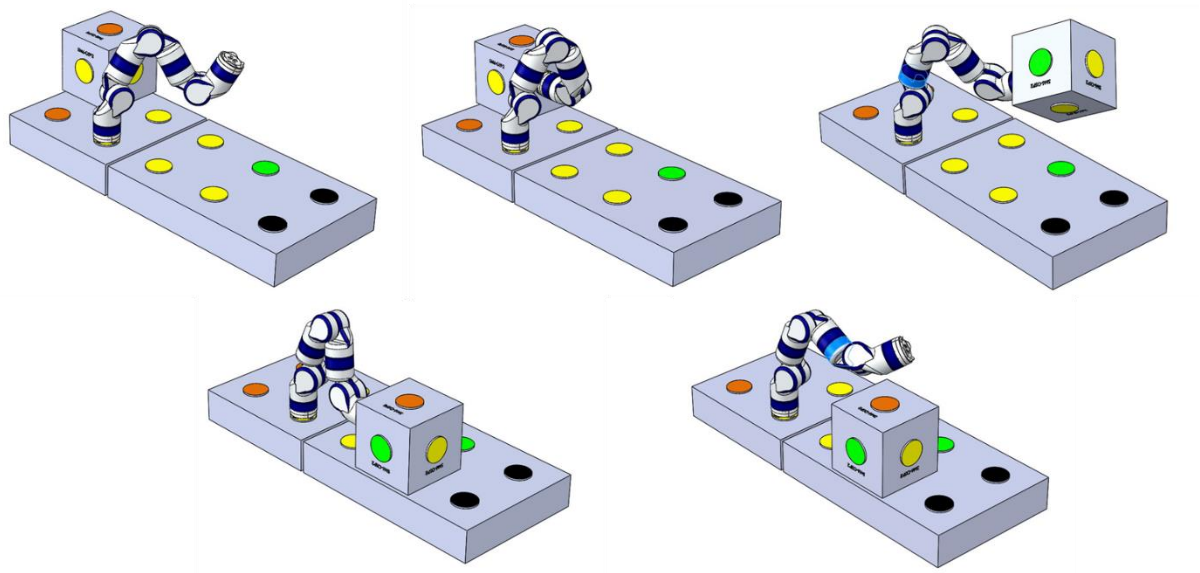


Figure 3-2: Routine 2 – SM re-localization

On top of the requirements presented section 3.1, this test address the following demonstration requirements:

ID	Title	Description
FuncR_A109	Spacecraft reconfiguration	The system shall be able to re-configure the CLT (e.g. SM exchange) in case of a defect (e.g. malfunction of a SM)
FuncR_B102	SM manipulation	The WM shall be able to move and assemble the functional modules in a 3-dimensional way
PerfR_B201	WM payload capability	The WM shall be able to manipulate a payload of 7kg all around his workspace
IntR_B302	WM data transfer	The WM shall be able to transmit TM/TC and data from the SVC OBC with the SM connected at its SI
IntR_D301	Mechanical Interface to Components	The standard interface shall provide a mechanical connection to the modules, spacecraft bus or robotic base/end-effector manipulator, compatible with the mechanical loads transferred through the interface.
IntR_B304	WM power transfer	The WM shall be able to transmit power to the SM connected at its SI

3.2.3 IT3 – Data Re-Routing

The purpose of this test is to demonstrate the capability for the system to re-route data transmission between different modules.

The following initial conditions need to be full-filed to start the sequence:

- The SM1-DMS and CLT are operational and connected to the OBC-S by the SpW network
- One payload SM is connected simultaneously with the CLT and SM1 SI (using the two active HOTDOCK)
- The SM1 is powered on and configured such that it gets power from the CLT SI and data from the SM1-DMS.

The test is successful if, at the end of the sequence, the payload SM gets data directly from the CLT SI and can be disconnect from the SM1-DMS, while keeping TM/TC from the MCC.

On top of the requirements presented section 3.1, this test addresses the following demonstration requirements:

ID	Title	Description
FuncR_A110	System redundancy	The system shall be able to re-route and reallocate resources (e.g. power, data, computational power, etc.) in case of a defect (e.g. interconnector of an APM)
FuncR_C103	SM data routing configuration	The baseline functionality of a Spacecraft Module shall include the ability to externally configure the SM's data routing function between the Standard Interfaces and services provided by SM

3.2.4 IT4 – Power Re-Routing

The purpose of this test is to demonstrate the capability for the system to re-route power transmission between different modules.

The following initial conditions need to be full-filed to start the sequence:

- The SM1-DMS and CLT are operational and connected to the OBC-S by the SpW network
- One payload SM is connected simultaneously with the CLT and SM1 SI (using the two active HOTDOCK)
- The SM1 is powered on and configured such that it gets power from the SM1-DMS and data from the CLT.

The test is successful if, at the end of the sequence, the payload SM gets power directly from the CLT SI and can be disconnect from the SM1-DMS, while keeping TM/TC from the MCC.

On top of the requirements presented section 3.1, this test address the following demonstration requirements:

ID	Title	Description
FuncR_A110	System redundancy	The system shall be able to re-route and reallocate resources (e.g. power, data, computational power, etc.) in case of a defect (e.g. interconnector of an APM)

3.2.5 T5 – Software Reconfiguration

The purpose of this test is to demonstrate the capability for the system to:

- Switch the responsibility of the SpW network management between the OBC-S and the OBC-C, and vice-versa (to switch between the nominal and reconfiguration operations)
- Update the CLT software in order to take into account new connected module/functionalities.

The first test is successful if the selected OBC can perform TM/TC with the spacecraft components

The second test is successful if the new module can get TM/TC from the MCC.

ID	Title	Description
FuncR_F101	Extension of TASTE for reconfigurable systems	The TASTE framework shall be extended to support modelling and code generation for software systems that can switch between different configurations known at design time

3.2.6 IT6 – Planned Operation

All the above integration tests have been performed by manual TC from the operator through the MCC (or potentially direct access to the components). The purpose of this test is to illustrate the capability for the system to perform the same operations, autonomously, by the execution of a sequence of operations commanded by the ERGO Agent.

Integration tests IT1 to IT4 will be repeated with the following sequence:

1. Definition of the initial and final spacecraft model
2. Building of the reconfiguration plan
3. Execution of the reconfiguration plan by the OBC-S ERGO Agent
4. Monitoring of the system parameters in the MCC

The test will target simple scenario cases, such that the FES is not mandatory and an “easy” valid plan can be found.

The test will be successful if the four integration tests can be replicated, reaching the same final configuration.

