IOSPR Maturation phase

Final Report

12/12/2022

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D-ORBIT
NEW SPACE SOLUTIONS

System Overview

Naming update and clarification

Nomenclature of the vessels has been changed for clarity purposes

Nomenclature		
Old name	Mothership	Life Extension Drone (LED)
New name	SSTV Sol	SSXV Proxima
Main Features		
Customer to service	Satellite A + Satellite B	Satellite C
Common features	Self orbit raise + RPO + Capture	
Specific feature	Transportation (SS**T**V): Large delta-v over a short time	Extension (SS**X**V): Small delta-v over a long time

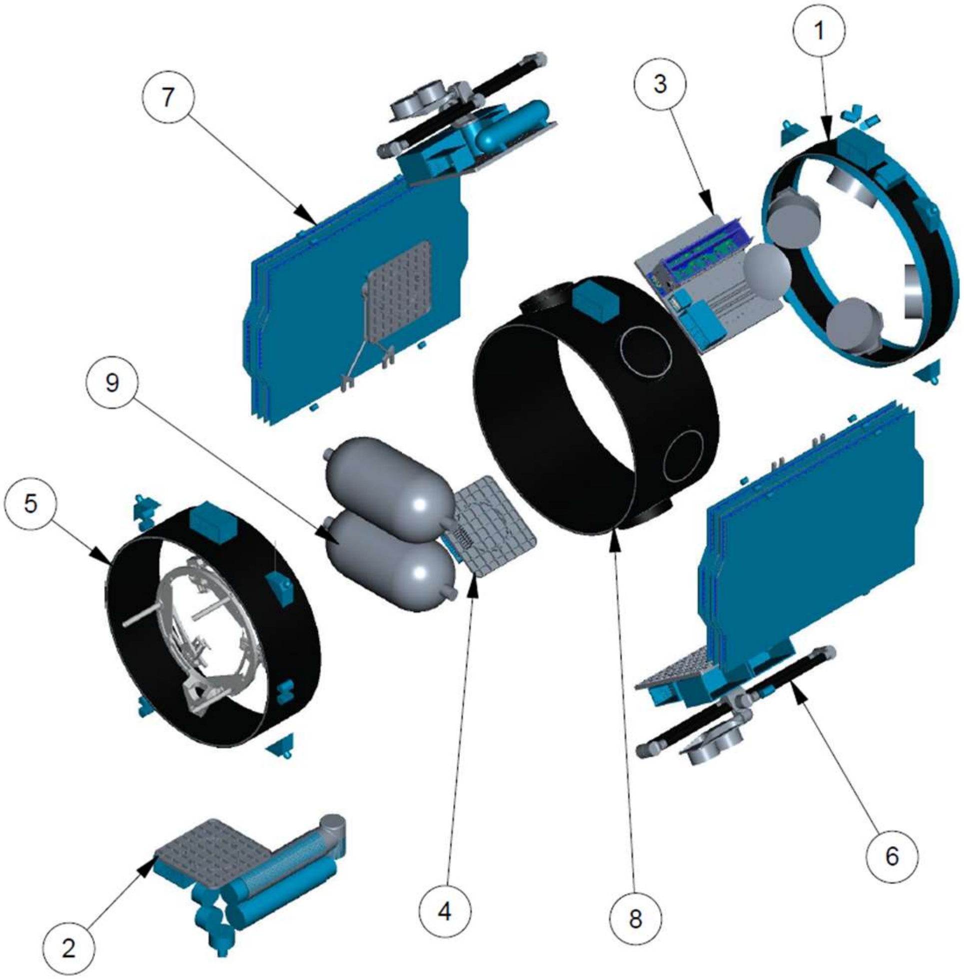
Common modules overview

Modularity is a main design driver. Due to this reason, common functions have been identified to drive the design of common modules.

Module Name	Module ID	Main Function
Attitude Control Module	M-ACS	Absolute orbital navigation Nominal attitude control (RW) RPO guidance
Robotic Arm Module	M-ARM	Capture Ring manipulation and general purpose inspection
Avionics Module	M-AVN	Primary OBDH duties and high datarate COM (X-band)
Battery Module	M-BAT	Electric energy storage
Axial Capture Module	M-CPA	RPO navigation and sensors Capture Ring storage and hard locking
Electric Propulsion Module	M-PRE	Absolute orbital control (electric propulsion)
Solar Array Wing Module	M-SAW	Power production and conditioning

When considering different specific vessels, this may lead to a sub-optimal solution.
However, the advantages of a *commonality over optimization* approach lead the selection of shared modules across different vessels architectures.

Proxima functional architecture



Common modules:

1. M-ACS
2. M-ARM
3. M-AVN
4. M-BAT
5. M-CPA
6. M-PRE*
7. M-SAW**

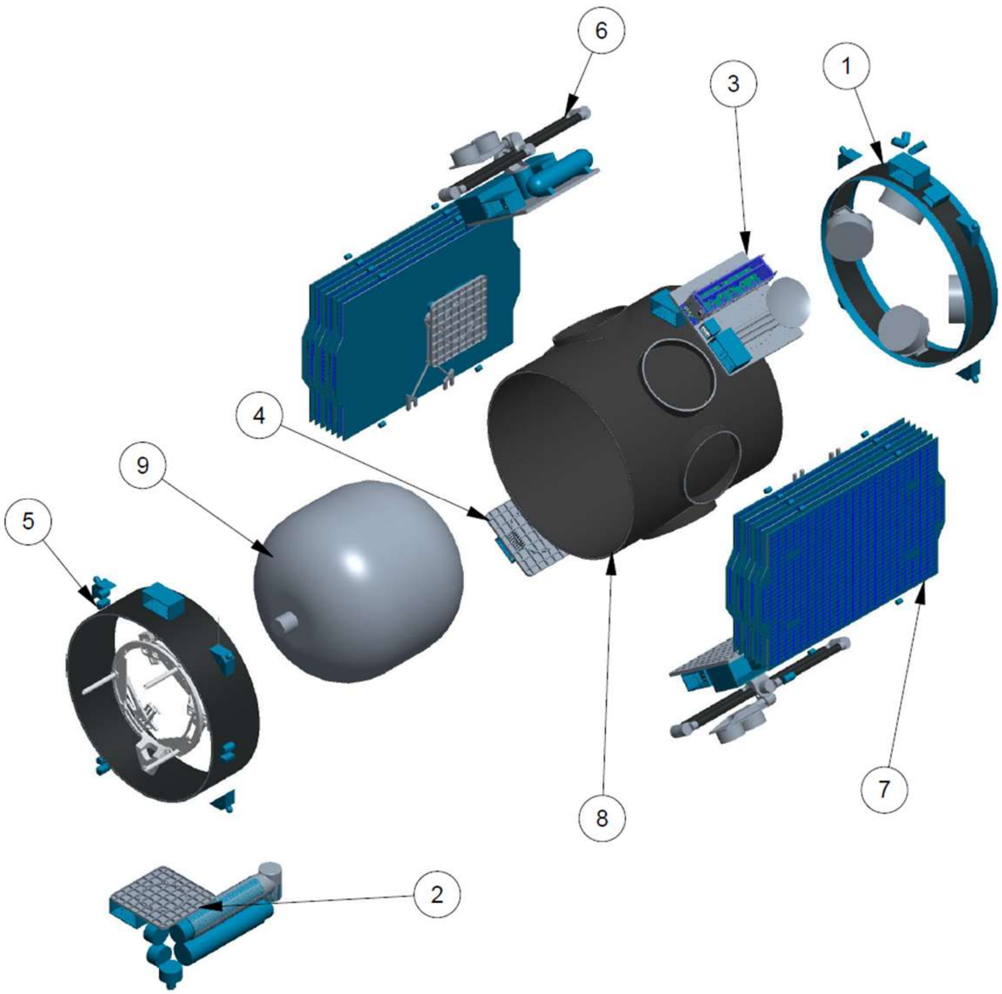
Design drivers for modules related to Proxima specific feature:

