Clean Space Industrial Days 2018

Guaranteeing the future of space activities by protecting the environment

Capturing and deorbiting Envisat with an Airbus Spacetug. Results from the ESA e.deorbit Consolidation Phase study.

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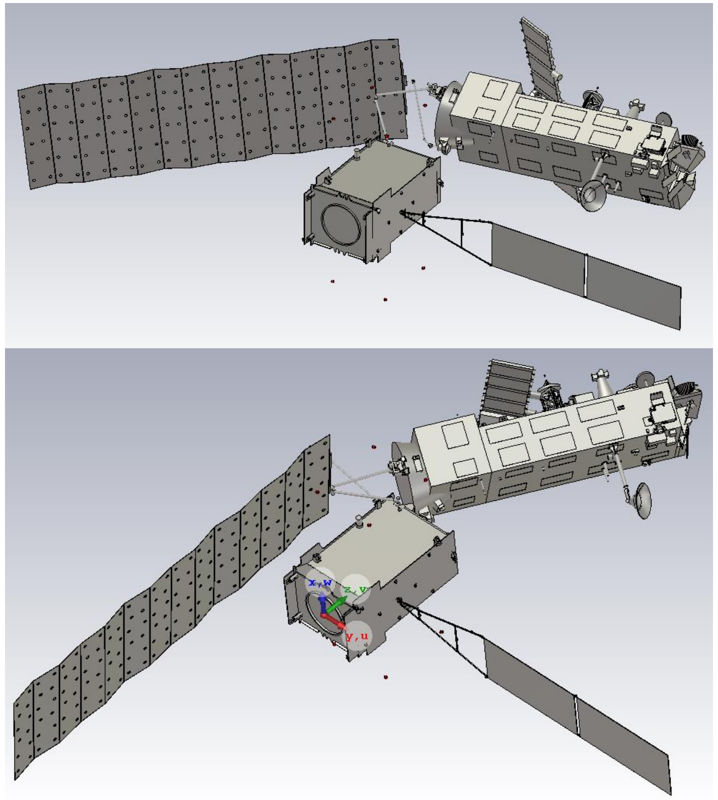


Objectives of the e.Deorbit Consolidation Phase

To consolidate the requirements for the developments related to Spacetug applications, robotic capture and the GNC system, and their impact on the platform design.

Study Technical Objectives:

1. Consolidation of platform design and capture techniques
2. Identify the synergies and differences of the technologies used within the space tug
3. A preliminary design of the robotic visual servoing system
4. The definition of the GNC avionics test bed architecture

The activity consists of six main tasks:

1. Consolidation of platform design and capture techniques
2. Analyse applicability to Spacetug
3. Consolidate System Engineering
4. Preliminary design of the robotic visual servoing system and Cartesian compliant controller
5. Definition of the GNC avionics test bed architecture
6. Preparation of the Maturation Phase

e.Deorbit Consolidation Phase – Industrial Team

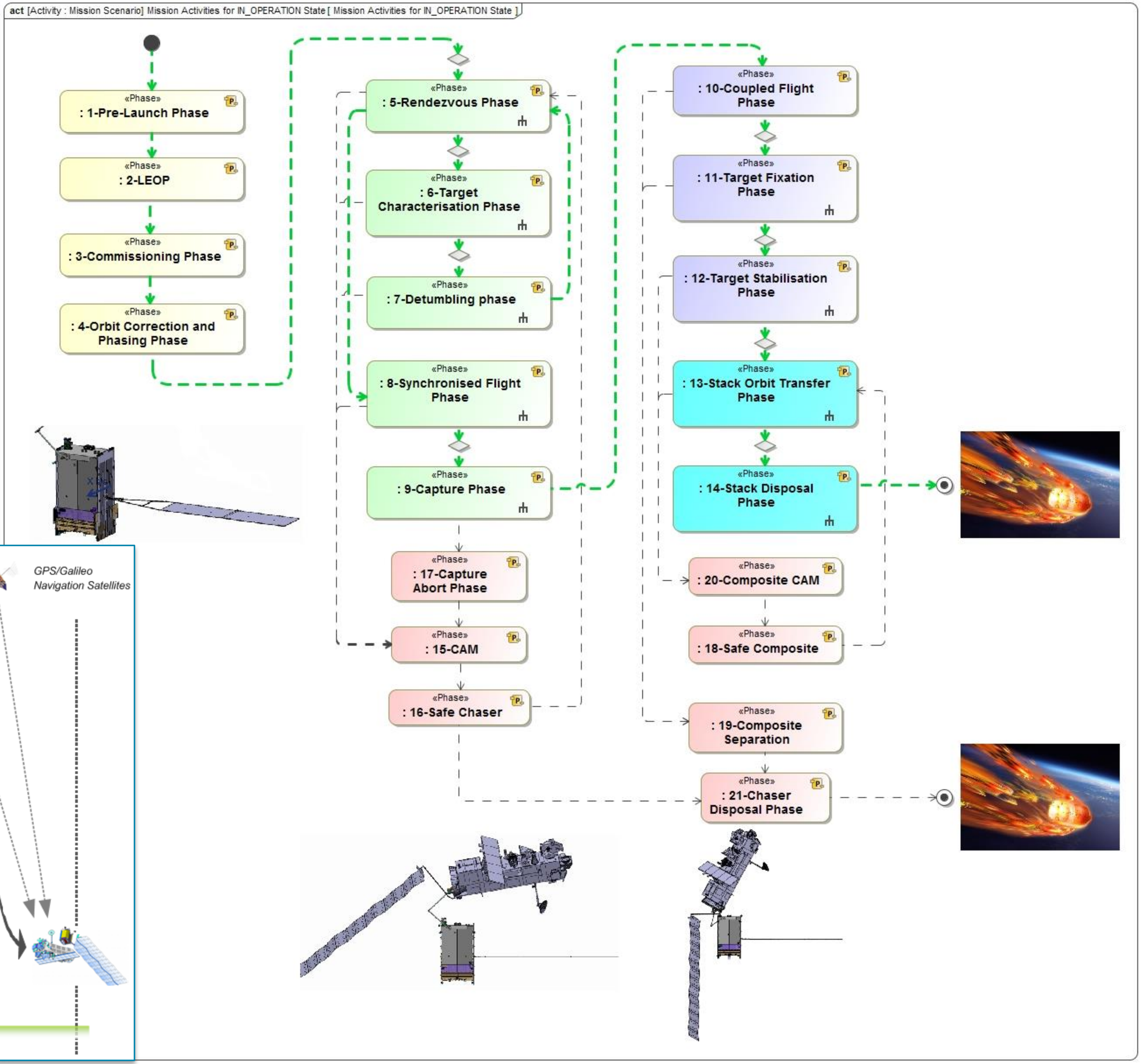
Consortium	Activities
AIRBUS	**Airbus DS (D, F),** Prime, System Engineering management, Chaser design definition, MBSE, safety and FDIR, definition of the GNC architecture, communications, visual-based navigation and programmatic.
CBK PAN	**CBK PAN (POL)**, Interdisciplinary research institute of the Polish Academy of Sciences, development of the robotic compliant control. Experts in robotic compliant control .
MDA	**MDA (CAN**), Brings expertise in manipulator dynamics and control from over 30 years of experience in space robotics design, development, operations and maintenance.
SENER	**SENER (POL)**, Definition of the chaser to target mechanical interface, Target analysis. Expert in high quality and performance space mechaisms.
gmv INNOVATING SOLUTIONS	**GMV (POR and POL)**, Mission and deorbit analysis, GNC dynamics analysis and design verification. visual camera-based navigation, GNC avionics test bed, concept of operations. Highly capable in complex GNC analyses and simulation, including proficiency on the GNCDE tool.