Additional tests can be performed to validate the management of issue during the execution of the plan. Three levels are envisaged:

- Function layer level, with specific procedure, as for instance to retry the operation
- Planner level, with a replanning of the operations to take into account a problem
- MCC / user level, with information to the user, such that he can red-define the strategy

This aspect will be investigated during the detailed design phase, and the validation plan will be updated according to the selected strategies(s)

On top of the requirements presented section 3.1, this test address the following demonstration requirements:

ID	Title	Description
FuncR_A112	Fault detection	The SVC OBC shall be able to react to a faulty behavior detected by the SM, WM or SI
FuncR_F105	ERGO robotic arm driver for WM	A robotic arm driver component shall be developed to execute the robot plan actions on the WM and return the observations needed by the Agent to manage the execution of the plan.
FuncR_F106	ERGO Agent for plan execution	An instance of the ERGO Agent shall be deployed on the OBC to command and monitor the execution of the robotic reconfiguration plan generated on ground.

4 Demonstration Scenarios (On-site, WP5)

The purpose of the MOSAR demonstrator is to illustrate five representative scenarios of modular spacecraft assembly and re-configuration operations. The baseline scenario is the one of a Servicer Spacecraft (SVC) transporting a cargo of Spacecraft Modules (SM) and a dedicated Walking Manipulator (WM), performing a number of operations with the transfer of SM from and to the Client Spacecraft (CLT) by the manipulator.

4.1 Scenario 1 (S1): Initial Assembly of SMs from SVC to CLT

4.1.1 Scenario Description

Objective: demonstrating the assembly of several SMs originally mounted on the SVC onto the CLT spacecraft bus, including both the placement of SMs on the CLT itself and on other SMs.

Initial Conditions: the initial configuration of the SMs is represented in Figure 4-1-left

- two SM are already installed on the CLT (fixed position for the demonstrations), the SM1-DMS (OBC) and SM2-PWS (power module)
- the four other SM are stored on the SVC
- the WM is stowed in parking position on the SVC
- the system is ready for assembly operations

Success Conditions:

- the desired SMs are mounted onto the CLT, as illustrated in Figure 4-1-right
- the newly mounted SMs are powered on and operational
- it should be possible to receive data / telemetry from each deployed SM and send commands to each of them, including video/picture rendering from the optical payload modules

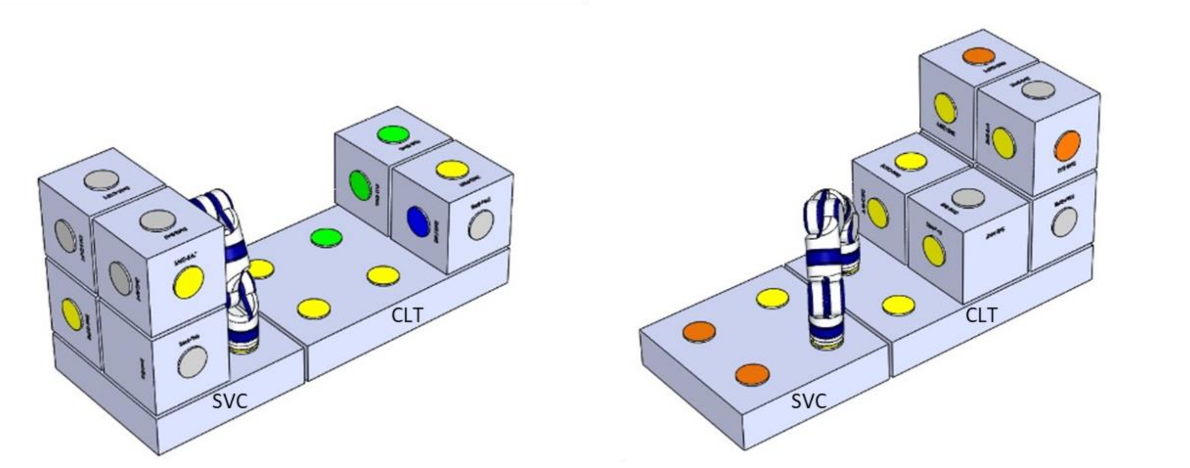


Figure 4-1: MOSAR scenario 1 initial and final configuration

4.1.2 Sequence of Operations

The first scenario illustrates the typical sequence of operations that is proposed by the MOSAR operational concept. It includes the following steps:

1. Model of the initial spacecraft configuration (SVC and CLT)
2. Model of the final target spacecraft configuration (SVC and CLT)
3. Validation of the (initial) and final configuration according to system constraints
4. Build of the initial reconfiguration plan
5. Validation of the initial reconfiguration plan with the FES and the Functional layer
6. Successive Iteration on the re-configuration plan, while a valid plan is not found
7. Storing of the validated execution plan (the analyst could be informed that no valid plan can be found, meaning that the design model shall be reviewed)
8. Uploading of the validation plan on the OBC-S (on-board autonomous agent)
9. Configuration of the SVC/CLT SpW network, such that the OBC-S (SVC) has the hand on the control of the components (WM, SI, R-ICU, cPDU)
10. Execution and monitoring of the execution plan by the OBC-S Agent. It will consist in a sequence of operations and routines of WM and SM re-localization to transit from the initial to the final configuration.

If the execution is successful, the OBC-S informs the MCC operator and the spacecraft network is reconfigured to allow the CLT to manage the components (e.g. SM TM/TC).

If the execution is not a success, three cases can be envisaged:

- Function layer level, with specific procedure, as for instance to retry the operation
- Planner level, with a replanning of the operations to take into account a problem
- MCC / user level, with information to the user, such that he can red-define the strategy

4.2 Scenario 2 (S2): Replacement of a failed SM

4.2.1 Scenario Description

Objective: demonstrating the detection and replacement of a failing module by an equivalent working module. This will be illustrated in the current scenario by the replacement of one of the optical payload modules by the second one.

Initial Conditions:

- the WM is stowed in parking position
- the CLT is assembled with the 6 SMs (final configuration of scenario 1) and operational (Figure 4-2-Left)
- the maintenance operation is ready to be carried out

Success Conditions:

- the faulty module should be brought back in the cargo area of the SVC
- the new optical SM has been mounted onto the same location of the failed SM on the CLT (Figure 4-2-Right)
- the newly replaced SMs should be powered and operational, i.e. recovery of functionality