8. M-SMS
   - core structure
   - host M-TKS
9. M-TKS
   - host propellant for 7 years AOCS takeover (including transportation to graveyard orbit)

*M-PRE is a common physical module. The equipped thruster can be used at different power levels according to the required performance

**M-SAW is partially common. This is because the same solar panels are used but in different amount according to the required power production

Sol functional architecture



Common modules:

1. M-ACS
2. M-ARM
3. M-AVN
4. M-BAT
5. M-CPA
6. M-PRE*
7. M-SAW**

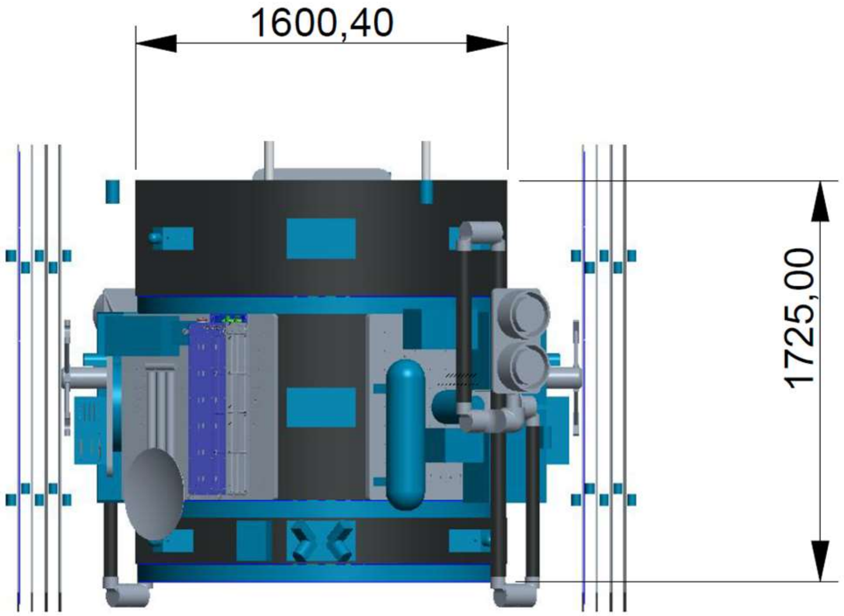
Design drivers for modules related to Sol specific feature:

8. M-SMD
    - sustain the loads in stacked launch configuration
    - core structure
    - host M-TKC
9. M-TKC
    - host propellant for at least 1 transportation service per year for 7 years

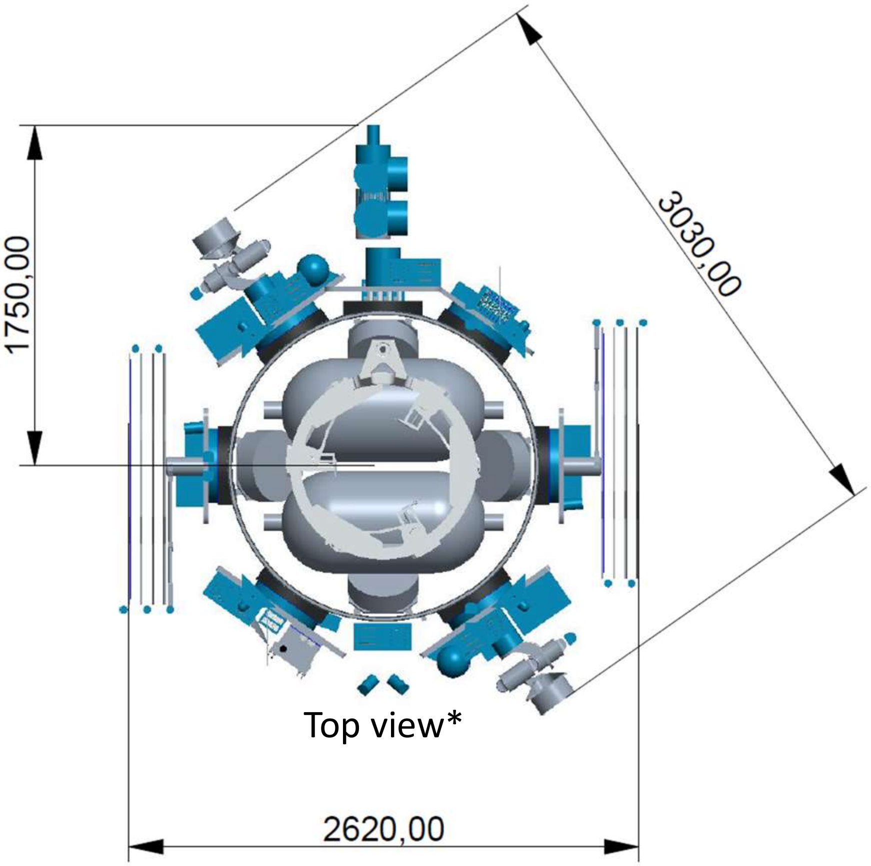
*M-PRE is a common physical module. The equipped thruster can be used at different power levels according to the required performance

**M-SAW is partially common. This is because the same solar panels are used but in different amount according to the required power production