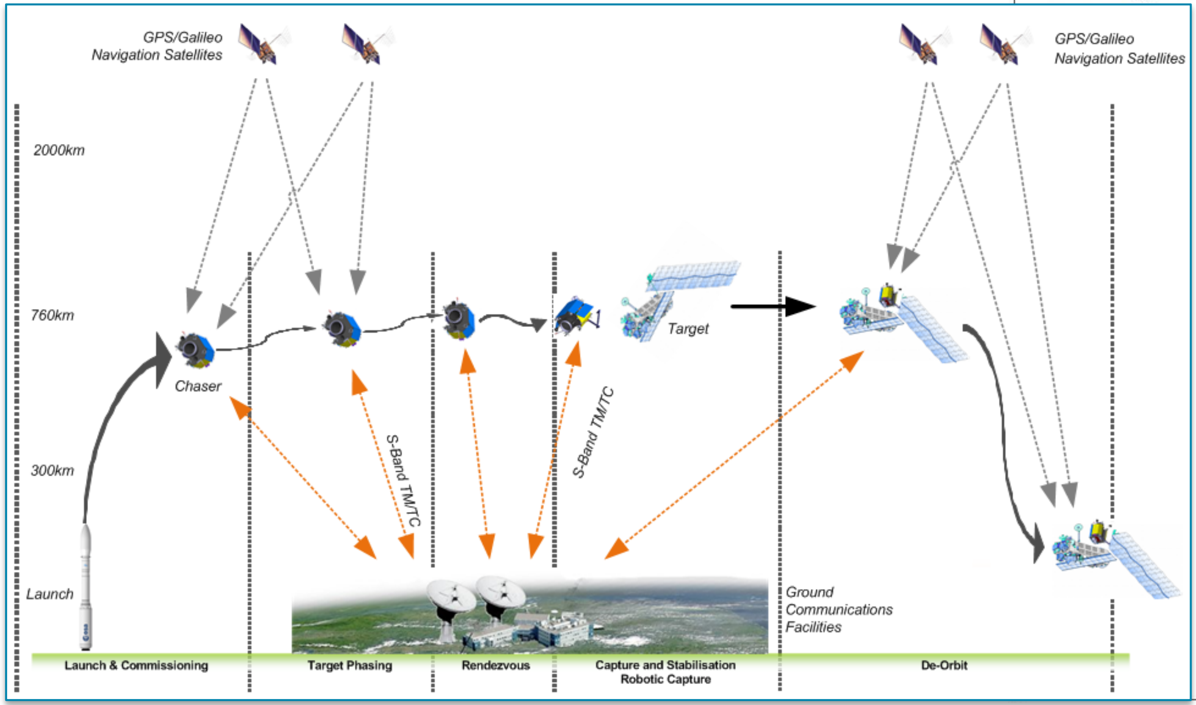
Mission activities

The mission activities cover Envisat detumbling, automatic rendezvous and capture, composite stabilisation and stack deorbiting.

