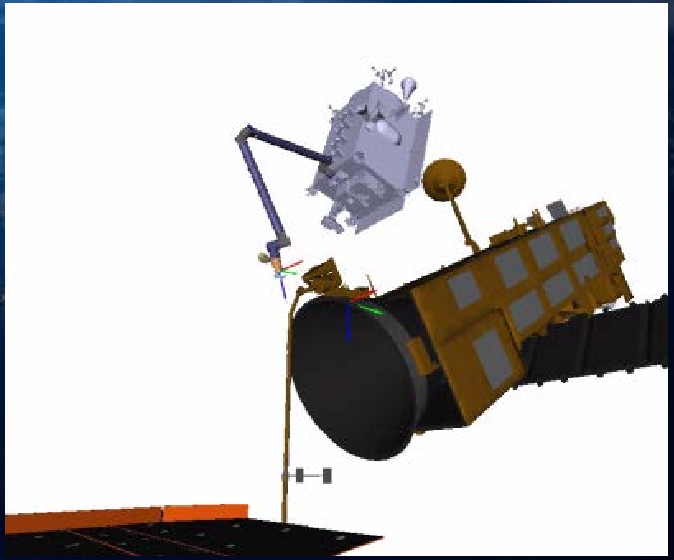
Results of the Airbus DS led e.Deorbit Phase B1 ESA study



DEFENCE AND SPACE

Dr.-Ing. Stéphane Estable
ESA Clean Space Industrial Days, 24-26 October 2017

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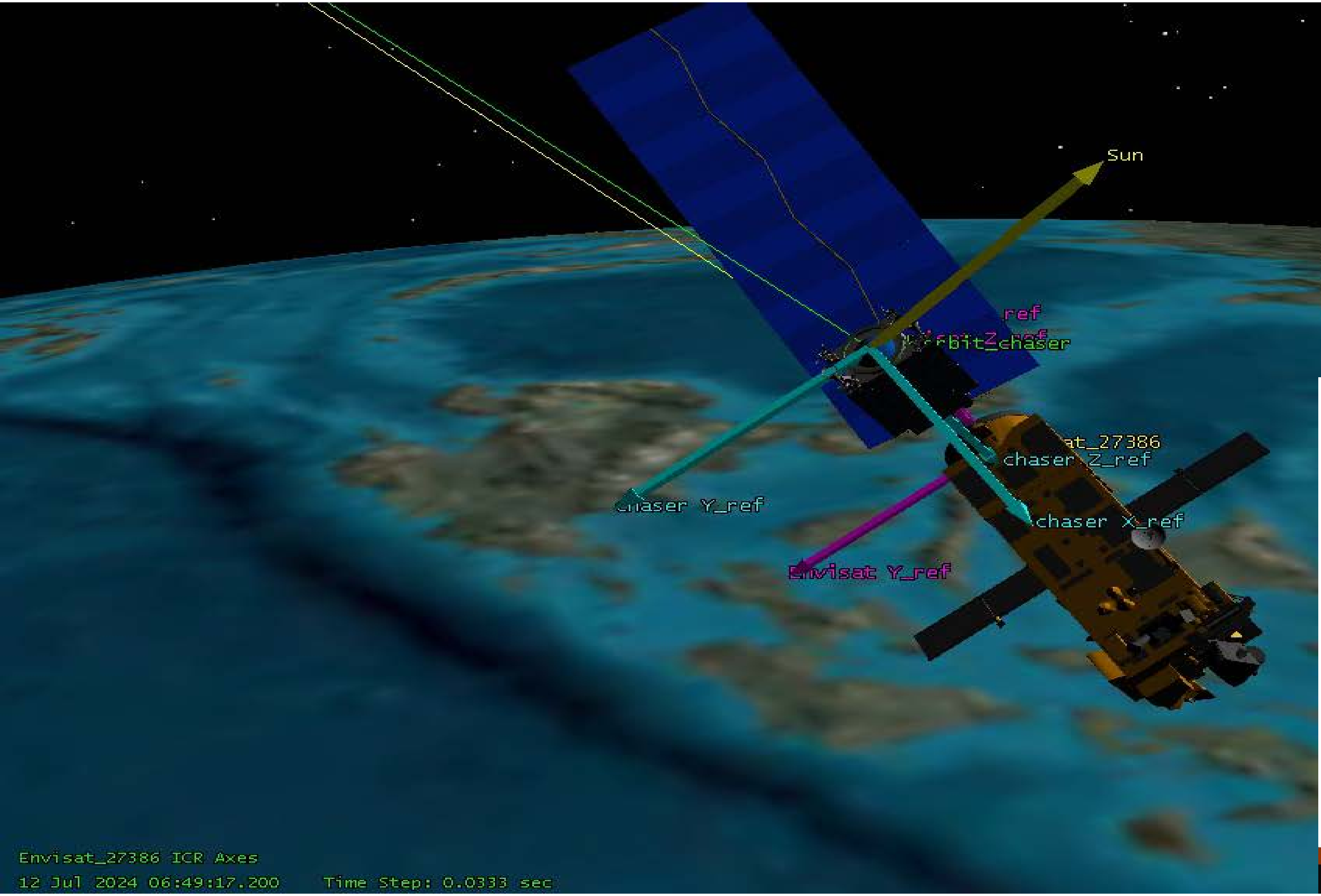
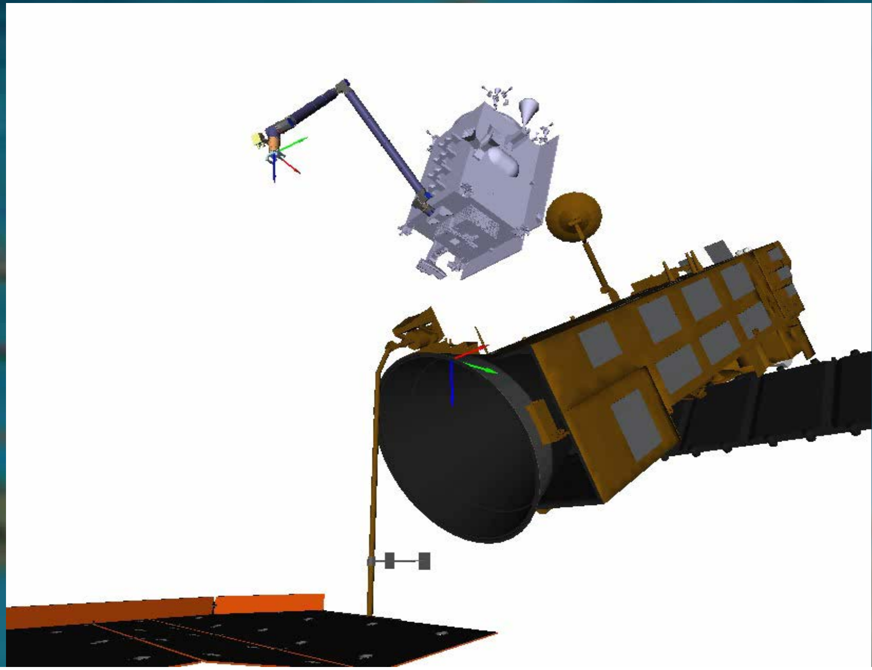
e.Deorbit Mission – Final rendezvous and capture phase