Proxima launch configuration



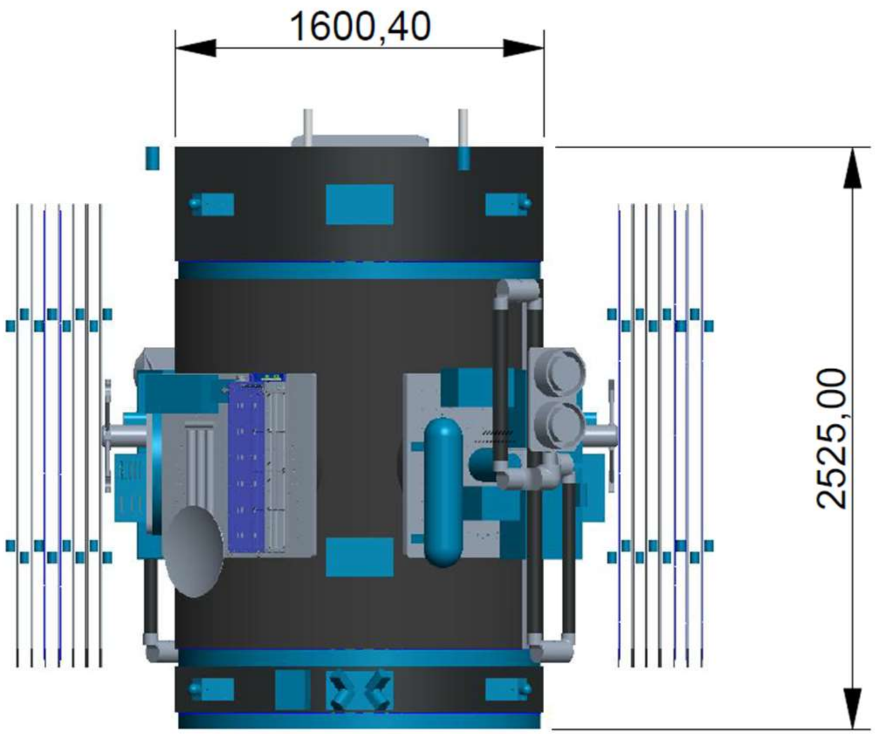
Side view*



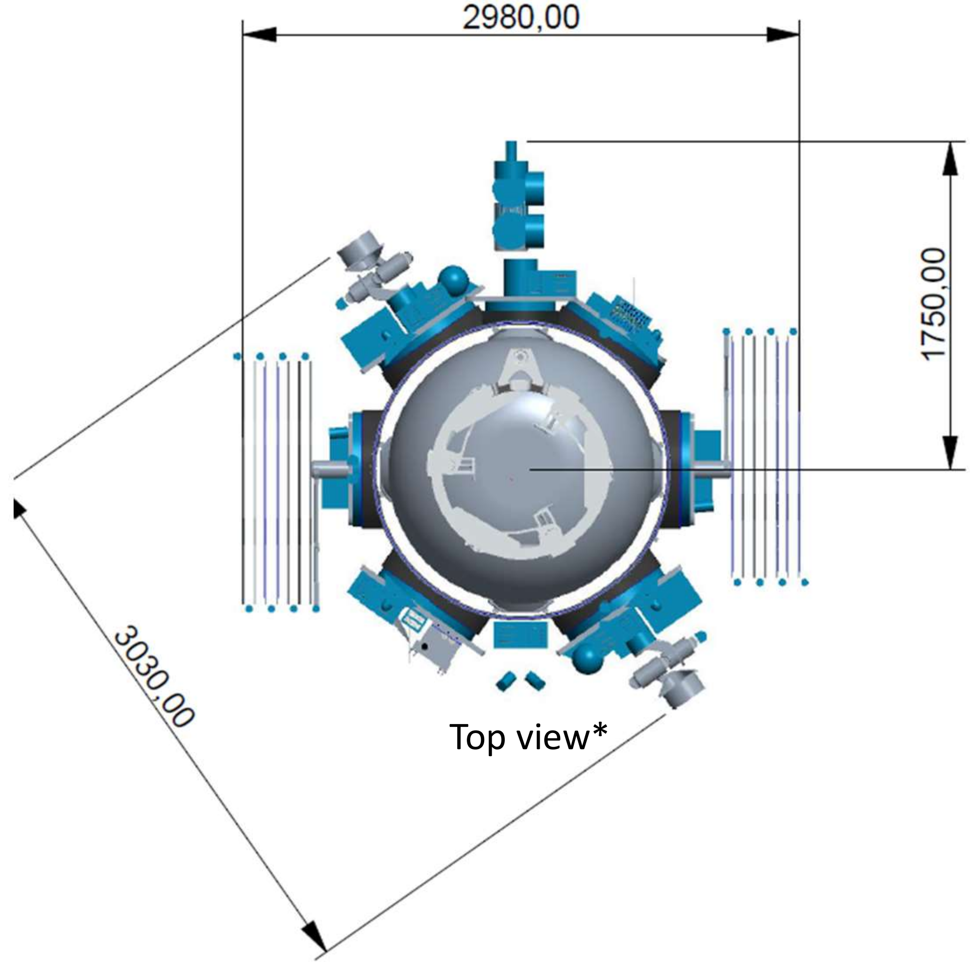
Top view*

*Lengths in mm

Sol launch configuration



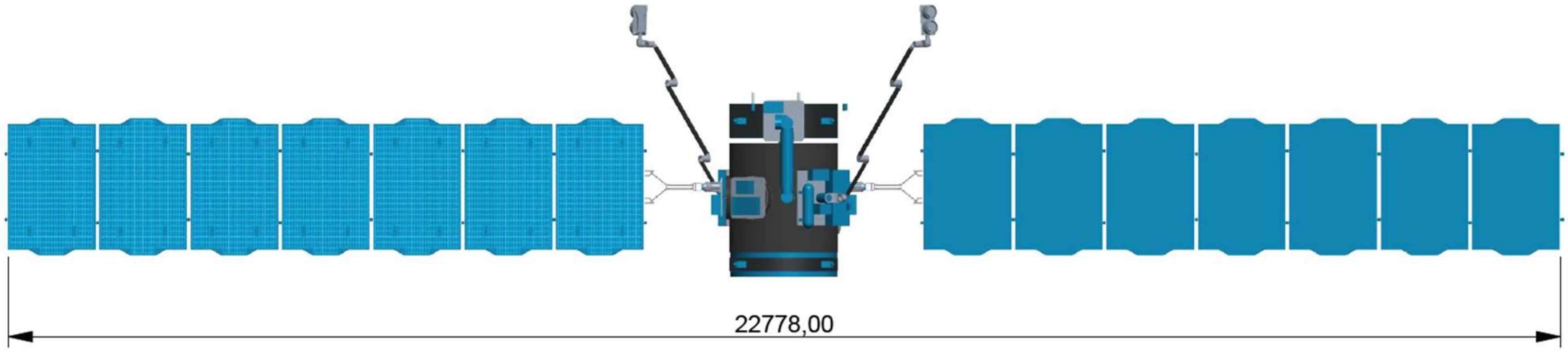
Side view*



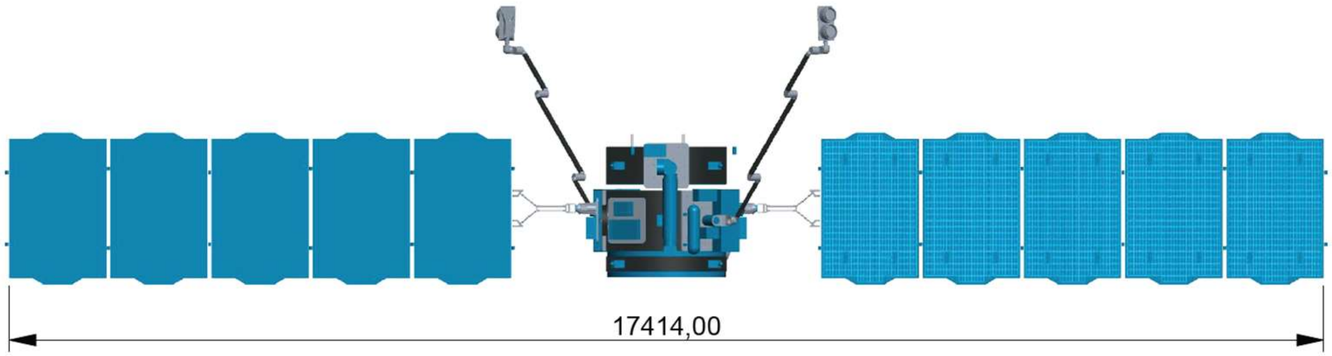
Top view*

*Lengths in mm

In-orbit configuration



SSTV Sol side view*

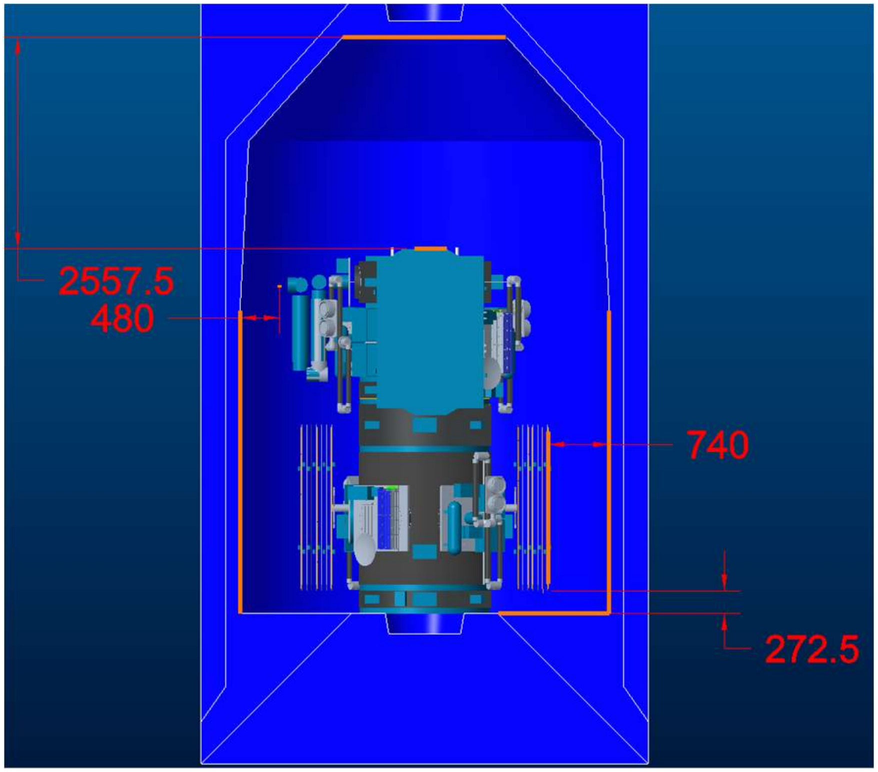


SSXV Proxima side view*

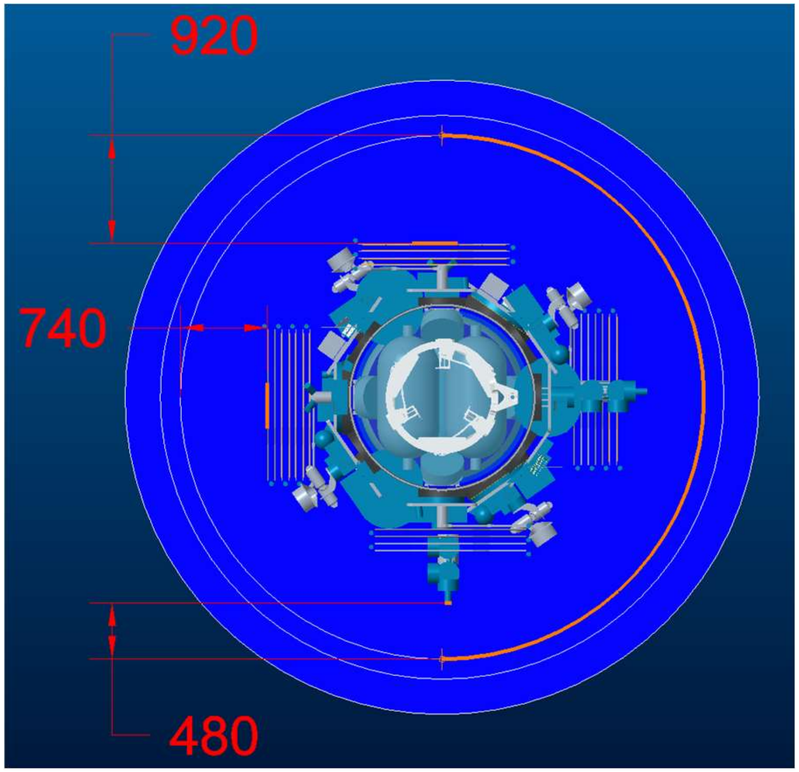
*Lengths in mm

Fairing accommodation

The considered fairing is the Ariane 6 lower floor in dual launch configuration



Side view*

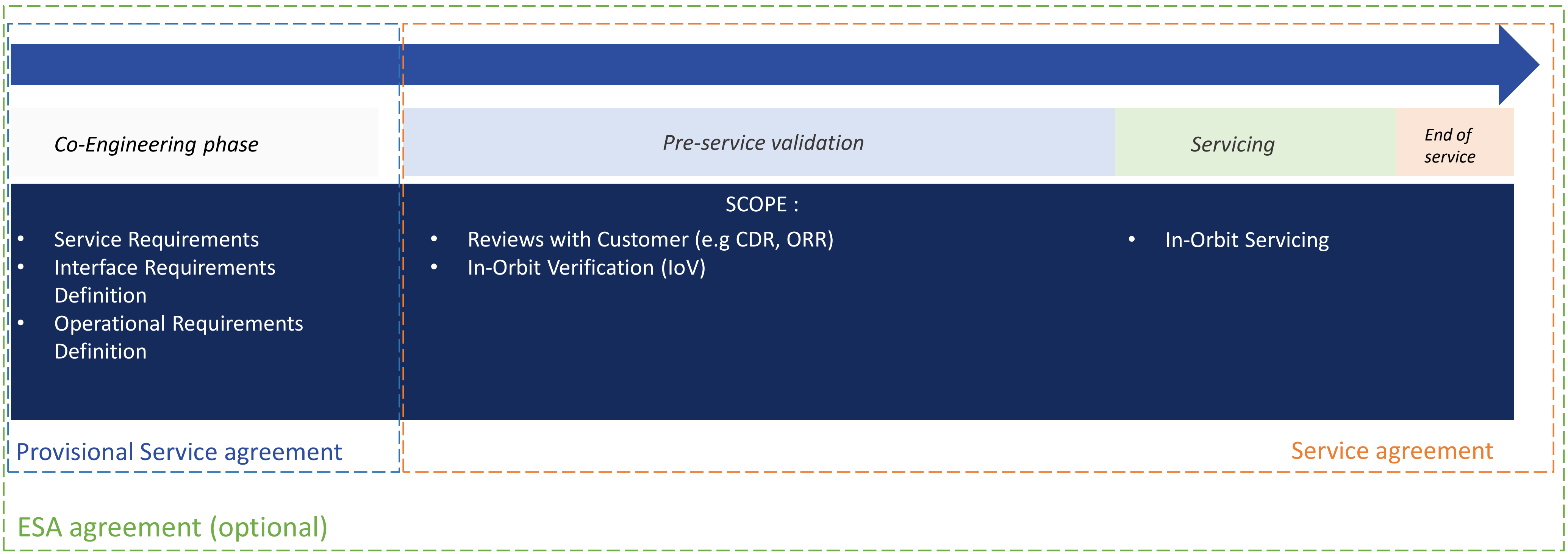


Top view*

*Lengths in mm

Provisonal Service Agreement

Contractual framework



Co-engineering phase Ending in Sept 2023

Aim of the Project

The Project aim is to develop and agree a definition of the key requirements and commercial terms for the IOS Mission, for the purpose of preparing and agreeing a service agreement that will govern the subsequent phases of the IOS Mission, including pre-service validation, servicing and end of service.

Defining key requirements – End of activity : March 2023

The key requirements to be defined for the IOS Mission are:

- Service requirements – identification and description of necessary information for development and delivery of the following service : Life Extension in GEO,
- Interface requirements – identification and definition of all interactions at systems and sub-systems levels, including prime operators involvement
- Operational requirements – production of all additional information to ensure delivery of the service and execution planning

Defining key terms – End of activity : September 2023

The key terms of an IOS Mission Service Agreement to be defined are:

- Acceptance criteria
- Project and/or payment milestones
- Responsibility at each operational phase of the mission
- Liability and risk allocation during each phase of the IOS Mission
- Termination and exit provisions applicable
- Intellectual property rights arising or relating to the performance of the IOS Mission

Contractual framework

CUSTOMERS FEEDBACK :

- Customers' feedback is **positive** on the overall approach.
- T&Cs for Provisional Service Agreement are in discussion with them.
- Final version to be signed **by January 2023**.

OPEN POINTS/CONCERNS :

- Possibility to get Customers involved in Service definition phase and therefore get **ESA funding for Customers WPs**.
- **Engagement with TAS and ADS** to be secured as soon as possible with ESA support.
- Level of engagement from Customers within ESA agreement to be defined.