Initial Envisat tumbling rate: 2,5 deg/s

Total DV = 409 m/s

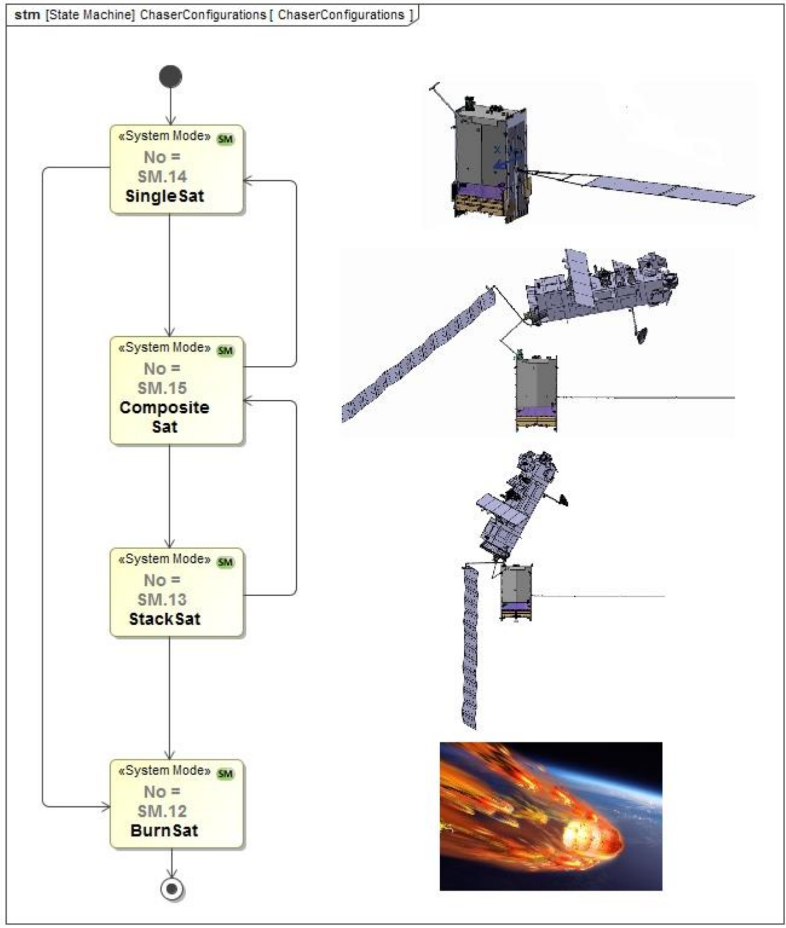


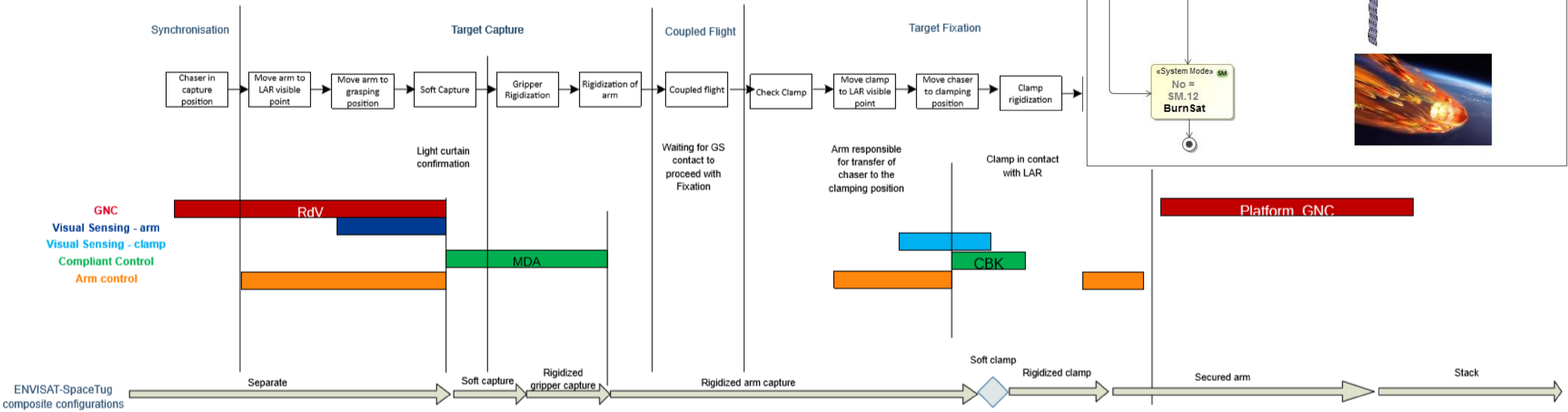


System configurations and modes

The spacetug system changes its configuration from single sat, to composite and stack sat to implement the mission activities.

The mission implementation involves a combination of many chaser and control modes.