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Phase B1 Team

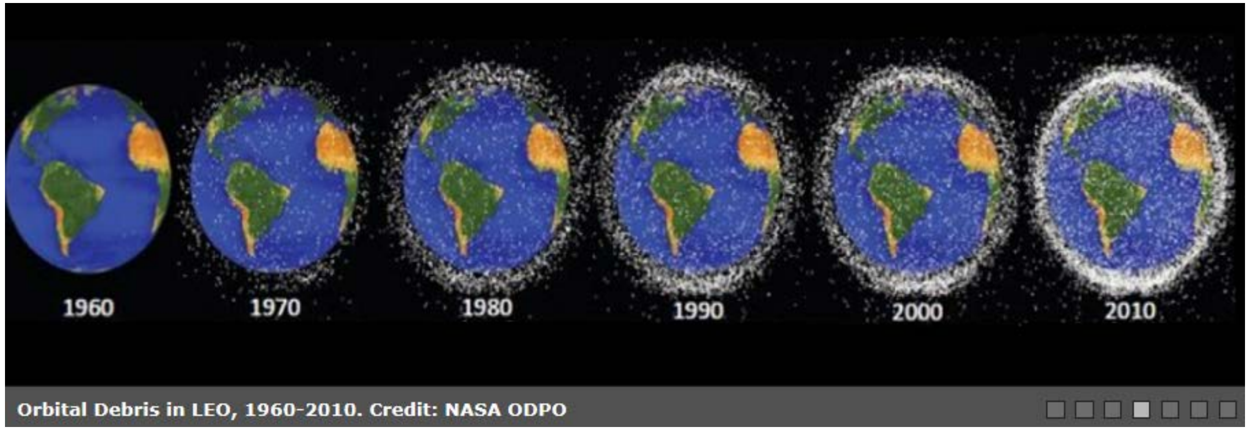
Key players in the Active Debris Removal field have implemented the ESA iSRR in November 2016