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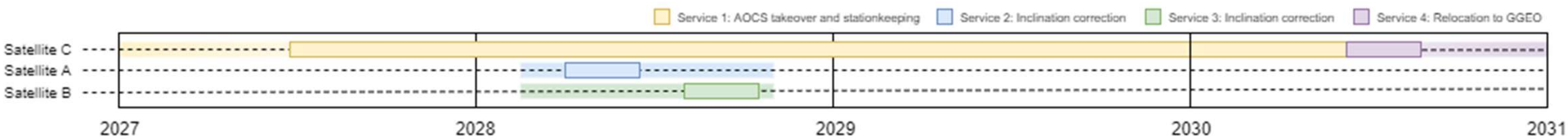
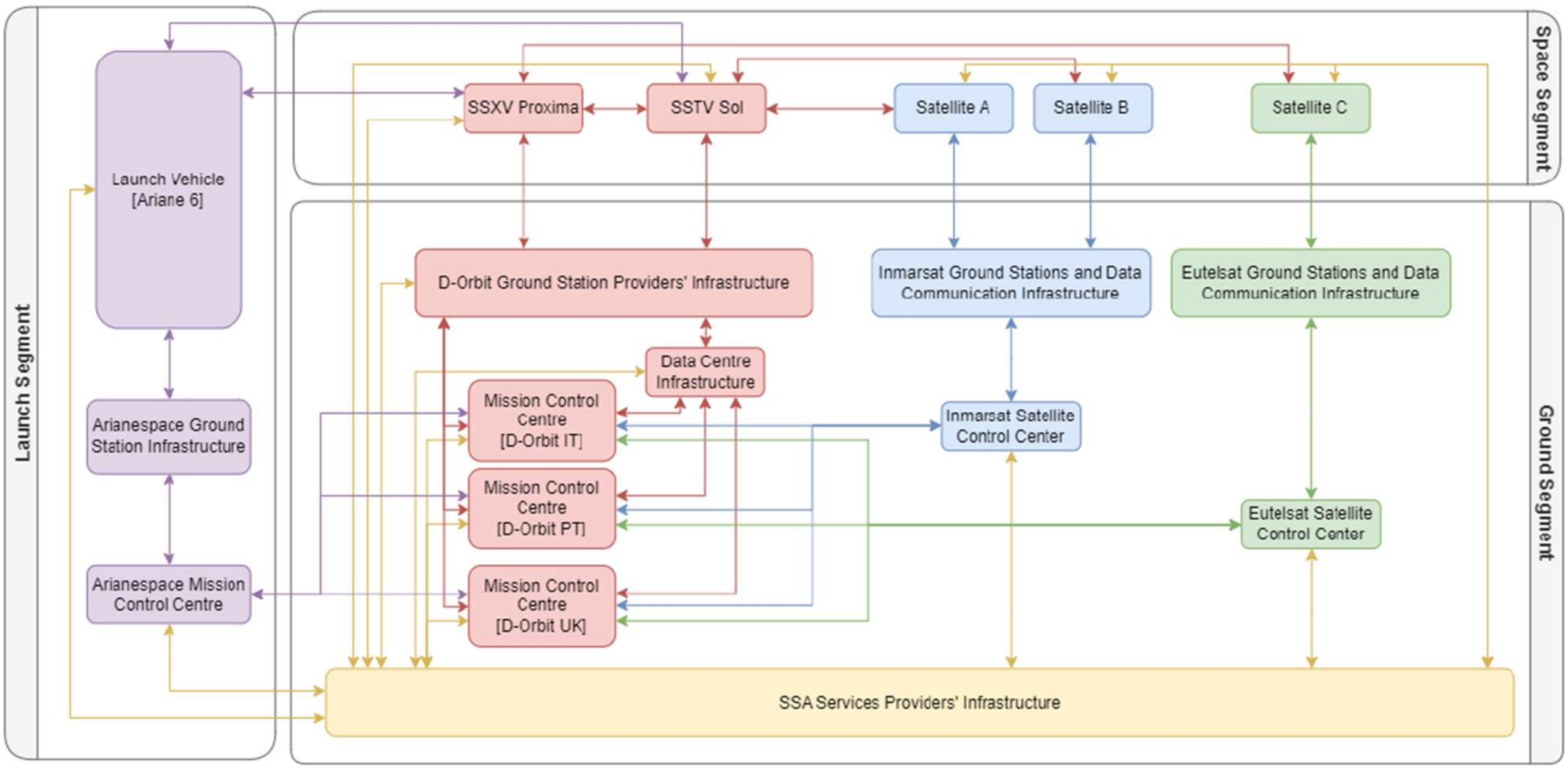
Mission Overview