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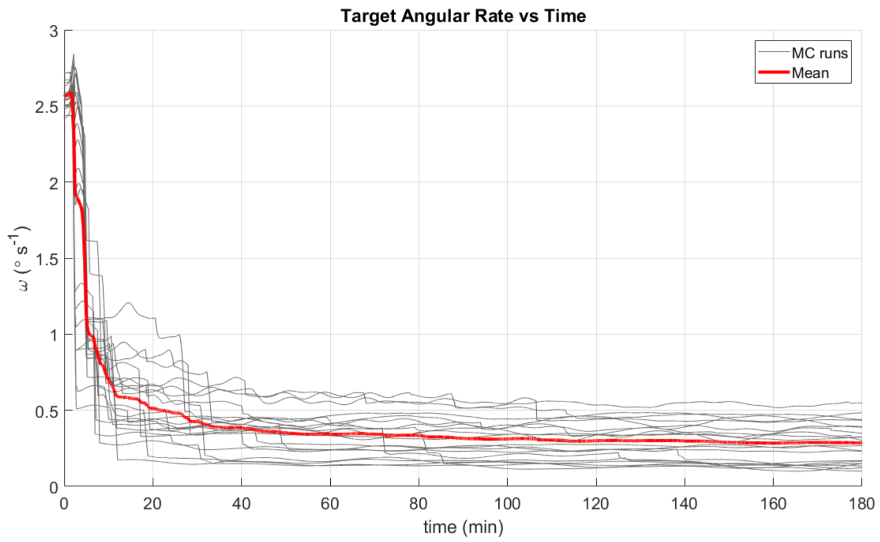
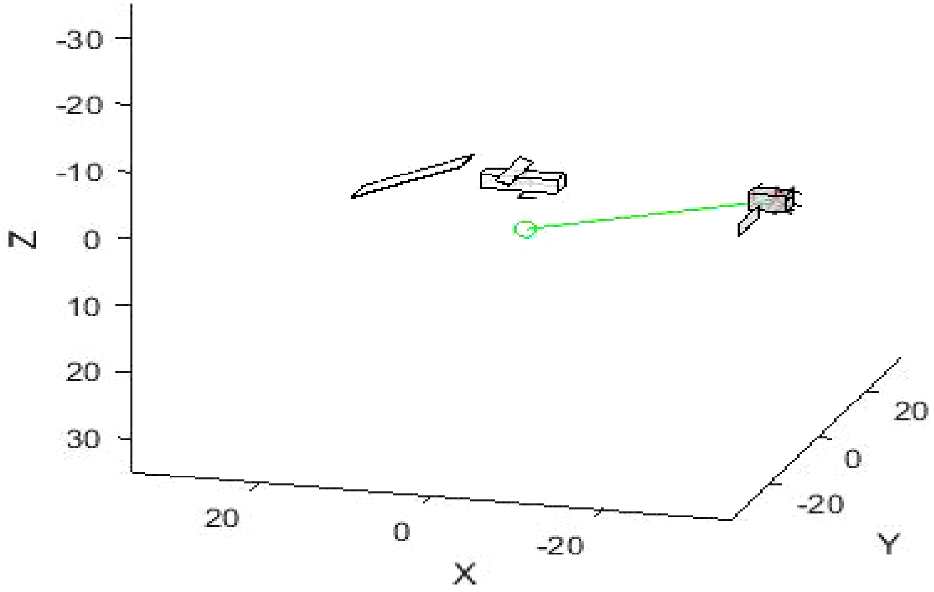
Contactless ENVISAT detumbling

The Envisat tumbling rate is reduced to 0.5deg/s before final rendezvous and robotic capture.



GMV



<u>Concept</u>:

- Gas jet exhaust from a thruster mounted on chaser impacting the target, generating forces and torques.
- Can be used for de-orbiting (imparting ΔV) and de-tumbling (momentum transfer).
- Attitude and angular rate of target controlled by pointing the thruster to different regions of its surface.
- Thruster pointing performed by controlling chaser attitude.

<u>Pros:</u>

- Low collision risk – chaser kept at a safe distance
- No special equipment required (AOCS devices present)
- High TRL of individual components (AOCS)

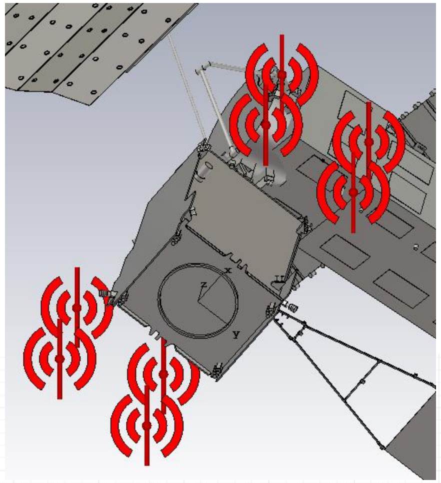
<u>Cons</u>:

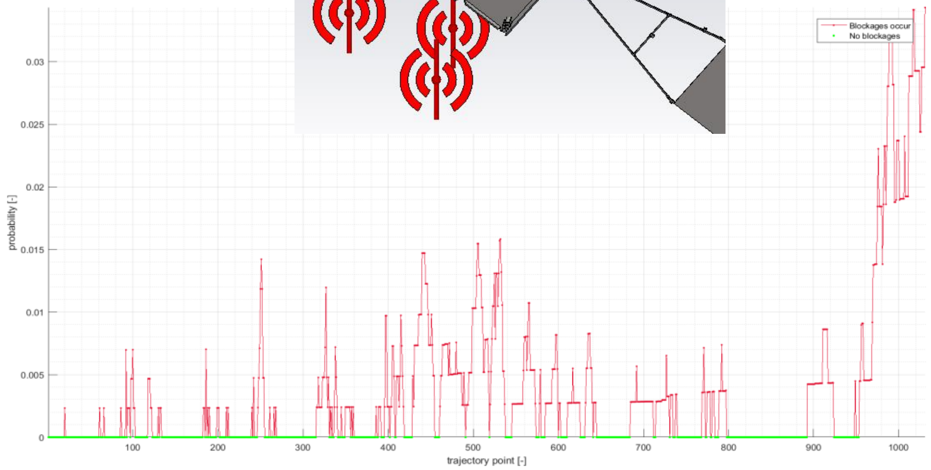
- Chaser design must allow for null net force and torque while firing thruster.
- Pushing thruster must point in the same direction of as bore sight of the relative sensor.

