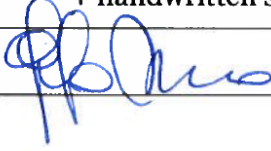

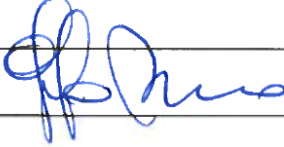


Ececutive Summary Report
OMAR - On orbit manufactured spacecraft

ESA Contract No. 4000129471/19/NL/AS

Written by	Responsibility + handwritten signature if no electronic workflow tool
G. Musso	
Verified by	
F. Massobrio	
Approved by	
G. Musso	

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1. INTRODUCTION

This Executive Summary Report concisely summarise the findings of the “On-orbit Manufactured Spacecraft - System Design Impacts of On-Orbit Manufacture and Assembly” study and provides an overview of the work done through the 4 tasks in which the study took place.

1. The objective of task#1 is to define the study case satellite(s) and mission level assumptions for the new design of a satellite optimised to be manufactured and assembled on-orbit and prepared to be serviced (i.e. refurbished, reused or recycled) on-orbit in the future.
2. The objective of task#2 is to define the design requirements for the study case satellite(s) in order to optimise the design making use of on-orbit manufacturing and assembly. The requirements shall also address the design impacts to allow for future servicing of the satellite.
3. The objective of task#3 is to define the conceptual design of the new satellite(s), addressing all the subsystems design impacts and deriving all the relevant system budgets to compare the performances of the new design in comparison to the former design.
4. The objective of task#4 is to identify the main open points and establish a technology roadmap

2. TASK #1

In the first task the different type of satellites/orbits have been identified and assessed:

Geostationary orbit (GEO) is used by satellites that need to stay constantly above one particular place over Earth, such as telecommunication satellites.	GEO →	- telecommunication satellites.
Low Earth orbit (LEO) is most commonly used for satellite imaging while communications satellites in LEO often work as part of a large combination or constellation, of multiple satellites to give constant coverage.	LEO →	- satellite imaging - communications sat. (constellation)
Medium Earth orbit (MEO) is commonly used by navigation satellites.	MEO →	- navigation satellites
Polar orbit and Sun-synchronous orbit (SSO): polar orbits are a type of low Earth orbit (LEO).		
Geostationary transfer orbit (GTO), for satellites addressed to permanently orbit and operate in GEO.		
Lagrange points (L-points) allow for orbits that are much, much farther away (over a million kilometers) and do not orbit Earth directly.		

Then, assessing the different characteristics, a trade off selected the two study cases for which on-orbit manufacturing and assembly is expected to result in significant benefits

	Service overview	OMAR pro	OMAR cons
NGEO (LEO): Earth observation	Satellite with large and powerful payloads (Radar, Optical)	<ul style="list-style-type: none"> • Large components • Critical on-ground/launch constraints • Good on-ground visibility • High test and pre-launch costs 	<ul style="list-style-type: none"> • Manufacturing and assembly complexity (1)
NGEO (LEO): Telecommunication (Constellation)	Constellation of small satellites with small payloads	<ul style="list-style-type: none"> • Good on-ground visibility 	<ul style="list-style-type: none"> • Small components • Lower costs w.r.t. large SAT • Lower on-ground/launch constraints • Manufacturing and assembly complexity
NGEO (MEO): Navigation	Satellite with large and powerful payload (NAV antenna)	<ul style="list-style-type: none"> • Large components • Critical on-ground/launch constraints • High test and pre-launch costs 	<ul style="list-style-type: none"> • Manufacturing and assembly complexity • Different on-orbit velocity (potentially robotize service problems) • Less visibility w.r.t. other orbits (longer period)
GEO: Telecommunication	Satellite with large and powerful payload (TLC antenna)	<ul style="list-style-type: none"> • Large components • Critical on-ground/launch constraints • Good and fixed on-ground visibility • High test and pre-launch costs 	<ul style="list-style-type: none"> • Manufacturing and assembly complexity *(1)

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The two study cases are:

- Telecommunication satellite in GEO

Orbit	Position	Mass at Launch	Dimensions	BOL Power	Design Lifetime
GEO ≈ 36000 km	2002/2015 → 12,5°W 2016/2018 → 36°W 2018/2018 → 59,3°E	≈2700kg	2,1 x 2 x 2,8 m 2,6 x 2,8 x 4,6 m	5 kW	15 years