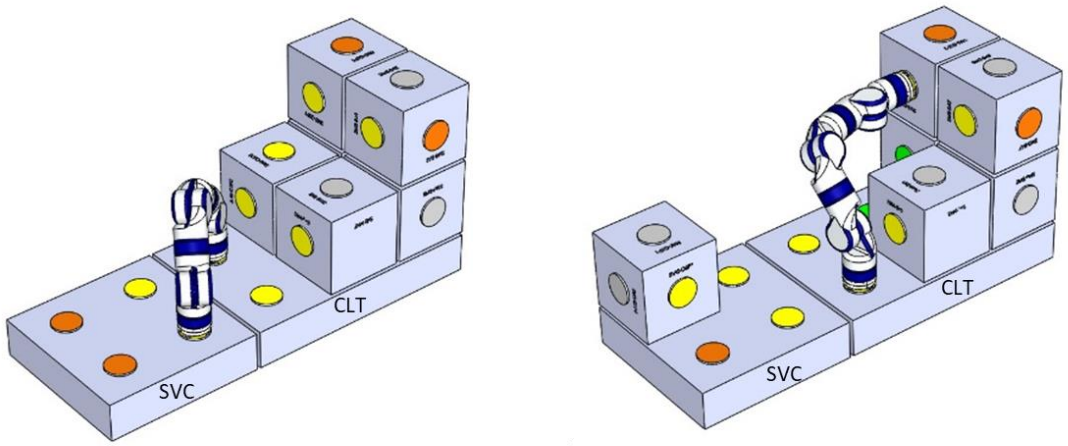


Figure 4-2: MOSAR scenario 2 initial and final configuration

4.2.2 Sequence of Operations

The sequence of operations for the scenario 2 will be initiated with the detection of a faulty behaviour in the SM5-OSP module (mounted on the top left of the CLT structure). This faulty behaviour will be triggered manually and detected by the Client OBC-C.

We currently consider to use an error status in the I3DS telemetry which indicates an unrepairable fault with the ZED camera (sensor failure). This will be propagated to the operator on the MCC that will then trigger a plan generation to replace the module.

It is not considered to use the visual system for this purpose, as their will be no direct link between it and the MCC monitoring

This will initiate the following sequence of actions:

- The CLT OBC-C will command to switch off the SM5-OSP module by opening all the power lines feeding the module (non-critical module isolation).
- The CLT OBC-C will inform the operator through the MCC about the issue (also visually displayed on the screen).
- The operator will request the analyst to provide a new spacecraft model, proposing the replacement of the faulty module with the SM6-OSP.
- The sequence of operations, as described in the first scenario is iterated based on the current and new final spacecraft configuration.

One objective of this scenario is to keep the spacecraft and the other SM operational during the replacement operations.

4.3 Scenario 3 (S3): Thermal transfer between two SMs

4.3.1 Scenario Description

Objective: demonstrating the active cooling of a SM producing heat (SM2-PWS) by a dedicated thermal handling module (SM4-THS)

Initial Conditions:

- the THS and the PWS modules are mechanically coupled and operational (final configuration of scenario 1)

Success Conditions:

- a heat transfer should be observed between the 2 modules (through telemetry reading with heat probes on the 2 sides).
- No leaks should have been observed.

4.3.2 Sequence of Operations

At the opposite of the two other demonstrations, this scenario doesn't require the operations of the ground segment simulator and planner, as the configuration remains static.

The system will be operated through the MCC user interface to perform TM/TC operations with the SM2-PWS and SM4-THS thermal payloads.

It will basically consist of the following sequence of actions:

- The temperature of the two modules is monitored on the MCC
- The heater in the SM2-PWS is switched on by the operator.
- The fluid transfer between SM2-PWS and SM4-THS is enabled by the operator (pump and valves commands).
- The fan (forced convection) is enabled on the SM4-THS.

AT each step, the temperature of both SM is monitored.

4.4 Scenario 4 (S4): Automatic CLT Network Reconfiguration

4.4.1 Scenario Description

Objective: demonstrating the ability of the SpaceWire network to automatically detect and adapt to faulty interfaces without the need of the SVC-OBC to be attached to reconfigure the network.

Initial Conditions: the configuration of the SMs represents a constructed spacecraft. The SVC is disconnected from the CLT.

- The optical SM is located at least one SM away from the OBC.
- The optical SM is part of a grid of SMs of a size of at least 2x2 (to provide two distinct network paths from the OBC to the optical SM).
- The network is configured such that the OBC can communicate with any SM in the network using logical addressing.
- All network links are active and running
- The OBC-CLT is running the application, constantly fetching image frames from the optical SM.

Success Conditions:

- The faulty link is detected by the CLT-OBC
- The network topology is rediscovered with the faulty link excluded
- A new valid network mapping is found
- The network is reconfigured successfully, traffic starts to resume to and from the CLT-OBC and the optical SM.

4.4.2 Sequence of Operations

This scenario starts from the spacecraft constructed and operating nominally. The process is started by failing a link via the R-ICU debug interface.

1. Ensure that spacecraft is assembled and running the optical payload operation.
2. Fail one of the active links carrying the payload data between the CLT-OBC and the optical SM by commanding the SpaceWire link to DISABLED using the R-ICU debug interface.
3. CLT-OBC detects error due to receiving EEP or RMAP reply timeout.
4. CLT-OBC automatically initiates SpW-PnP network discovery sequence and rediscovers the network layout.
5. CLT-OBC runs network mapping algorithm on results of SpW PnP discovery to find shortest routing paths between nodes and CLT-OBC.
6. CLT-OBC uses RMAP to update the routing tables of all SpW routers in the network
7. CLT-OBC switches back to nominal mode
8. Optical payload operation continues using the discovered redundant network path.

Telemetry from the R-ICU debug port (USB UART) can be used to track this sequence, however when ran autonomously it is anticipated to be too fast to for an operator to interact with.

4.5 Scenario 5 (S5): Software Reconfiguration

4.5.1 Scenario Description

Objective: demonstrating the ability of the TASTE approach to ease reconfigurable software development and anticipate scheduling issues at design time.

Initial Conditions:

- A TASTE model represents a simplified version of the CLT software and associated hardware.
- Active software functions correspond to the initial SMs in place

Success Conditions:

- Active software functions correspond to the final SMs in place
- The delay to reach the final software configuration is less than the given deadline

4.5.2 Sequence of Operations

- Initial and final configurations are defined into the TASTE model
- The corresponding AADL "Concurrency View" is generated
- Scheduling analysis is performed at AADL model level
- C source code is generated and compiled
- A run-time scenario is executed

4.6 Demonstrator Requirements Addressed by the Scenarios

On top of the requirements presented sections 3.1 and 3.2, these demonstrations address the following demonstration requirements:

ID	Title	Description	Scenarios
FuncR_A101	Demonstrator purpose	The MOSAR demonstrator shall illustrate the repair and update of modular spacecraft by manipulation and repositioning of SM with the WM.	S1, S2