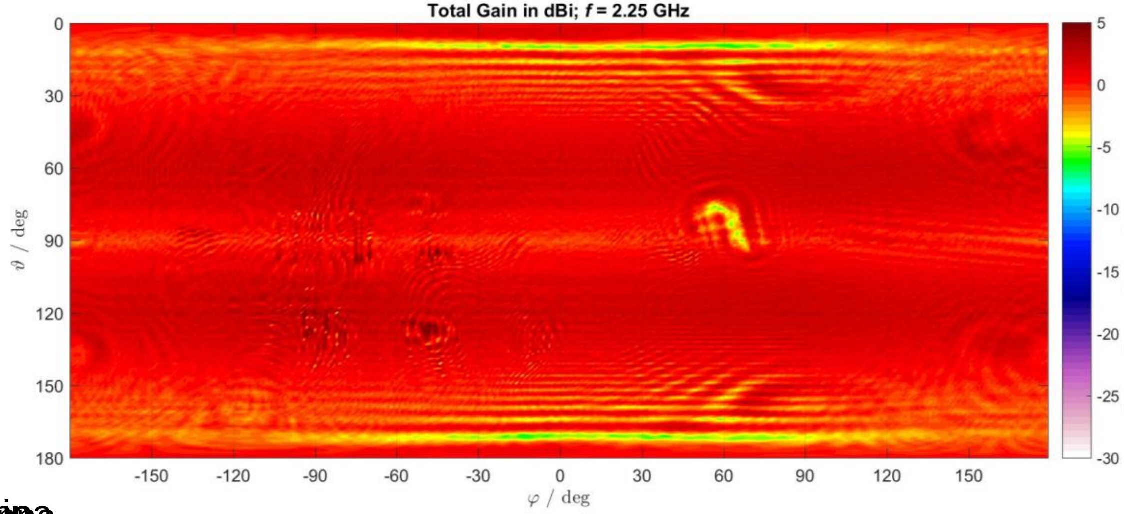
Blockage-free communications during capture

A working configuration of the antenna accommodation and boom length on the spacetug was selected.

- Blockage analysis done for synch and capture trajectory from GNC simulations for the rotational speed of the Target of 0.5°/s
- Computation of geometrical blockage probability per capture trajectory point to identify working antenna configurations
- Assessment of installed Antenna Gain for 2 m long booms in the capture and clamping positions using the full wave MLFMM method along with realistic antenna input patterns (Antenna patterns from the S-band Helix antennas)
- Two possible antenna configurations have been identified which can lead to a coverage of 100 %. Both these configurations show a positive minimum margin for the more critical downlink from the satellite







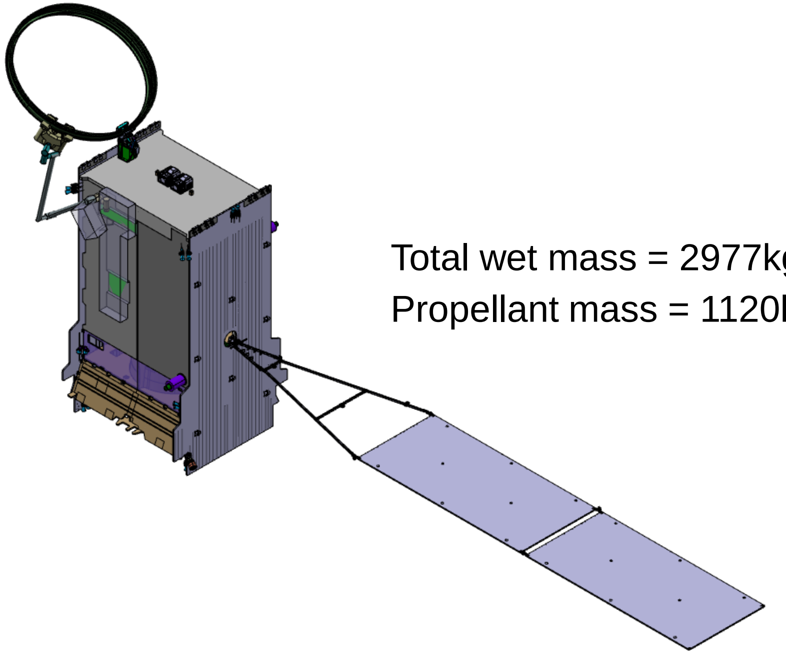
Installed single antenna patterns for the MXMYMZ and the PXMYMZ positions (left plot)

MXMYMZ Antenna PXMYMZ Antenna

Space Tug Configuration

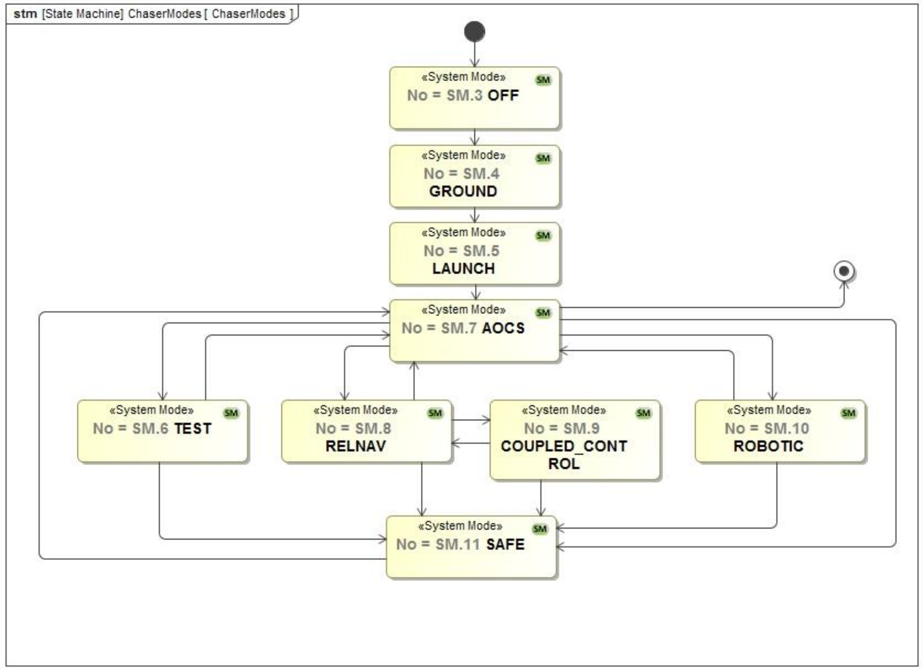
The Airbus Spacetug can accommodate all the specific equipment needed for Envisat capture and deorbiting.