- Earth observation satellite in LEO

Orbit	Position	Mass at Launch	Dimensions	EOL Power	Design Lifetime
LEO ≈ 700 km	SSO (Sun synchronous Orbit)	≈2200kg	1,3 x 1,3 x 3,25 m 2,5 x 2,6 x 3,9 m	4,8 kW	7,25 years

3. TASK #2

The System Requirement Documents of the two study cases selected for this study have been assessed and merged in order to compile a list of requirements covering both the selected satellites. They are assessed and defined into 3 categories:

- Most of the requirements, at SRD level, remain unmodified since they address the operational performance of the functional S/C. The performance represents the primary operational function and the purpose of the satellite and it must be guaranteed regardless of whether the satellite is manufactured and integrated on ground or on orbit.
- Many other requirements refer to ECSS standards that, actually, do not consider the on orbit performed activities. Therefore a new/update set of ECSS documents shall be developed to be referred as standards for the new on orbit performed activities (as intended in the OMAR approach).
- Another set of requirements, that are neither among those considered UNMODIFIED nor among those that make reference to ECSS standard, have been reviewed and addressed to the OMAR selected study case.

Requirements for on orbit manufactured satellites are in the frame of a new manufacturing, integration/assembly and verification /qualification process that shall be redefined to include the activities that will transferred from ground to orbit.

Safety aspects related to the services and new design constraints are also assessed in accordance with the following considerations:

- In the frame of the (unmanned) OMAR activities the safety aspects are related to the on orbit activities in relation to the design aspects and the planned on orbit operations.
- Safety from ever since is supported by dedicated standards that, today, do not encompass the in orbit activities as they are intended in the OMAR approach.
- As per ECSS Safety, the objective of safety assurance is to ensure that all safety risks associated with the design, development, production and operations of space product are adequately identified, assessed, minimized, controlled and finally accepted through the implementation of a safety assurance programme.
- The identification and the discussion of the safety aspects related to the services and new design constraints (as required by SOW) will be performed taking into account the possible hazard and discussing their application to the services (on-orbit manufacturing and/or assembly, refurbishment service and the additional capabilities: reuse, recycle, growth capability), new functions and the relevant new design constraints.

Then the satellite equipment/parts that potentially benefit from manufacturing and/or assembly in space are analysed in order to define a list of the the satellite equipment/parts that would potentially benefit from manufacturing and/or assembly in space. The result of this analysys, together with the following additional parameters (agreed with ESA) feed the trade-off between the two different study cases to select the baseline scenario to address to task 3.

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The additional parameters identified for the selection of the baseline scenario are the following:

- Technological obsolescence of the parts
- Reusability potentials of the parts (parts having longer lifetime that can be standardised and reused in other satellites)
- Large structures constrained by launch
- Orbital aptitude (orbital aspects that could affect the applicability in orbit services, as visibility wrt orbital period, constant orbital velocity, e.g. objects in MEO that do not require higher precision of the approaching servicer and therefore higher risks)
- Re-design potentials to ease external and internal access to components for enable OMAR
- Capability to provide scaling opportunities of the solution and therefore growth capability of the subsystems to better address future and unpredictable market needs and evolution

The final trade off selected the **TELECOMMUNICATION SATELLITE in GEO** as baseline scenario for the phase 3.

The following table, relevant to the selected baseline scenario, shows the satellite equipment/parts that potentially benefit from manufacturing and/or assembly in space.