FuncR_A103	Plan execution	The SVC OBC shall execute autonomously the assembly/ reconfiguration plan prepared by the design and simulation tool	S1, S2
FuncR_A106	WM modules operations	The WM shall be able to add and replace SM (ASM/APM) by using SI	S1, S2
FuncR_A109	Spacecraft reconfiguration	The system shall be able to re-configure the CLT (e.g. SM exchange) in case of a defect (e.g. malfunction of a SM)	S2
FuncR_A110	System redundancy	The system shall be able to re-route and reallocate resources (e.g. power, data, computational power, etc.) in case of a defect (e.g. interconnector of an APM)	S2, S4
DesR_D403	Diagonal Engagement	The standard interface shall allow diagonal engagement up to 55 deg	S1
VerR_G101	Validation purpose	The MOSAR demonstrator shall allow to verify and validate the following functionalities relevant for future modular spacecraft missions: • Creation of a re-configuration execution plan (FuncR_S105) • Simulation of the execution plan (FuncR_S106) • Manipulation and repositioning of SM (FuncR_S101) • Control and re-location of the WM (FuncR_S104, FuncR_S107) • Update/upgrade of satellite functionalities (FuncR_S102) • Data and power transfer between SM • Heat management between SM (FuncR_S115) • Failure detection and handling (FuncR_S111) • Resources re-allocation, data and power routing (FuncR_S110)	S1, S2, S3
VerR_G102	Validation sequence	The validation shall include the following sequence: 1. Calibrate/verify the simulation tool 2. Simulate the reconfiguration process and generate a valid robot execution plan 3. Execute the plan on the demonstrator setup	S1, S2

5 Demonstration Setup

This section presents the setup and layout for the MOSAR demonstrator that includes the ground segment with the MCC and the space segment with the servicer and client satellite.

5.1 General Layout

The MOSAR demonstrator setup will be installed in the Space Applications Laboratory. Figure 5-1 and Figure 5-2 illustrates respectively the MOSAR setup 3D implementation view and top view layout. These views don't highlight yet the integration of the visual subsystem that will be refined during WP4. The following view is based on the estimated size of the servicer and client satellite bus.