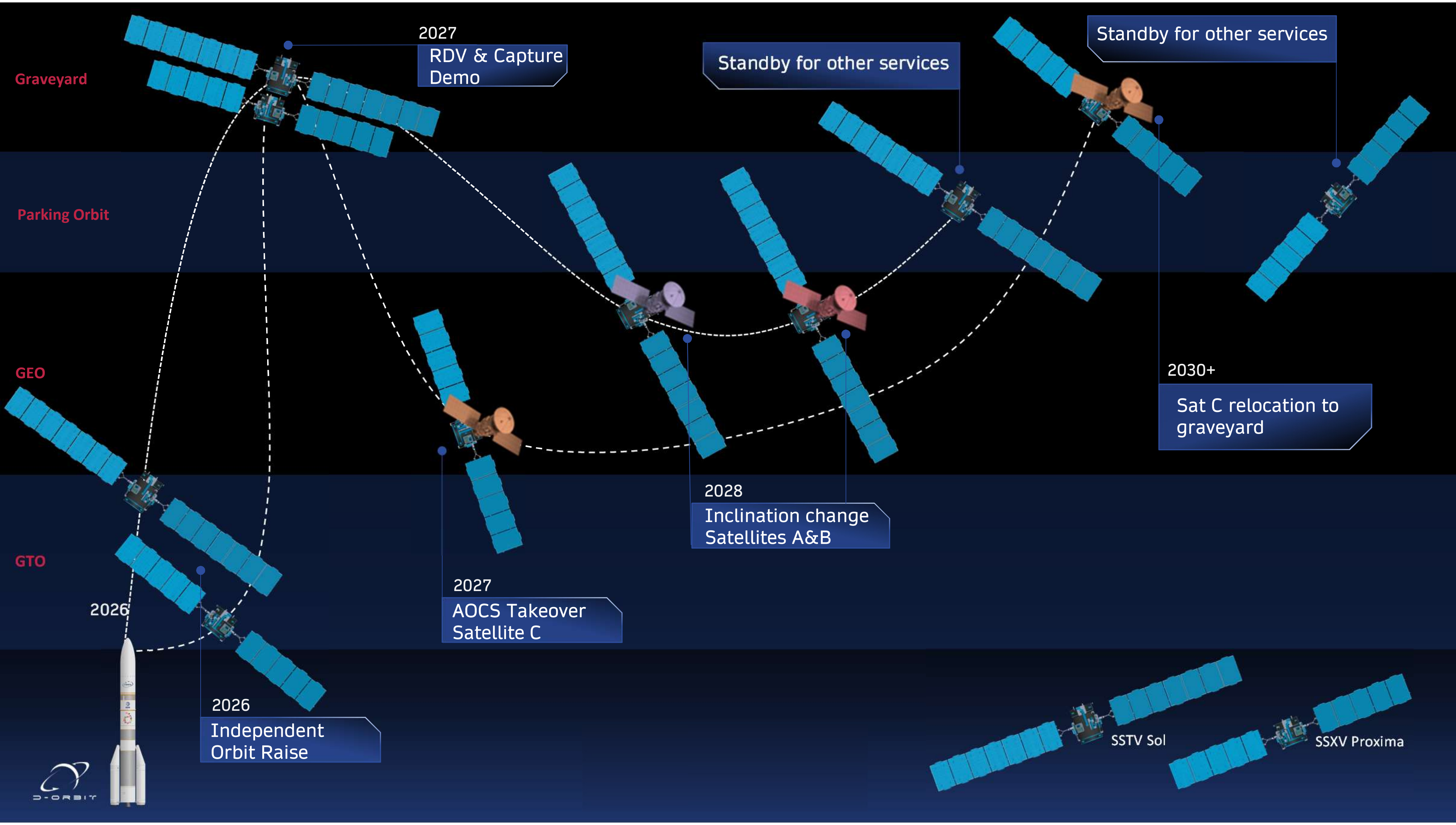
Mission requirements

Requirement ID	Requirement description
IOSPR-HL-MIS-001	The IOS mission shall reduce the inclination of satellite A’s orbit from 6 deg to 3 deg
IOSPR-HL-MIS-002	The IOS mission shall reduce the inclination of satellite B’s orbit from 6 deg to 3 deg
IOSPR-HL-MIS-003	Satellites A and B shall be serviced between February and November 2028
IOSPR-HL-MIS-004	The IOS mission shall demonstrate in-orbit its Rendezvous and Docking capabilities before servicing satellite C
IOSPR-HL-MIS-005	The IOS mission shall perform orbital station keeping for satellite C by keeping it in a ±0.05 deg control box for at least 3 years
IOSPR-HL-MIS-006	The IOS mission shall assume the AOCS function for satellite C and control its attitude with an accuracy of 0.05 deg for at least 3 years
IOSPR-HL-MIS-007	The IOS mission shall transport satellite C into a Geosynchronous Graveyard Orbit (GGO) at the end of satellite C’s operational life
IOSPR-HL-MIS-008	During servicing operations, satellite communications of satellite C shall not be interrupted
IOSPR-HL-MIS-009	The pointing disturbance of satellite C during docking and release shall be lower than **TBD** degrees
IOSPR-HL-MIS-010	Satellite C shall be serviced in 2027
IOSPR-HL-MIS-011	During servicing operations, satellites A and B’s pointing shall be controlled with an accuracy of 0.1 deg
IOSPR-HL-MIS-012	The IOS mission solution shall keep satellites A and B within a ±0.05 control box during their respective service operations
IOSPR-HL-MIS-013	The IOS mission solution shall deliver satellites A and B to their respective final location with a position tolerance of 7km
IOSPR-HL-MIS-014	The downtime that Inmarsat can allocate for the service disruption caused by the pointing disturbance during capture and separation sequences shall not exceed 12 h



Top-level mission architecture

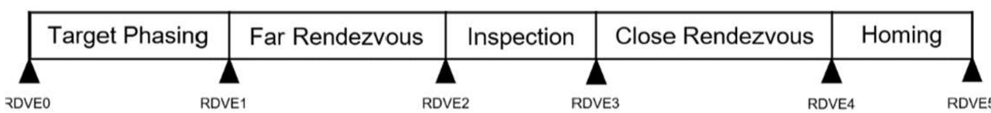




Graveyard
Parking Orbit
GEO
GTO
2027
RDV & Capture
Demo
Standby for other services
Standby for other services
2030+
Sat C relocation to
graveyard
2028
Inclination change
Satellites A&B
2027
AOCS Takeover
Satellite C
2026
2026
Independent
Orbit Raise
SSTV Sol
SSXV Proxima
D-ORBIT

Critical phases: RPO

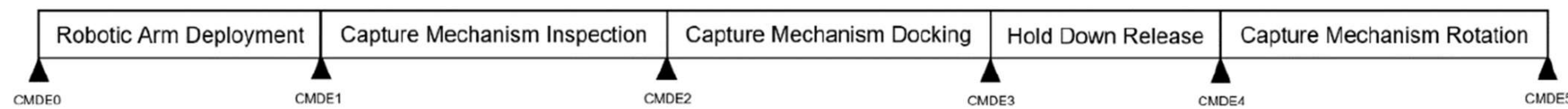
Design Drivers	Description
Target safety	The interaction between the target and the chaser shall be minimized.
Continuity in target communication with ground	The chaser shall stay out of a designated cone to ensure the target communication with ground can continue as usual.
Continuity in target power production	The chaser shall stay out of a designated cone to ensure the target solar panels are not shadowed.
GEO slots occupation	The chaser shall stay-out of any GEO slot. The chaser can enter the target GEO slot only after customer approval.
RPO sensors pointing and power production	RPO sensors that shall always be pointed towards the target . Solar wings shall point to the Sun when using HET.



RDVE0: The target is ready to be approached
RDVE1: The chaser reaches the Approach Zone border
RDVE2: The chaser reaches the Keep Out Zone border
RDVE3: Final Approach Point and Capture Point identified
RDVE4: The chaser reaches the Final Approach Point
RDVE5: The chaser reaches the Capture Point

Critical phases: Capture

Design Drivers	Description
Target safety	The deployment of the arm and the re-orientation of the capture mechanism are completed at a safety distance, prior to the final proximity manoeuvres.
Minimize unexpected collision forces	Capture ring and robotic arm will be able to sense reaction forces. Impedance control or even joint level torque control will be evaluated in order to implement a compliant active reaction.
Establish robust connection with the customer	The capture ring is intrinsically redundant foresees 3 points of attachments but the connection will be robust even with only 2 attachments and still achievable, with derated performances, with only 1 point of attachment.
High Capture System Reliability	

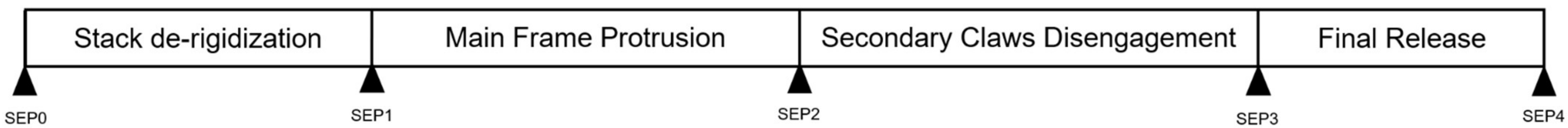


Critical phases: Servicing

Design Drivers	Description
Target safety	The interaction between the target and the chaser shall be minimized.
Minimize plume impingement	The customers shall define stay-out zones for critical hardware that shall not interact with the thrusters' plume by any means.
Continuity of the customer satellite nominal operations	The customers shall define a maximum shadow surface that the servicer can cast on its solar panels. The servicer configuration shall not exceed the designated surface.
Continuity of the customer satellite nominal operations	Seamless interaction between D-Orbit MCCs and both customers shall be granted to monitor and coordinate activities
Minimize unstable lighting conditions	Avoid service delivery during unstable lighting conditions, whenever possible.

Critical phases: Separation

Design Drivers	Description
GEA SSV and Target Safety	Minimize risks of collisions. The relative speed of the two bodies shall be controlled by the movement of the robotic arm during separation. In case of failure on the clamp or main claws mechanisms, the robotic arm could decide as an emergency action, also to sacrifice the capture ring by disconnecting the capture ring from its end effector docking interface.
Avoid creation of debris	The release sequence shall be performed in order to minimize the risk of uncontrolled thumbling of the 2 spacecrafts after the release of the capture mechanism. The robotic arm will apply a push-forward force while the clamps are opened in order to separate the 2 bodies.



Programmatic

Consortium overview - Subcontractors

Company Name	Country	Module/WP	Element	Status
D-Orbit UK	UK	Service Design and Management, some design	N/A	Confirmed
D-Orbit PT	PT	Mission Control Software & Ground Segment	N/A	Confirmed
Catapult	UK	Business plan & Strategy	N/A	Confirmed
CGI	UK / DE	Mission Analysis and Security Analysis	N/A	Confirmed
DLR	DE	Relative navigation testing facility	N/A	Confirmed
Re Fraschini	IT	M-SMD/M-SMS	Core Structure	Confirmed
Sitael	IT	M-PRE	Thrusters	Confirmed
Sitael	IT	M-PRE	Fluidic & PPU	Confirmed
DHV	ES	M-SAW	Solar Panels	Confirmed
Maxon Motors	CH	M-CPA/M-PRE	Robotic Joints	TBC
DLR	DE	M-CPA/M-PRE	Robotic Arms	TBC
Beyond Gravity	CH	M-CPA/M-PRE	Robotic Arms	TBC
Redwire	LUX	M-CPA/M-PRE	Robotic Arms	TBC