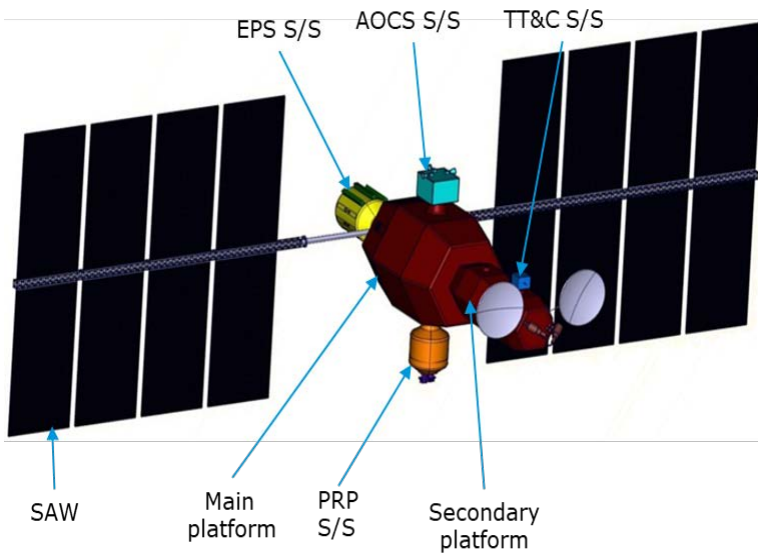
TLC SATELLITE H/W MATRIX		ASSY	MFG	REUSE	RECYC	REFUR	GROW
STRUCTURE S/S	PANELS	Y	Y	Y	Y	Y	Y
	CENTRAL CYLINDER	Y	Y	Y	Y	Y	Y
	STR MISC. (TERTIARY + MISCELLANEA)	Y	Y	Y	Y	Y	Y
POWER S/S	POWER CONDIT. & DISTRIBUTION S/S	Y		Y	N	Y	Y
	POWER STORAGE S/S						
	BATTERY UNIT	Y				Y	
	POWER GENERATION (SOLAR ARRAY)	Y	PY	PY	PY	PY	PY
	SOLAR ARRAY DRIVE ASSY.	Y		Y			
	SOLAR ARRAY WING UNIT	Y	PY	Y	PY	PY	Y
PLATF. INTEGR. CONTROL S/S	INFRARED EARTH SENSOR	Y		Y		Y	
	LAE DRIVER UNIT	Y		Y		Y	
	MIN INERTIAL MEASUR UNIT	Y		Y		Y	
	MOMENTUM WHEEL ASSY	Y		Y		Y	Y
	REMOTE UNIT A (AOC)	Y		Y		Y	
	REMOTE UNIT B (PTF)	Y		Y		Y	
	SUN ANALOG SENSOR	Y		Y		Y	Y
	SPACECRAFT CONTROL UNIT	Y		Y		Y	Y
UNIFIED PROPULSION S/S	PRESSURANT TANK	Y	Y	Y	Y		
	PROPELLANT TANK	Y	Y	Y	Y		
	FILTERS	Y					
	VALVES	Y					
	PRESSURE REGULATOR & TRANSDUCER	Y		Y		Y	
	LIQUID APOGEE ENGINE	Y		Y		Y	
THERMAL CONTROL S/S	REACTION CONTROL THRUSTER	Y		Y		Y	
	THERMAL BLANKETS	Y		Y		Y	
	HEATERS	Y		Y		Y	
	SECOND SURFACE MIRRORS	Y	Y	PY	Y	Y	
	THERMAL DOUBLERS	Y	Y	Y	Y		
	HEAT PIPES	Y	Y	Y	Y		
KU-BAND REPEATER	LOW NOISE AMPLIFIER	Y		PY		PY	
	DOWN CONVERTER	Y		PY		PY	
	CHANNEL AMPLIFIER	Y		PY		PY	
	T.W.T. ASSEMBLY	Y		PY	PY	PY	
	FILTERS	Y		PY		PY	
	CHANNEL FILTERS & MULTIPL.	Y		PY		PY	
	REDUNDANCY SWITCH MATRIX	Y		PY		PY	
	LOWPASS FILTER	Y		PY		PY	
	CONFIG. SWITCH DRIVE UNIT	Y		PY		PY	
KU-BAND ANTENNAE	Rx ANTENNA - EUROP. COVERAGE	Y	Y	Y	Y	Y	Y
	Tx ANTENNA - EUROP. COVERAGE	Y	Y	Y	Y	Y	Y
	Rx-Tx ANTENNA AMERICAN COVERAGE	Y	Y	Y	Y	Y	Y
TELEM. TRACK. & COMM. SECT.	CMD RECEIVER	PY				PY	
	TLM TRANSMITTER	PY				PY	
	Ku-BAND BEACON TRANSMITTER	PY				PY	
	S-BAND TRANSPONDER	PY				PY	
	TT&C ANTENNAE	PY				PY	
DC & PYRO HARNESS	DC HARNESS	Y					
	PYRO HARNESS	Y					

4. TASK #3

Task #3 defined the conceptual design of the satellite optimised to be manufactured and/or assembled on-orbit and serviced.