- Platform based on Airbus GEO satellite Eurostar-Neo
- Full chemical propulsion system
  - ➢ 1x LAE 430N Main Engine for deorbiting maneuvers
  - ➢ 11x 22N thrusters for attitude control and rendezvous
  - ➢ 1x 22N thruster for detumbling
- Adapted solar array configuration (one wing rotating with 2 panels), downscaled battery
- Use of sensors for AOCS and VBN needs (Lidar, cameras)
- Accommodation of the overall structure regarding RDV sensors, thruster architecture and capture systems.



Total wet mass = 2977kg

Propellant mass = 1120kg



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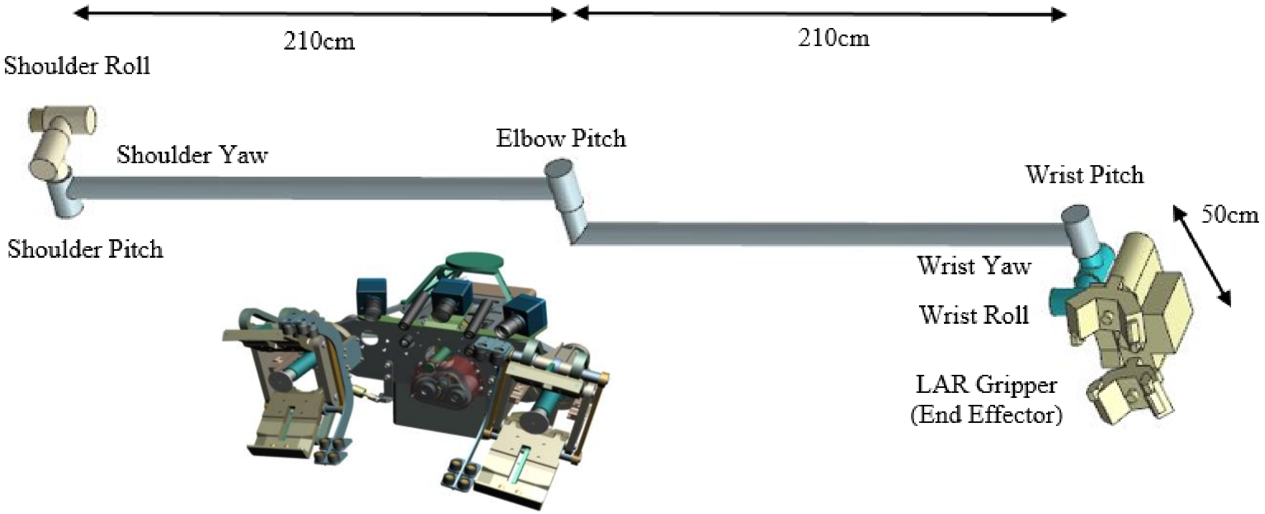
Robotic Configuration based on robot arm, gripper and clamping

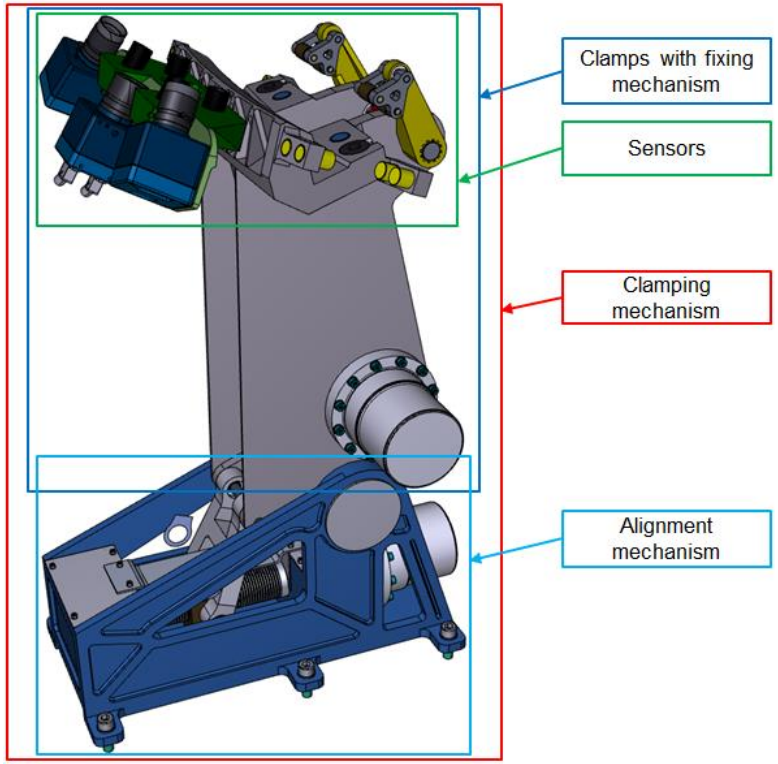
The Envisat capture, displacement and firm connection are implemented with dedicated mechanisms.

MDA designed robot arm and gripper



Degrees Of Freedom (DOF)	7
Topology	RYPPPYR
Overall Length [m]	4.385
Repeated Output Torque [Nm]	200
Momentary Output Torque [Nm]	314
Mass (including Gripper) [kg]	52.43 (59.92 w/ Margin)
Stowed Volume [cm]	226.5 X 123.9 X 24

SENER designed clamping mechanisms

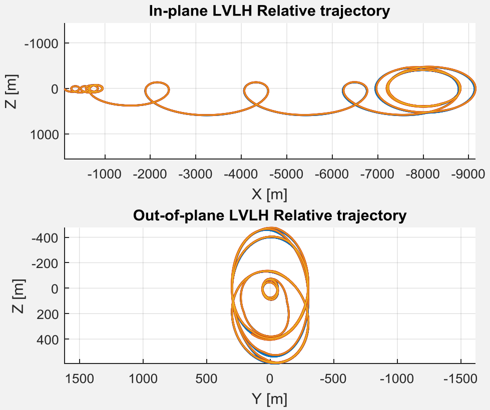


Rendezvous and robotic simulations

The overall system performance was analyzed in various GNC / Robotic simulations and the feasibility of the selected vehicle configuration was confirmed.