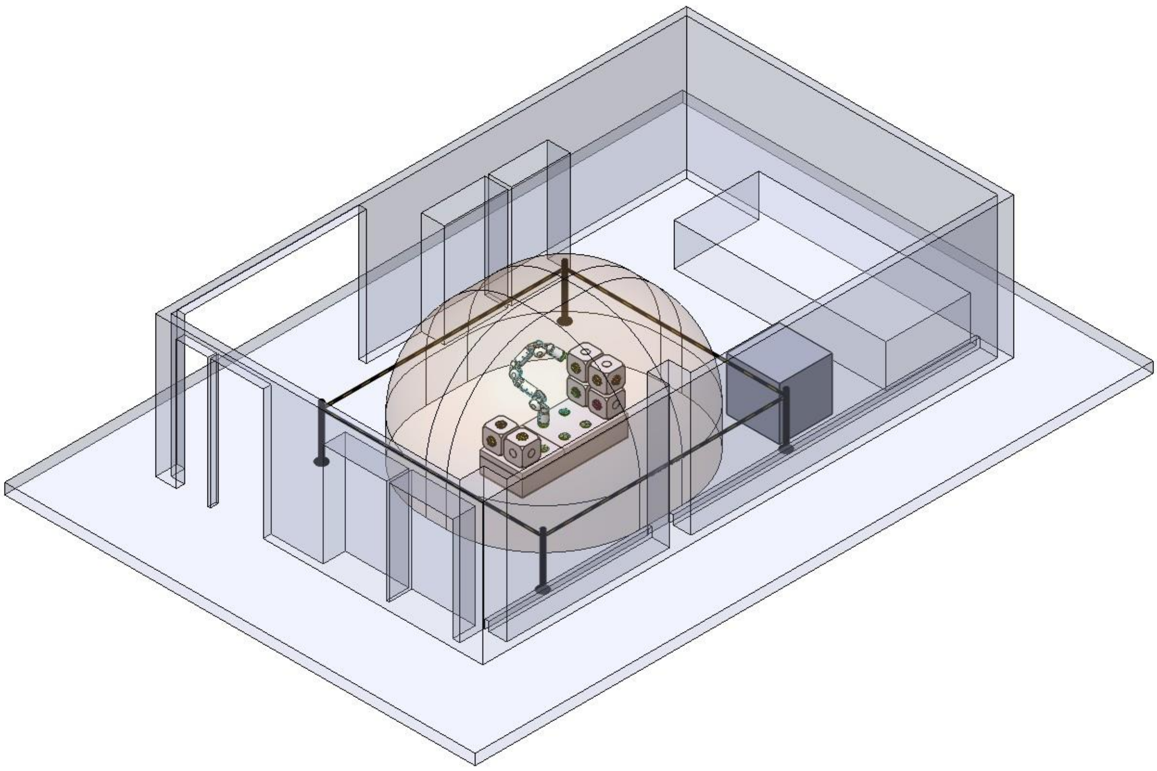


Figure 5-1: MOSAR Setup View in SpaceApps Laboratory Environment

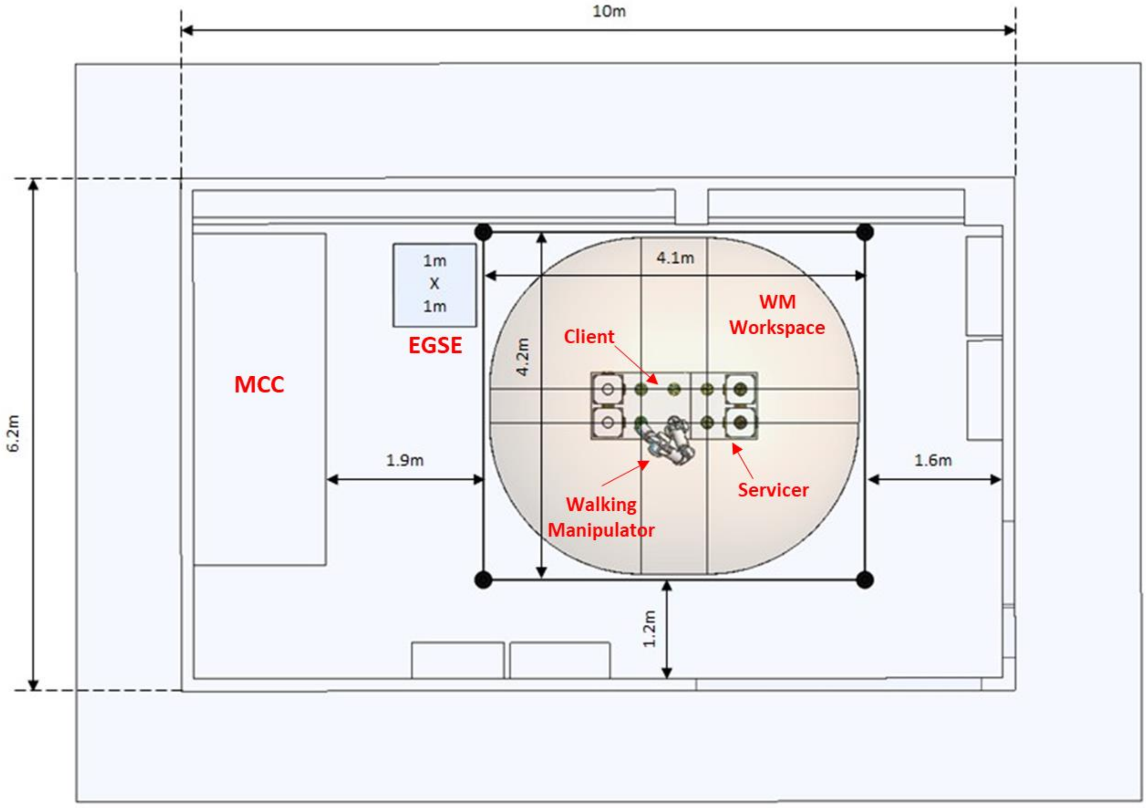


Figure 5-2: MOSAR Setup top layout

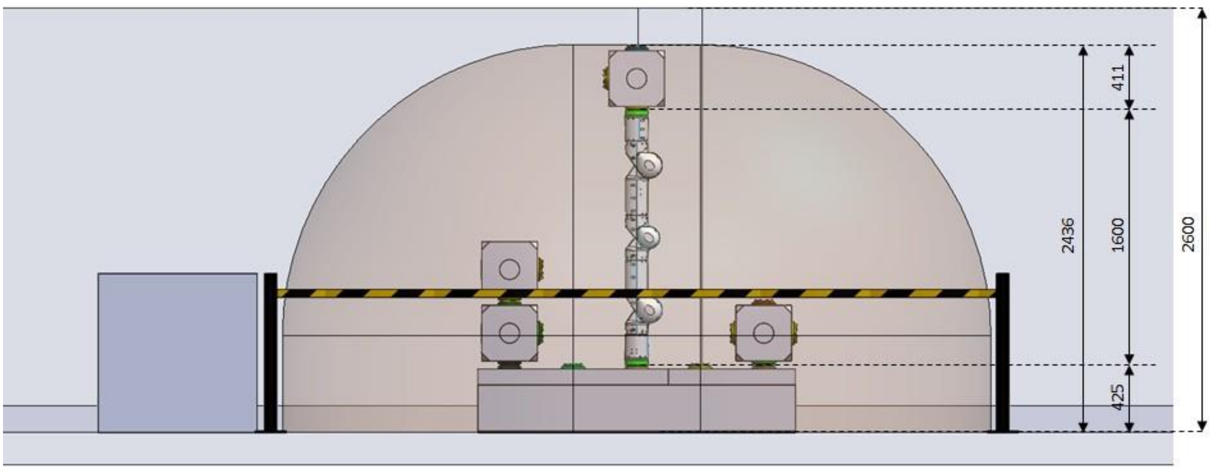


Figure 5-3: MOSAR setup side layout

5.2 Demonstrator Components

The MOSAR demo setup can be mainly divided in two main groups that are the Ground Segment (MCC) and the Space Segment. On top of this, other side components are also integrated. This section lists the main components of each part.

5.2.1 Ground Segment – Monitoring and Control Centre

The MCC setup will be composed of three computers:

- The Design and FES PC, able to support the preparation of the spacecraft design and the simulation in communication with the planner. It is based on a standard PC (x86) with decent CPU and graphical performance, with Windows OS, running MATLAB/Simulink (design tool) and the DLR FES software.

- The Planning PC, running the Planner Agent (in association with the FES) to find a valid sequence of operation to re-configure the spacecraft. It will run on a standard PC (x86), with Linux OS (Ubuntu 18.04 or above), running ESROCOS and ERGO.

- The Monitoring and Control PC, to allow monitoring and controlling the demo setup. It will run on a standard PC (x86), with Linux OS (Ubuntu 18.04 or above), running ESROCOS and the PUS Console/Service. This unit could potentially be merged with the Planning PC.

These three computers will be interconnect on the same Ethernet network in order to enable the communication between them (e.g. UDP between FES and Planner) and with the Space Segment (PUS service between MCC and spacecraft OBCs to represent the data link).

The MCC will use the existing Space Applications Monitoring and Control infrastructure (Figure 5-4). It is composed of a screen wall (3x55'' curved UHD Samsung), a large desk and series of smaller (touch) PC screens. A sub-set of these elements will be enough for the MOSAR setup application.

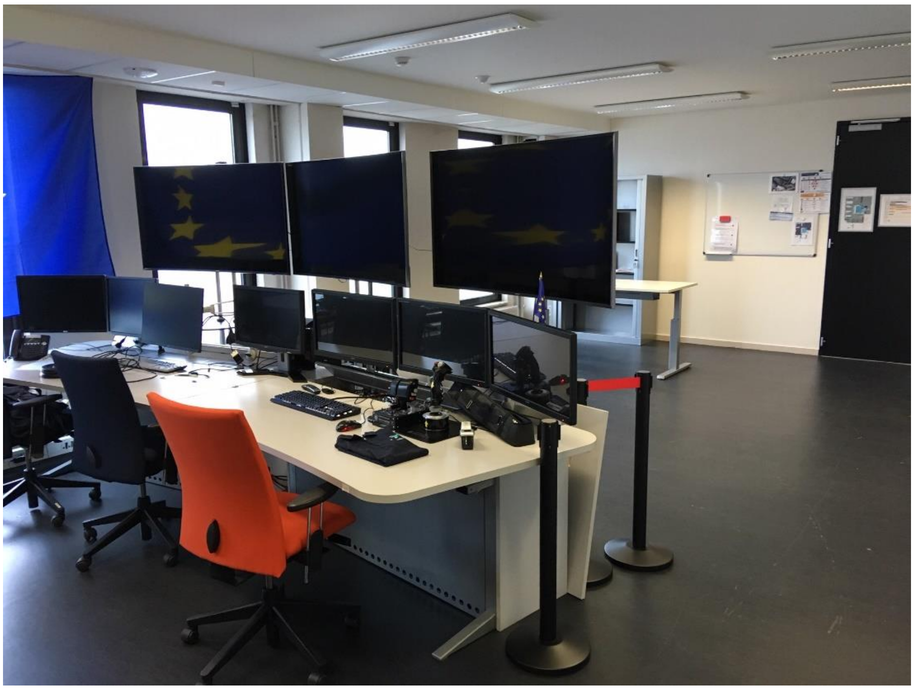


Figure 5-4: MCC Setup and visualization screens

5.2.2 Space Segment

Most of the Space Segment components are described in RD6. It includes:

- The Servicer and Client Satellite platforms equipped with HOTDOCK standards interfaces. The servicer includes the OBC-S, which is responsible to manage the spacecraft re-configuration operations, with communication to the MCC and with the internal components of the Space Segment setup. It is based on an Intel NUC board, running ESROCOS/ERGO on top of a Linux operating system (Ubuntu 18.04). The OBC-S is powered through the nominal spacecraft power bus.