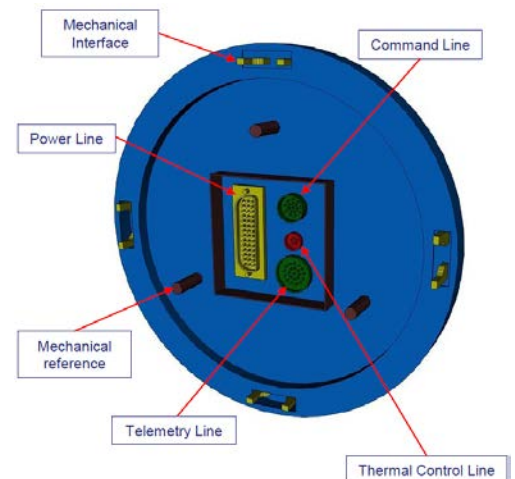
The re-designed satellite can be defined as Modular multi-mission platform.

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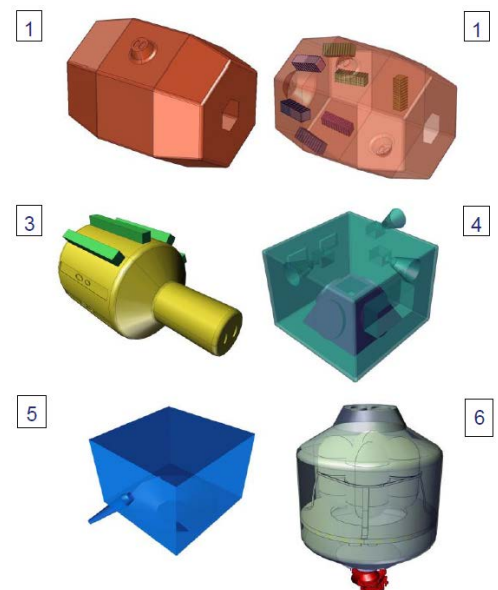
Abbreviation	Meaning
AOCS	Attitude and Orbit Control System
TT&C	Telemetry Tracking & Control
EPS	Electrical Power System
SAW	Solar Array Wing
PRP	Propulsion

- Every S/S of the S/C has its own interface in order to communicate with the main platform.
- The interface is thought to be a standard for every S/S. It includes:
 - Power Line
 - Telemetry Line
 - Command Line
 - Thermal Control Line
 - Mechanical interface and reference to allow the docking phase.
- Ease of equipment's upgrade by simply plug and play them from the S/C structure through a mechanical/electrical interface.
- Possibility to make the S/C a multi-mission platform with huge growth potential, due to the modularity and the shape of the structure that is far from the usual one.
- No need to replace the entire EPS S/S when an equipment upgrade is necessary, as only the battery assembly requires to be upgraded. This can be performed by means of a service robot arm that simply inserts the new batteries (sent from ground) into the EPS structure through a power/signal interface.



The Structure S/S is composed by:

1. The main structure of the platform, where all the power distribution units are installed. It's the main body of the S/C and presents many electro-mechanical interfaces that allow the installation of new equipment.
2. The secondary structure of the platform, which has the same shape of the main one, but its dimensions are way too lower (so it's not figured). It has to be connected to the main platform in order to accommodate new equipment.
3. The structure of the EPS S/S, where the necessary battery assemblies are installed on through their power/TM-TC IF. PCU is inside this structure.
4. The structure of the AVS S/S, that accommodates all the actuators and instruments necessary for the attitude control of the spacecraft (RW, STT, etc...).
5. The structure of the TT&C S/S, where both the transponder and the S-band antennas for the S/C – Ground communication are located.



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6. The structure of the PRP S/S, containing tanks and all the electrical units necessary for the function of the propulsion S/S. The exterior surfaces could be equipped with some robotic arms in order to orient the direction flow of the thrusters.
7. The tertiary structure and miscellanea, which are respectively, the connector brackets and the screws of the S/C.