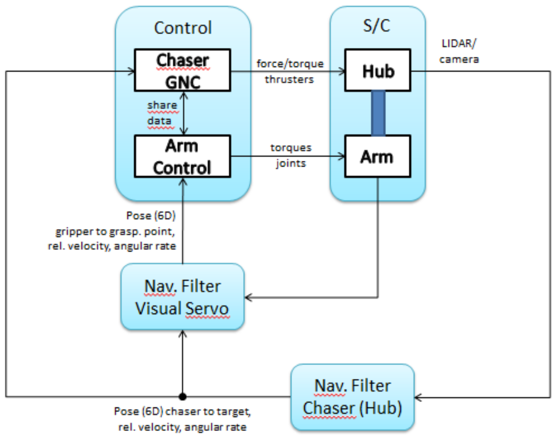
GNC Simulations (GMV)

The control synthesis methodology adopted is H∞ Mixed Sensitivity Design.
The sensitivity function shaping is achieved with frequency varying weights (of MIMO nature).
The Two-Input Two-Output Port (TITOP) is the selected modelling technique of a multi-body system.



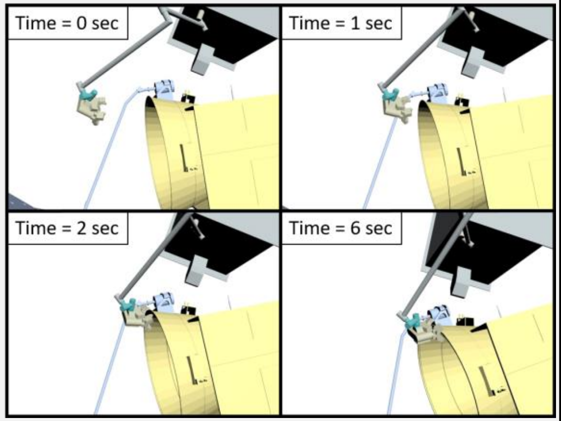
Coupled control design (Airbus)

The coupled control structure separates the robotic arm control from the GNC control of the Chaser.
The GNC operates relative to the Target in order to control the attitude of the Chaser with a frequency of 1 Hz. The robot controller has a higher bandwidth and its sampling time is 1 ms (1 kHz frequency).



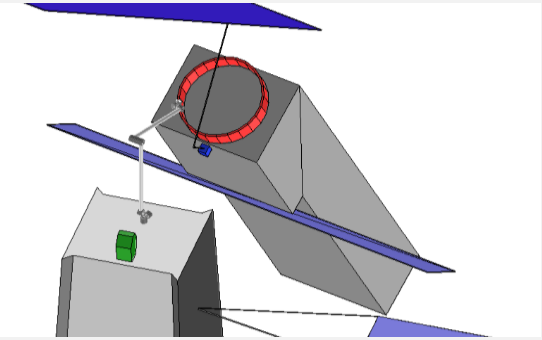
Visual Servoing simulations (MDA)

The LAR POSE information, via visual servoing, is used to guide the robotic arm to the capture position.
POSE estimates are computed with the error model, which is sent to the visual servoing algorithm where the POSE estimates are used to determine the arm tip control commands (PD feedback scheme).



Compliant control simulations (CBK)

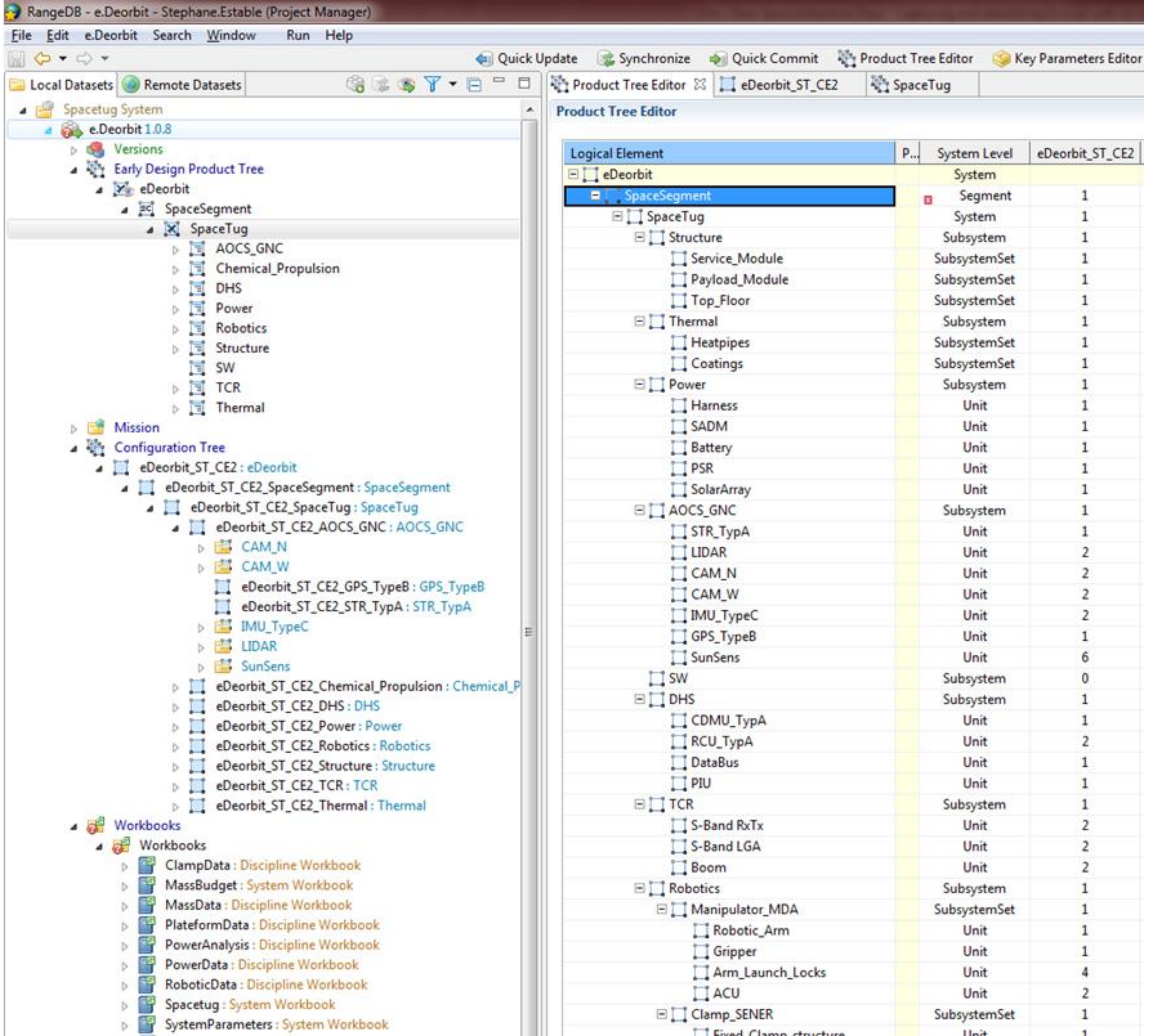
The goal of the compliant control (impedance control) is to ensure that during the motion of the arm the forces and torques (especially acting on the gripper) will be kept within a certain limit and that the gripper, the robotic arm and the clamp will not be damaged.