Consortium overview - Suppliers

Company Name	Country	Module/WP	Element	Status
T4i	IT	M-SMD/M-SMS	Cold Gas Thrusters & Lines	TBC (Back-up)
Astrofein	DE	M-ACS	Reaction Wheels	Confirmed
Maxon Motors	DE	M-CPA/M-PRE	Actuator	TBC
New Imaging Technology	FR	M-CPA	SWIR Camera	Confirmed
Civitanavi	IT	M-ACS	Gyroscope	TBC
iXblue	FR	M-ACS	Gyroscope	TBC
LITEF	DE	M-ACS	Gyroscope	TBC
Sitael	IT	M-PRE	PPU	Backup
Safran	FR	M-PRE	PPU	Backup
Syrlinks	FR	M-AVN	Radio	Confirmed
Satlab	DK	M-SMD/M-SMS	Radio	TBC
RUAG	SE	M-SMD/M-SMS	Separation ring	TBC
Thales Alenia Space	(TBD)	M-SAW	SADM	TBC
Beyond Gravity	CH	M-SAW	SADM	TBC
OPS Solutions	NO	M-TKC/M-TKS	Tank	TBC
MAHYTEC	FR	M-TKC/M-TKS	Tank	TBC
CPP Gransden	UK	M-TKC/M-TKS	Tank	TBC
CIKONI Composites Innovation	DE	M-TKC/M-TKS	Tank	TBC
CirComp	DE	M-TKC/M-TKS	Tank	TBC
IZOREEL Composites	TR	M-TKC/M-TKS	Tank	TBC
Optimal Structures Solution	PT	M-TKC/M-TKS	Tank	TBC
Novotech	IT	M-TKC/M-TKS	Tank	TBC
Peak	AT	M-TKC/M-TKS	Tank	TBC
Blackwave	DE	M-TKC/M-TKS	Tank	TBC
Faber	ITA	M-TKC/M-TKS	Tank	TBC
Lia Aerospace	UK	M-TKC/M-TKS	Tank	TBC

Consortium overview - Co-engineering activities

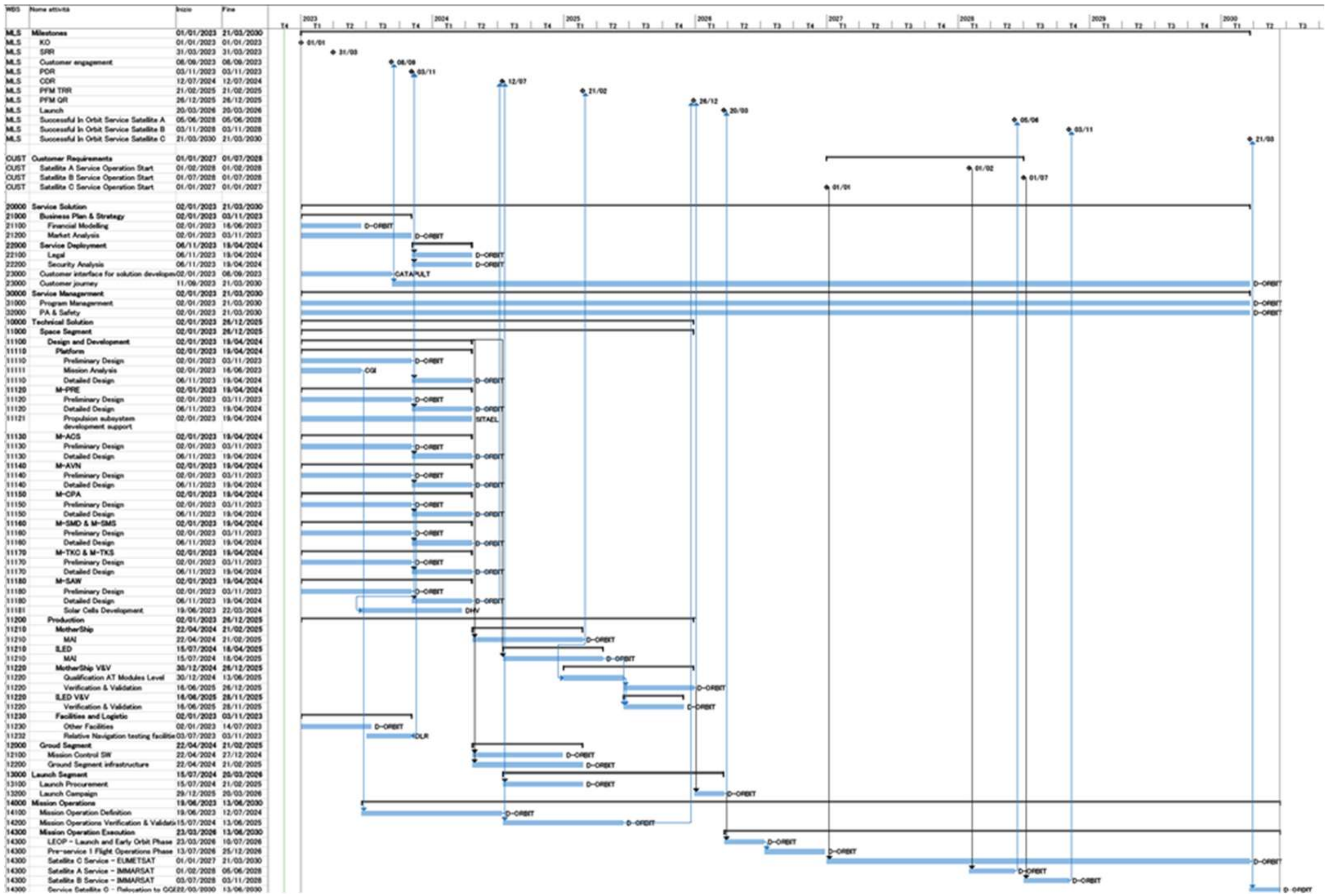
Several co-engineering activities with some of the most important partners have been agreed during the Maturation Phase to be carried out during the project. In particular:

- **SITAEL** (Italy - Electric Propulsion): discussion is around a solution based on procuring "off-the-shelf" Sitael HE thruster and to co-engineer the electronics (i.e. PPU). Several videoconferences meeting have been carried out, and also physical co-location last month at Sitael's HQ (Pisa)

- **DLR** (Germany – Simulation Facilities): As part of the RFI, DLR is to support in the design and development of the target and chaser Engineering Models for the Rendezvous and Capture testing campaigns.

- **Refraschini** (Italy – M-SMD and M-SMS): Refraschini is to support in the design and the development of the structural modules by supporting material selection, layup definition and inserts selection

Overall plan



Business Plan Update

Service Pricing Assumptions

SERVICES & TOTAL CONTRACT VALUE & SERVICE DELIVERY VEHICLE	TCV (€)
Pre-planned Last-mile delivery	12.000.000
Pre-planned Life extension - AOCS Takeover	10.000.000
Pre-planned Life extension - Fuel Pack	80.000.000
Pre-planned Life extension - Inclination correction	35.000.000
Pre-planned Life extension - Shift to Graveyard	10.000.000
Pre-planned Launch protection	22.000.000
Emergency Life extension - AOCS Takeover	11.500.000
Emergency Life extension - Inspection	5.000.000
Emergency Life extension - Fuel Pack	90.000.000
Emergency Life extension - Inclination correction	43.500.000
Emergency Life extension - Shift to Graveyard	75.000.000

Cash Flow Projections

Financial Metrics:	
Internal Rate of Return	44,47%
Average Gross Margin	52,59%
Average EBITDA Margin	47,67%
Payback period with Instit. Grant	Mid 2027
Payback period without Instit. Grant	Mid 2031

Next Steps

Validate assumptions, including:

Model further market scenarios to stress test the business model in many different cases (rather than 3 made manually) and include direct calculation of optimization of service delivery vs vehicle availability

CAPEX & OPEX modelling needs improving – to spread out costs over years and must be kept updated as design matures

Currently the bottleneck based seems to be based on speed of manufacturing capability and launch rather than addressable market. Estimates on speed of scale-ability of manufacturing and launch need to be looked into to see if this can be increased.