The manufacturing / assembly of the structure subsystem can be approached in two different ways.

This scenario is also reflected in the AIV / AIT plan. In fact the AIT activities performed on orbit are based on a different philosophy w.r.t. the traditional AIT plan as we are used to deal with for a spacecraft assembled on ground and then launched in space.

In fact it is not only simply matter of transferring the AIT activities (or part of them) on orbit but all the process must be reviewed (starting from the manufacturing to the acceptance phase, where the property of the spacecraft passes from the manufacturer to the customer), where also other aspects (e.g. contractual) must be considered.

As seen in the table before, 95 % of a spacecraft can be potentially assembled on orbit while <30 % can be potentially manufactured on orbit.

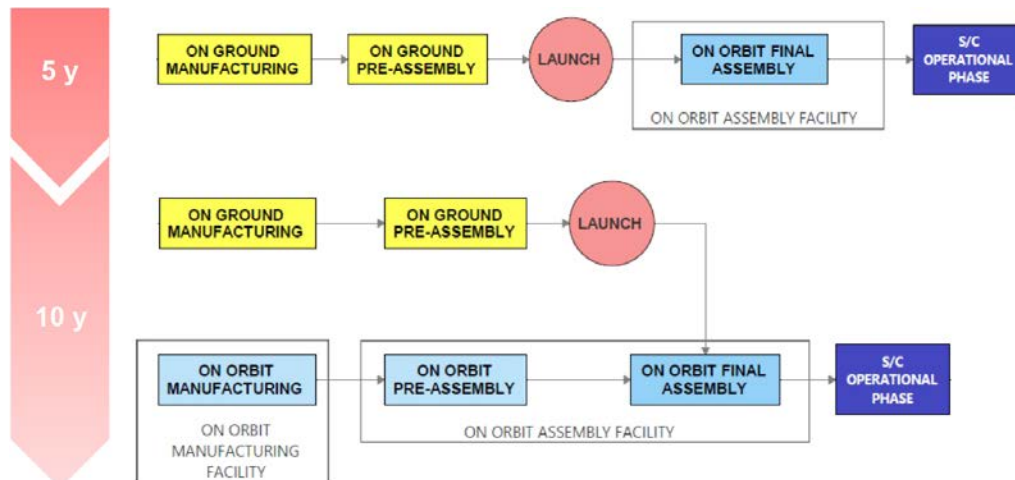
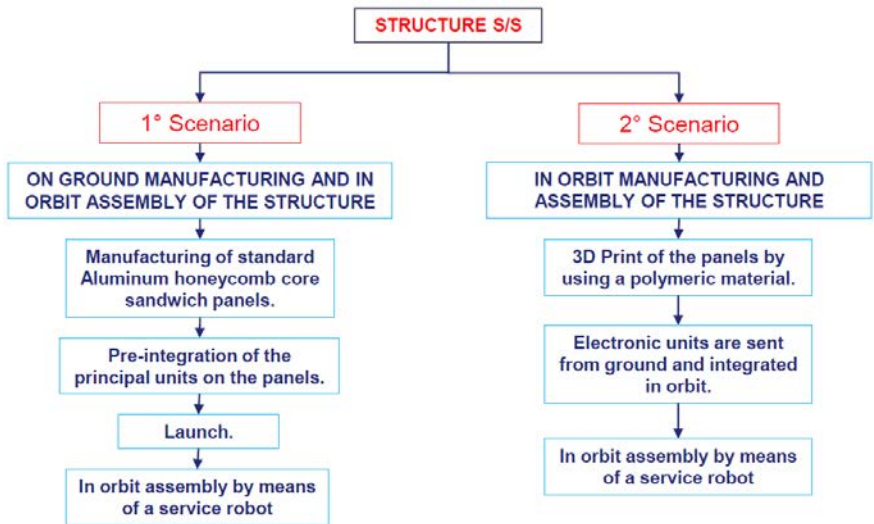
This means that, anyhow, some of the activities remain on ground while others are transferred on orbit.

The verification process activities are incrementally performed at different product decomposition levels and in different stages, applying a coherent bottom-up strategy and utilizing a suitable combination of different verification methods.