Spacetug models

The spacetug system and mission are described in models to support the data exchange with ESA and partners.

- RangeDB model for product tree, budgets and system parameters
- SysML Model for system activities, capabilities, modes and functional breakdown
- Mapping of the Airbus RangeDB/ ECSS-E-TM-10-23A and ESA OCDT/ ECSS-E-TM-10-25A Conceptual Data Models for data transfer

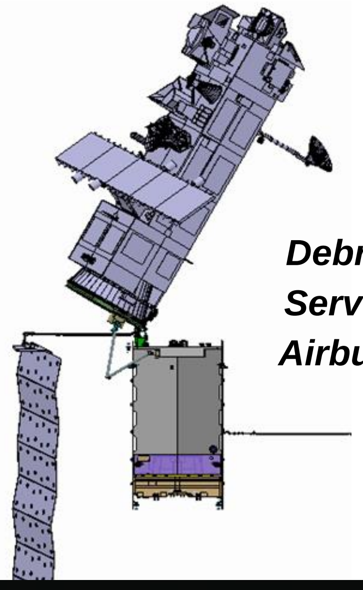


Demonstrator for innovative technologies toward IOS

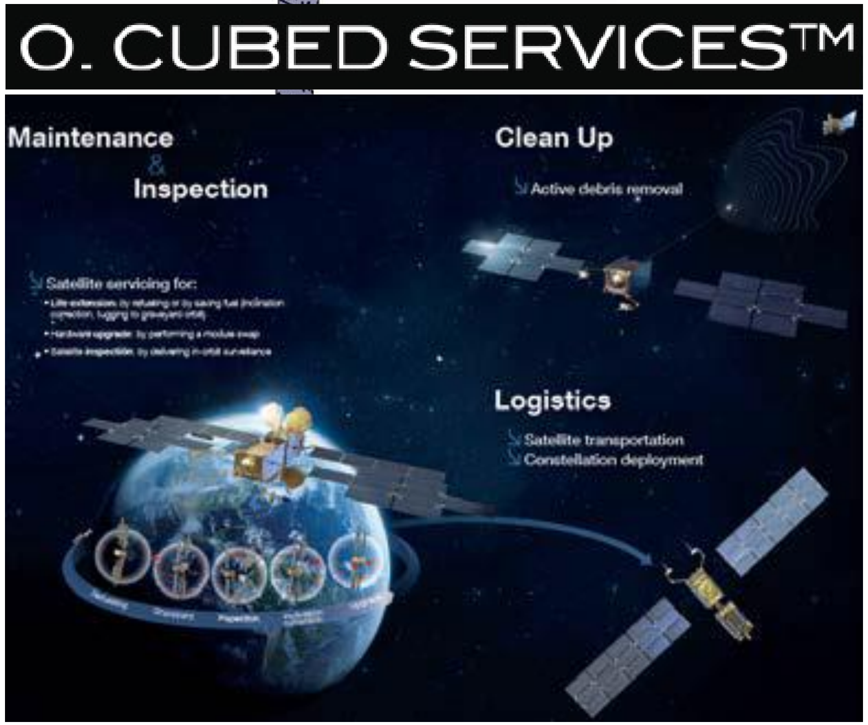
The Airbus Spacetug is designed for implementing services for e.g. Debris Removal and GEO-Satellite refueling and inspection.

e.Deorbit mission as demonstrator of innovative technologies:

- In-orbit characterization of the Target based on measurements from Chaser sensors
- Navigation to uncooperative Targets in all lighting conditions
- Contactless detumbling operations of the Target
- Synchronized flight with the Target
- Tumbling Target capture and stabilization with a robot arm in compliant mode
- Gripper integrating fast soft capture and grasp rigidization
- Coupled-control between the Chaser platform and the robotics
- Onboard monitoring concept for safe automatic operations
- Definition of a robust communications concept including onboard communications architecture and ground station selection



Debris Removal Service with the Airbus Spacetug



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