Trade-offs and open points

Critical make-or-buy trade-offs

Trade-Off	Decision
Electric Propulsion Power Processing Unit – PPU	Make
Electric Propulsion Krypton Flow Control – KFC	Make
Electric Propulsion (Electronic) Management System – EPMS	Make
Robotic Arm	Hybrid Architecture, requirements and kinematic managed by D-Orbit. Robotic Joints (including motor driver electronics) procured externally starting from legacy high TRL items.
Capture Ring	Hybrid Mechanisms procured based on D-Orbit specification form a partner with high experience in electromechanical systems. Electronics cross-procured from D-Orbit AVH4 components.
Vision Navigation Instrument – VNI	Make
Attitude Sensor Head – ASH	Make
Laser Ranging – LasR	Buy
SWIR Camera	Buy
Wing Control Unit (solar array conditioning)	Make
General avionics (OBCs, Mass Memory, OBDH)	Make

Open points

Trade-Off	Description
Solar Array Deployment Mechanism	Deployment mechanism selection and kinematic profile definition, accounting for simplicity, reliability, and low impacts on AOCS.
LasR Selection	Space qualified/qualifiable Laser ranging equipment is not widespread. Further investigation is needed to find the best fit in terms of costs, power consumption and functionalities. At the moment of this proposal submission, discussion with three European laser ranging and Lidar suppliers are ongoing. All three own equipment solutions at TRL 5 or higher.
SWIR Camera	SWIR space cameras are usually targeted to Earth observation applications, hence are not easily adaptable to the rendezvous scenario. Further analyses are required to evaluate the application of the technology, the correlated equipment and the compliance with the environmental requirement expected for this kind of mission.
GNC Algorithms	Development of Guidance, Navigation and Control algorithms and sub-modes for the Proximity Operations phases.
COM Hardware	Some COM physical solutions will need to be confirmed (i.e. X-band antenna and APM) and delta-qualified for GEO environment.
Ground Segment	Selection of ground segment provider, and its integration architecture in the operations concept of D-Orbit is ongoing.
Tanks Supplier	D-Orbit is currently identifying a common supplier that can be leveraged by the different internal programs.
Test facilities	The scouting for test facilities is ongoing, the most relevant issue is related to finding facilities large enough to test the complete vessel at the required levels. Such facilities include, but are not limited to, shaker, TVAC chambers.

Design, Development and Verification Plan

Critical equipment

Equipment	Equipment Type	Make/Buy	TRL	Milestones for TRL advancement
ASH	Attitude Sensor	Make	4	Jun 2023: 5 Sep 2023: 6 Jan 2024: 7
VNI	Camera	Make	4	Jul 2023: 5 Nov 2023: 6 Mar 2024: 7
SWIR Camera	Camera	Buy	5	Undergoing discussion with suppliers
LasR	Attitude Sensor	Buy	5	Undergoing discussion with suppliers
High Voltage Battery Pack	Electronic Unit	Make	5	Sep 2023: 5 Nov 2023: 6 March 2024: 7
WCU	Electronic Unit	Make	3	Jul 2023: 4 Nov 2023: 6 Mar 2024: 7

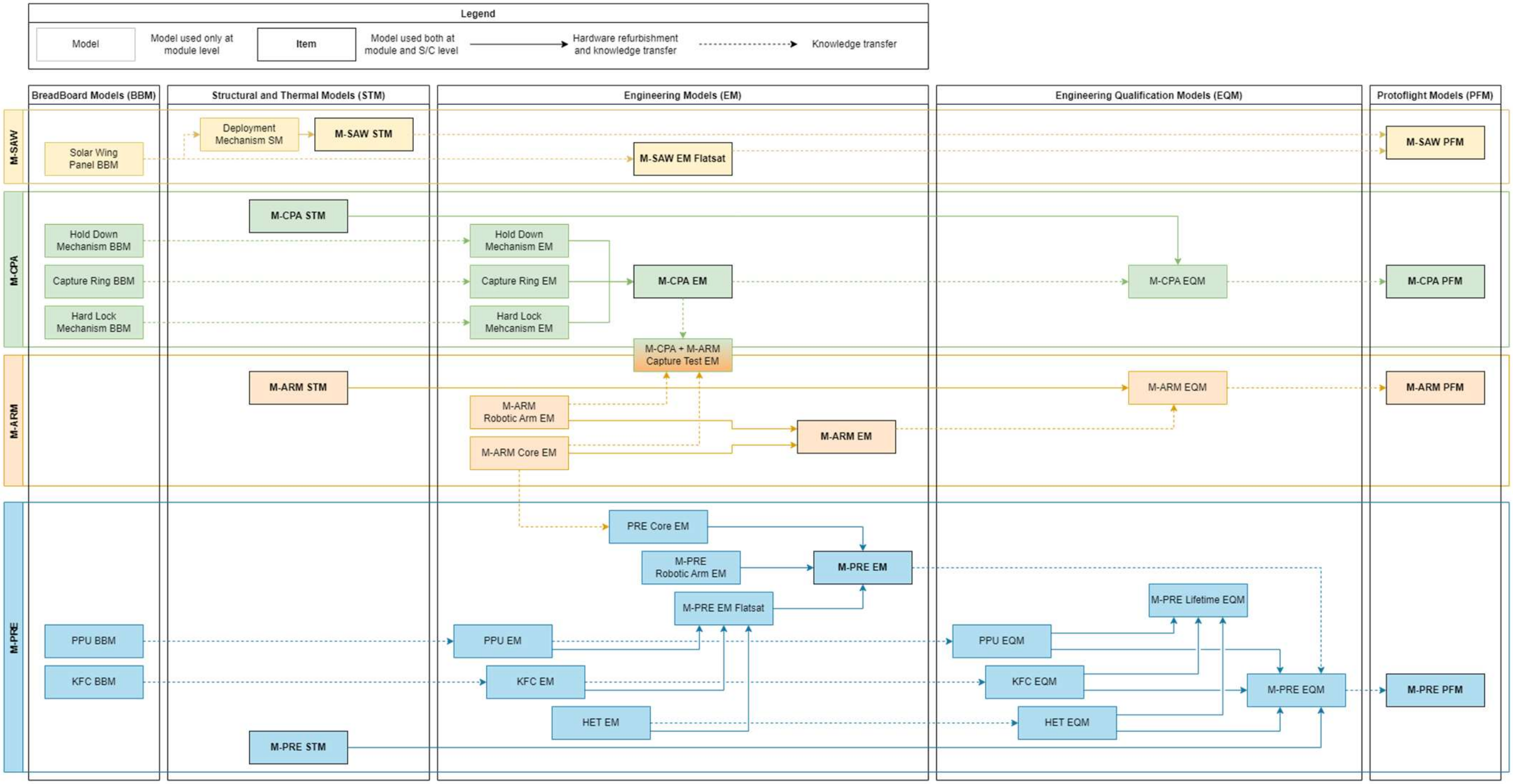
Critical equipment

Equipment	Equipment Type	Make/Buy	TRL	Milestones for TRL advancement
EPMS	Electronic Unit	Make	4	Sep 2023: 6 Jan 2024: 7
PPU	Electronic Unit	Make	3	Jul 2023: 4 Oct 2023: 5 Dec 2023: 6 Mar 2024: 7
KFC	Propulsion Unit	Make	3	Jul 2023: 4 Nov 2023: 6 Jan 2024: 7
Tank E and Tank F	Propellant Tank	Buy	4	Sep 2023: 6 Dec 2023: 7
TMDC	Propulsion Thruster	Make	5	Sep 2023: 6 Dec 2023: 7

Verification approach

- Verification process to go from equipment level to spacecraft level passing through subsystem level
- Refurbishment of low-level models to feed into high-level ones whenever possible
- Types of models:
  - Hardware models
    - Breadboard models (BBM)
    - Structural and Thermal models (STM)
    - Engineering models (EM)
    - Engineering Qualification models (EQM)
    - Proto-flight models (PFM)
  - Software models
    - CAD model
    - Structural FEM
    - Thermal Mathematical Model (TMM)
    - EMC model
    - ESA Simulus compliant spacecraft simulator
    - Simulink models

Model philosophy



Model philosophy