In case of a spacecraft designed to be partially (as specified above) manufactured and assembled on orbit, the solution to adopt is to manage the model philosophy in accordance with a protoflight model (PFM) approach applied at each level of decomposition of the space system, where all the assembly / integration phases are proved on ground and then performed in orbit on a recurring unit (flight model, FM).

Qualification, acceptance and pre-launch stages shall be completed before launch.

For the scope of this study, the verification activity considered ends at the final acceptance event performed prior to the close-out that, in case of the in orbit manufacturing/assembly activities, includes also the in-orbit phase.



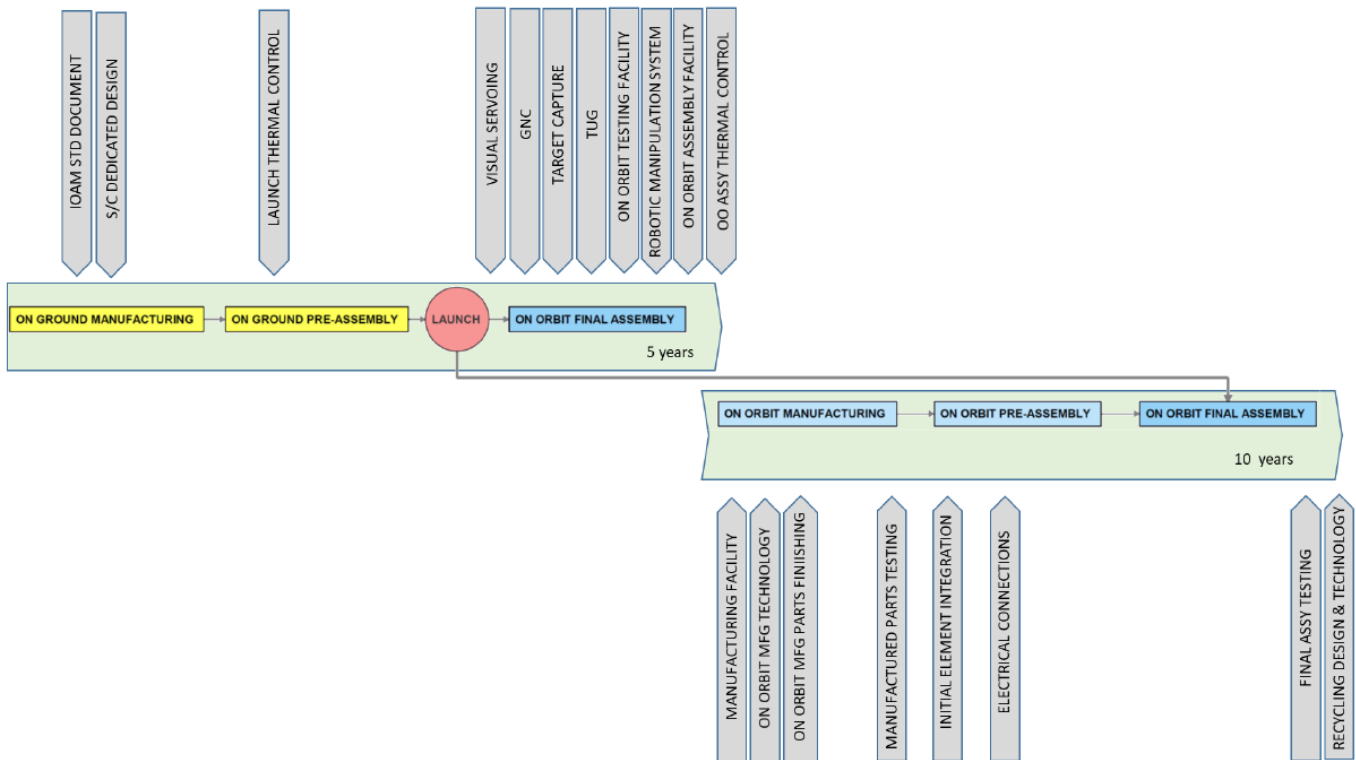
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5. TASK #4

The development of the S/C concept selected and outlined in during the study is supported by differ technologies with different technological development levels.

As part of the last task is the following identification in chronological order of the technologies and the elements needed to enable the different on orbit assembly and manufacturing (as included in OMAR).

Then the existing technologies suitable for the selected mission scenario and their development levels are assessed and mapped.



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