- The spacecraft modules that represent different functionalities of the client satellite. The SM1 module includes the OBC-C, which is responsible to manage the spacecraft nominal operations, with communication to the MCC and with the internal components of the Space Segment setup. It is based on an Intel NUC board, running ESROCOS/ERGO on top of a Linux operating system (Ubuntu 18.04). The OBC-S is powered through the nominal spacecraft power bus.

  Most of the components embedded in the modules are powered through the nominal power bus. Some specific components, like the thermal heater is directly powered through the main supply. It is also always envisageable to power the two OBCs, also from the main supply, as backup solution.

- The walking manipulator that can move along the two spacecraft and manipulate the modules. It includes its own OBC, which is not interfaced through the standard Setup Ethernet network, but through the SpW link (due to its movable nature). It has however an Ethernet plug to enable direct connection to it, mainly for debugging purpose.

- The EGSE that provide the electrical components required to operate the system. This includes:
  - The 48V bench power supply (range 600W-1kW) to provide the main power bus to the Space Segment (e.g. Keysight Technologies Digital Bench N6701C or equivalent)
  - The Ethernet Switch that interconnects the FES, Planner, Monitoring and OBCs computers)
  - The power plugs to connect side components to the main supply

Figure 5-5: DC Bench power supply (Keysight or equivalent)

- The Visual Subsystem, as described in RD6. In order to support different scene configuration and lighting an occultation system will be considered around the setup. This is under investigation. The proposed approach would be to implement mate black curtains from the ceiling, around the setup (inside the safe zone). This is offering the advantage to present soft limits, in regards to WM operations and motions.

5.2.3 Other Components

Beside the ground and space segments, other components will be considered during the integration and demonstration activities:

- Each partner will provide specific tools to support low-level control of their components in support to the integration activities. This includes hardware and software that are used during their own local integration (not part of the demo setup).
- Standard electrical and mechanical tools and equipment to support the integration phase (e.g. multimeter, …)
- Safety equipment and devices as described in the following section
- Cameras for pictures and video recording along the integration and demonstration phases.

5.3 Demonstrator Safety

The main safety hazard of the setup is the operations of the Walking Manipulator when it is moving or manipulating the spacecraft modules. The purpose of the safety measure is to protect the human operators working around the setup, and as much as possible also the integrity of the setup hardware. Although the motion of the arm will be slow, different strategies will be implemented on the demonstration setup to ensure the safety of the operations:

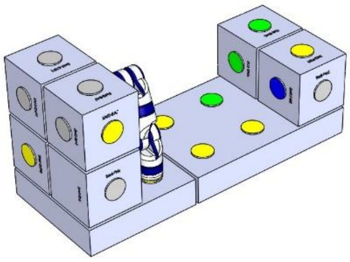
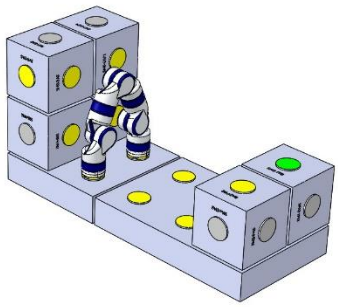
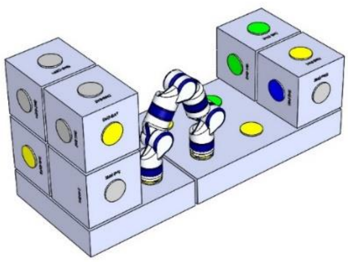
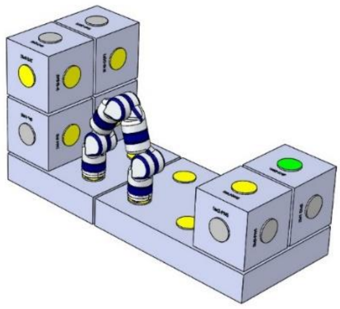
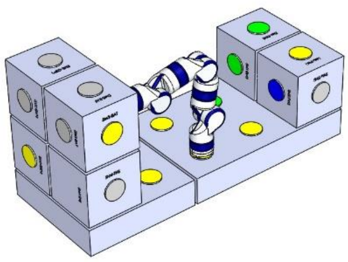
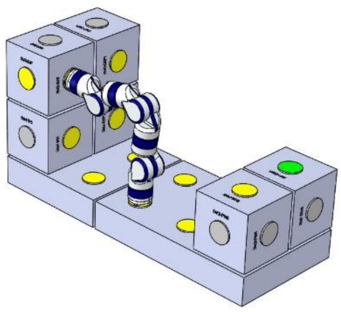
- Electrical emergency stops will be integrated on the EGSE power line, accessible from the MCC, as well as from one or two other locations around the setup (e.g. also with a mobile switch, that can be worn by an operator). In case of major failure of the operations, that would allow to fully power off the space segment.
- Soft safety measures will be implemented at software level, based for instance on the interaction force/torque sensing on the WM. Other strategies will also be considered. The WM is equipped with brakes, which ensures it is keeping its position when powered-off.
- The reachability area of the WM (including manipulated SM) will be protected by security bands, such that the operator doesn't enter the area. The typical protection zone is illustrated in Figure 5-2. At this stage, we would like to not consider rigid protection such that the area can be better accommodated when the setup is not operational. We are currently evaluating the possibility to implement more active sensors (e.g. infrared/laser barrier), but the practicalities, efficiency and cost need to be evaluated.
- A flashing light will be installed near the Space Segment setup, to inform operators when the setup is powered-on.

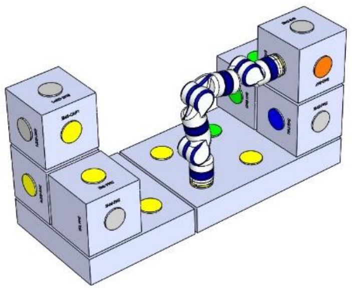
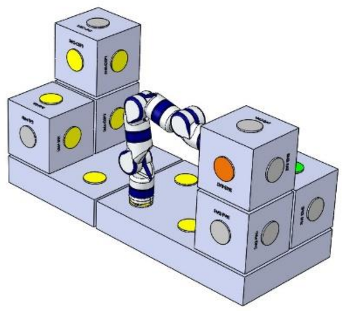
6 Annex

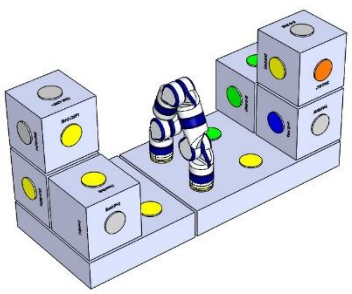
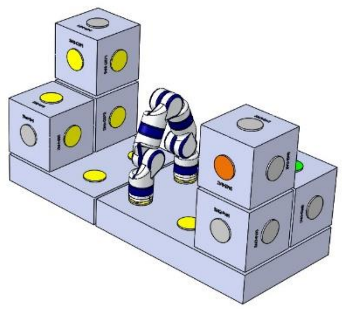
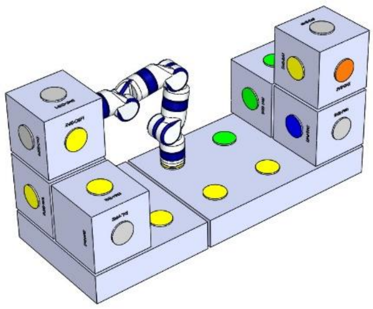
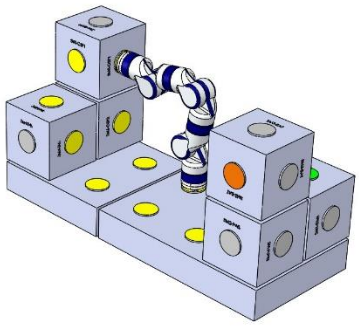
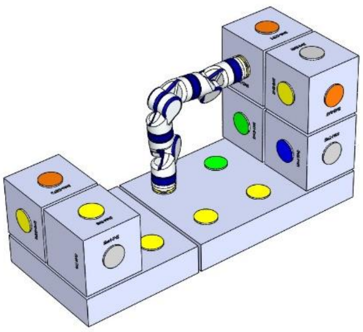
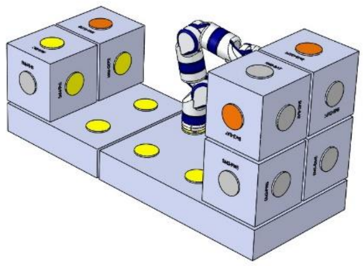
6.1 MOSAR Sequence of Manipulations Example

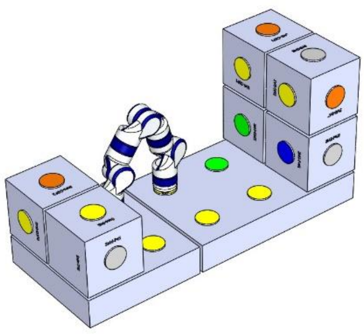
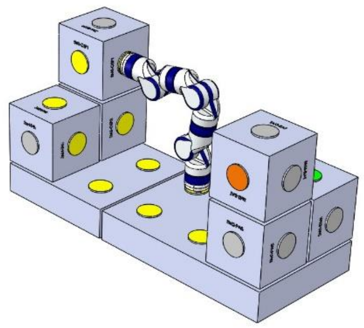
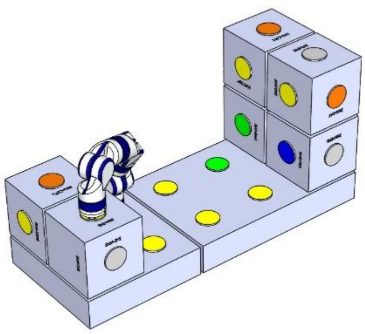
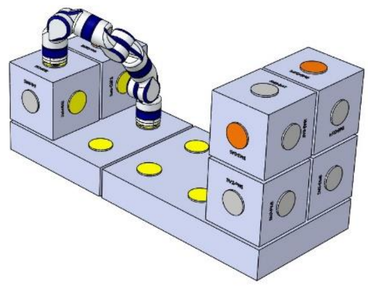
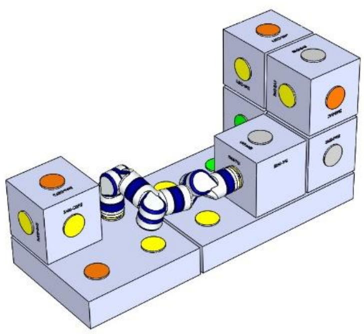
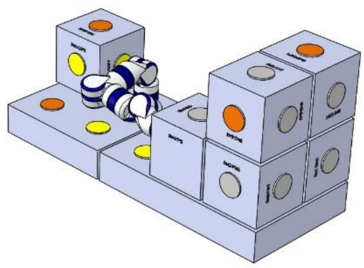
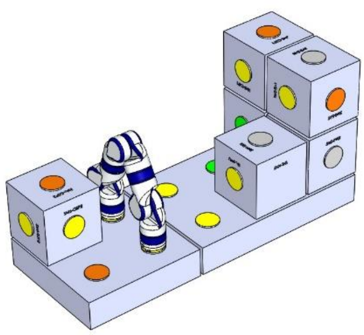
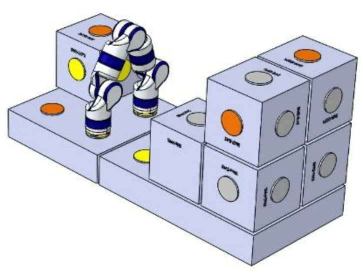
The following table provides a possible step-by-step sequence of operations. covering the scenarios 1 and 2.

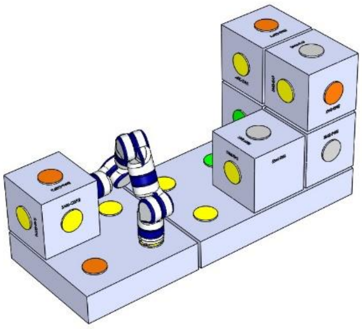
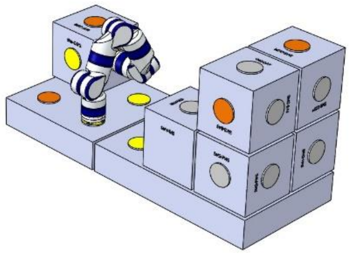
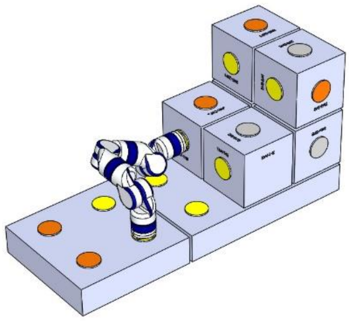
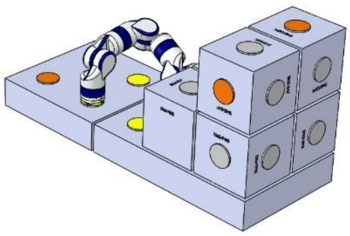
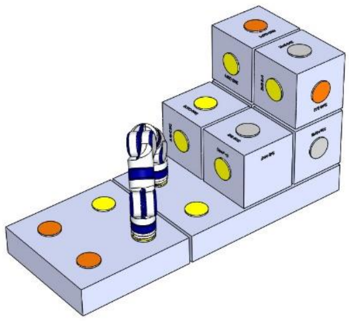
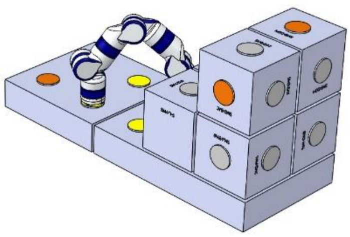
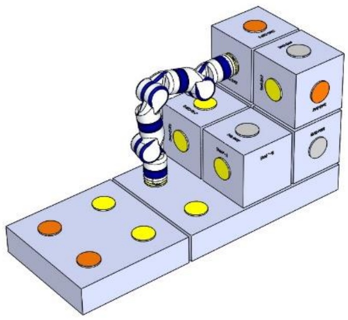
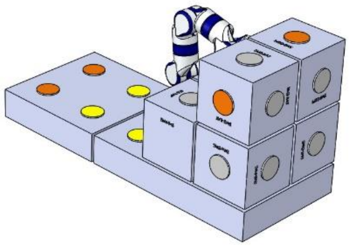
Table 6-1: Scenarios 1 and 2 step-by-step sequence of operations

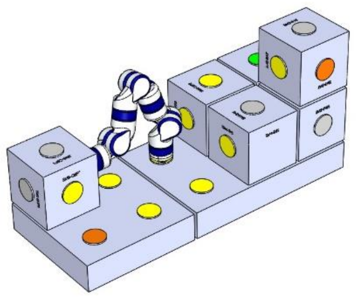
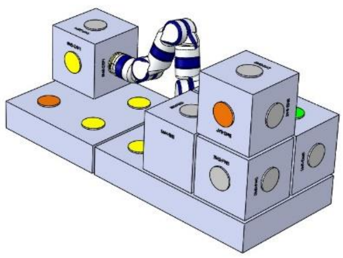
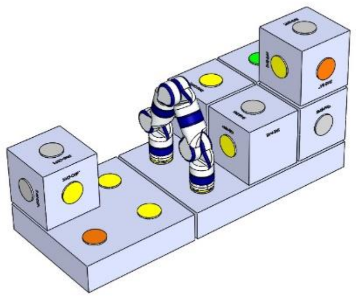
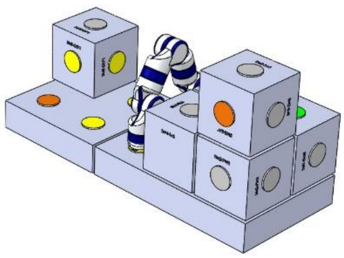
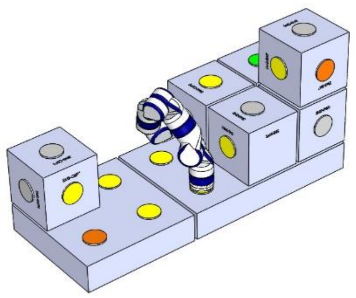
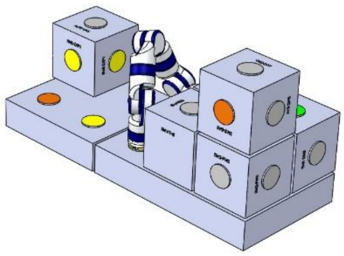
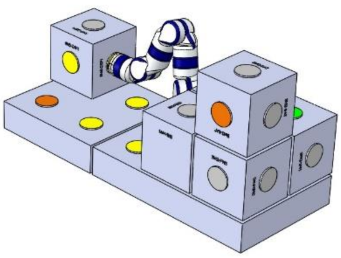
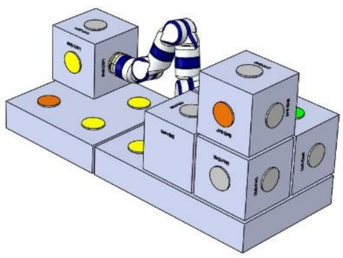
Step 0: Initial Position 	**Step 0: Initial Position** 
Step 1: WM-A to CLT-B 	**Step 1: WM-A to CLT-B** 
Step 2: WM-B to SM3-BAT 	**Step 2: WM-B to SM3-BAT** 

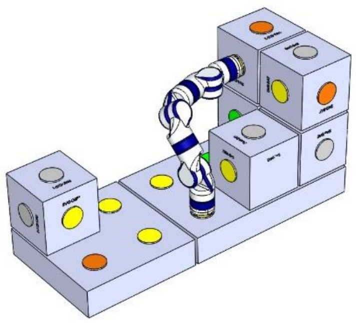
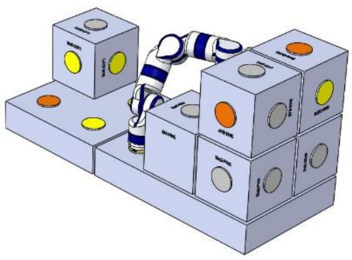
Step 3: SM3-BAT to SM2-PWS	**Step 3: SM3-BAT to SM2-PWS**
	

Step 4: WM-B to CLT-A	**Step 4: WM-B to CLT-A**
	
Step 5: WM-A to SM5-OSP1	**Step 5: WM-A to SM5-OSP1**
	
Step 6: SM5-OSP1 to SM1-DMS and SM3-BAT	**Step 6: SM5-OSP1 to SM1-DMS and SM3-BAT**
	

Step 7: WM-A to SVC-W	**Step 7: WM-A to SVC-W**
	
Step 8: WM-B to SM4-THS	**Step 8: WM-B to SM4-THS**
	
Step 9: SM4-THS to SM2-PWS	**Step 9: SM4-THS to SM2-PWS**
	
Step 10: WM-B to SVC-X	**Step 10: WM-B to SVC-X**
	

Step 11: WM-A to SM6-OSP2	Step 11: WM-A to SM6-OSP2
	
Step 12: SM6-OSP2 to CLT-E, SM1-DMS, SM4-THS	**Step 12: SM6-OSP2 to CLT-E, SM1-DMS, SM4-THS**
	
Step 13: WM-A to CLT-A	**Step 13: WM-A to CLT-A**
	
Step 14: WM-B to SM5-OSP1	**Step 14: WM-B to SM5-OSP1**
	

Step 15: SM5-OSP1 to SVC-Y	Step 15: SM5-OSP1 to SVC-Y
	
Step 16: WM-B to CLT-B	**Step 16: WM-B to CLT-B**
	
Step 17: WM-A to SM6-OSP2	**Step 17: WM-A to SM6-OSP2**
	
Step 14: WM-B to SM5-OSP1	**Step 14: WM-B to SM5-OSP1**
	

Step 18: SM6-OSP2 to SM1-DMS and SM3-BAT	Step 18: SM6-OSP2 to SM1-DMS and SM3-BAT
	

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