Consortium	Activities
AIRBUS DEFENCE & SPACE	**Airbus DS (D),** LSI. System Engineering management, MBSE, definition of the GNC architecture, propulsion, visual-based navigation, concept of operations and programmatic.
QinetiQ Space nv	**QinetiQ Space (B)**, Chaser design definition, communications architecture and performance, ground segment concept definition. Experienced in the end-to-end development of cost-effective, pragmatically implemented platforms and operations with highly performant avionics.
DLR	**DLR Institute of Robotics and Mechatronics (D**), Robotic arm analyses, design and configuration. Bring the expertise in robotics and in rigid link based capture.
SENER	**SENER (POL)**, definition of the chaser to target mechanical interface. Expert in high quality and performance space mechanisms.
gmv INNOVATING SOLUTIONS	**GMV (POR and POL)**, mission and deorbit analysis, GNC dynamics analysis and design verification. Highly capable in complex GNC analyses and simulation, including proficiency on the GNCDE tool.
MDA	**MDA (CAN)**, gripper design. Leading company in the development of space robotics solutions.

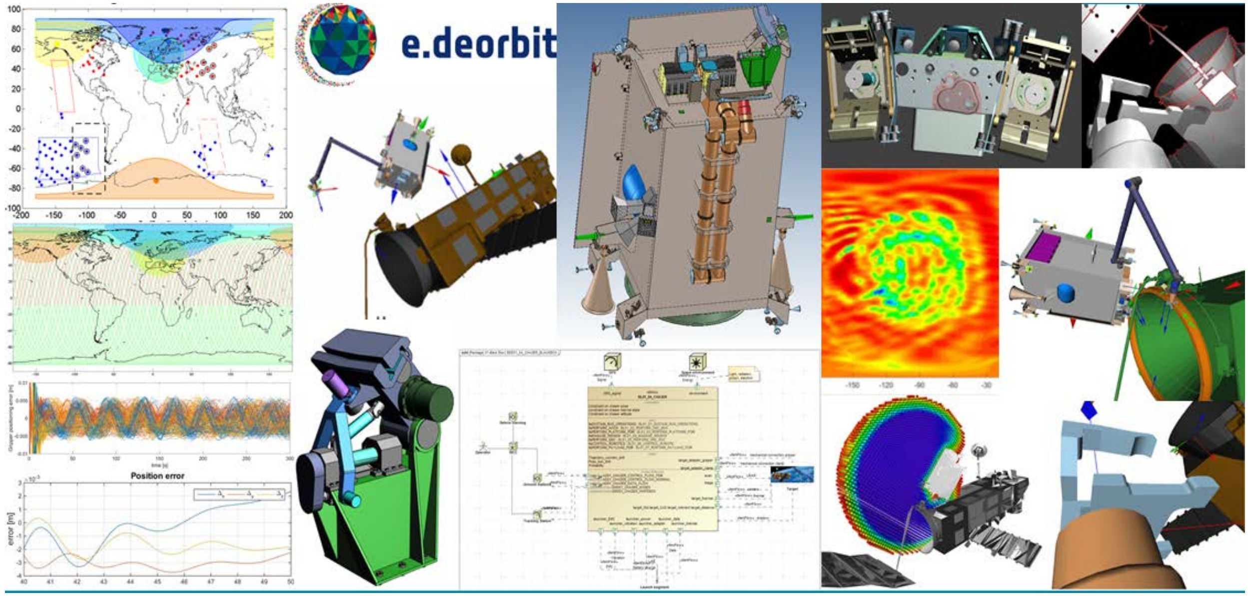
Content

1. Mission phases
2. System properties
3. System safety approach
4. Chaser control modes
5. Chaser main functions
6. Chaser configuration and budgets
7. Beyond e.Deorbit mission
8. Conclusions

The problem:



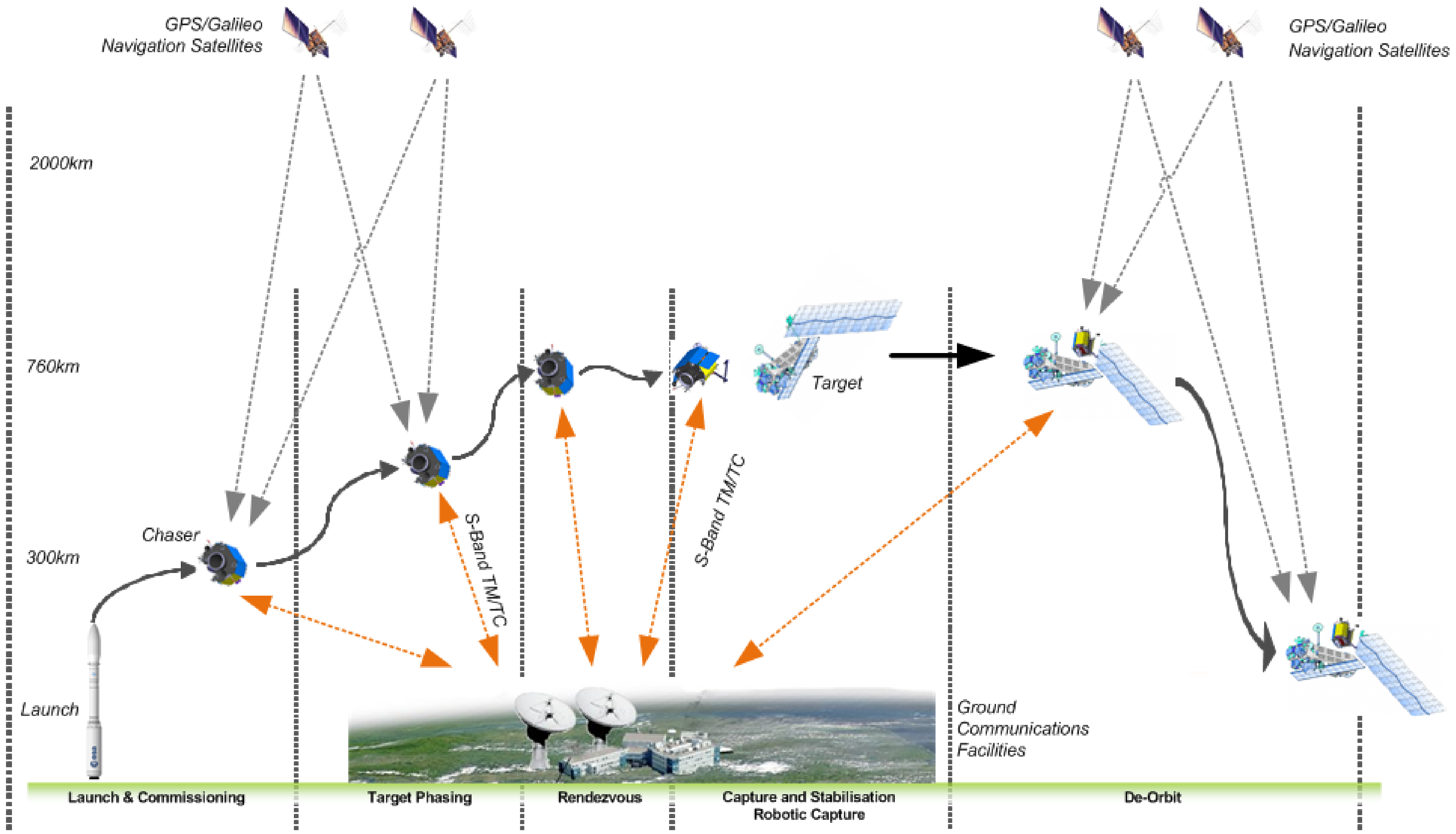
e.Deorbit is one contributor to the solutions to be implemented



e.Deorbit Phase B1 Final Report Airbus DS: *EDEB1-RIBRE-RP-0020-1.0_Final_Report* available at ESA

e.Deorbit mission phases

Objective is to „Remove a single large ESA-owned Space Debris from the LEO protected zone"



- Mission implementation in 2021 (to 2024)
- Mission duration 6 months
- Target angular rates up to 5°/s around any arbitrary axis
- 20min comm time with Redu, Weilheim, Kiruna Svalbard and Fairbanks for final rendezvous and capture.
- Stack orbit transfer and disposal strategy with 3 burns

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System properties

The chaser spacecraft is a constrained automated vehicle with autonomous fail-safe monitoring and reaction behavior functions.

Chaser property	
Capabilities	Sustain bus operations, manage mission, AOCS/GNC, control robotic, coupled control, manage FDIR, automatic onboard operations
Behaviour	System **states**, mission **phases** and subphases, system **modes**, behavioral states, dynamic states, configuration states
Autonomy levels	ECSS **E1** (Mission execution ground control) **to E4** (Execution of goal-oriented mission operations on-board)
Physical	Injection mass of 1573 kg (TBC) with Vega-C **60N** on each chaser axis for the synchronized flight **800N main engine** for the deorbit burns + attitude control assist engine Capture operations on **battery for 1.5 orbit** **Omni-directional communications** with limited blockage to ground Arm capable to withstand the stack stabilisation (up to **160Nm torques**) Gripper with **fast and form-closure grappling**
Chaser / Arm dynamic	**Coupled control** between the chaser platform and robot controllers GNC sensors to keep Target in field-of-view in all phases Capture equipment with adequate workspace clearance
Operations	**Automatic on-board activity** execution after timeline ground validation **Autonomous on-board decision** making based on safety constraints **Real-time ground supervision** based on the raw and processed onboard data with 400ms data latency and 4Mbps bandwidth
Safety	System control structure to **reinforce the safety constraints** Tanks with membrane, light independent navigation sensors

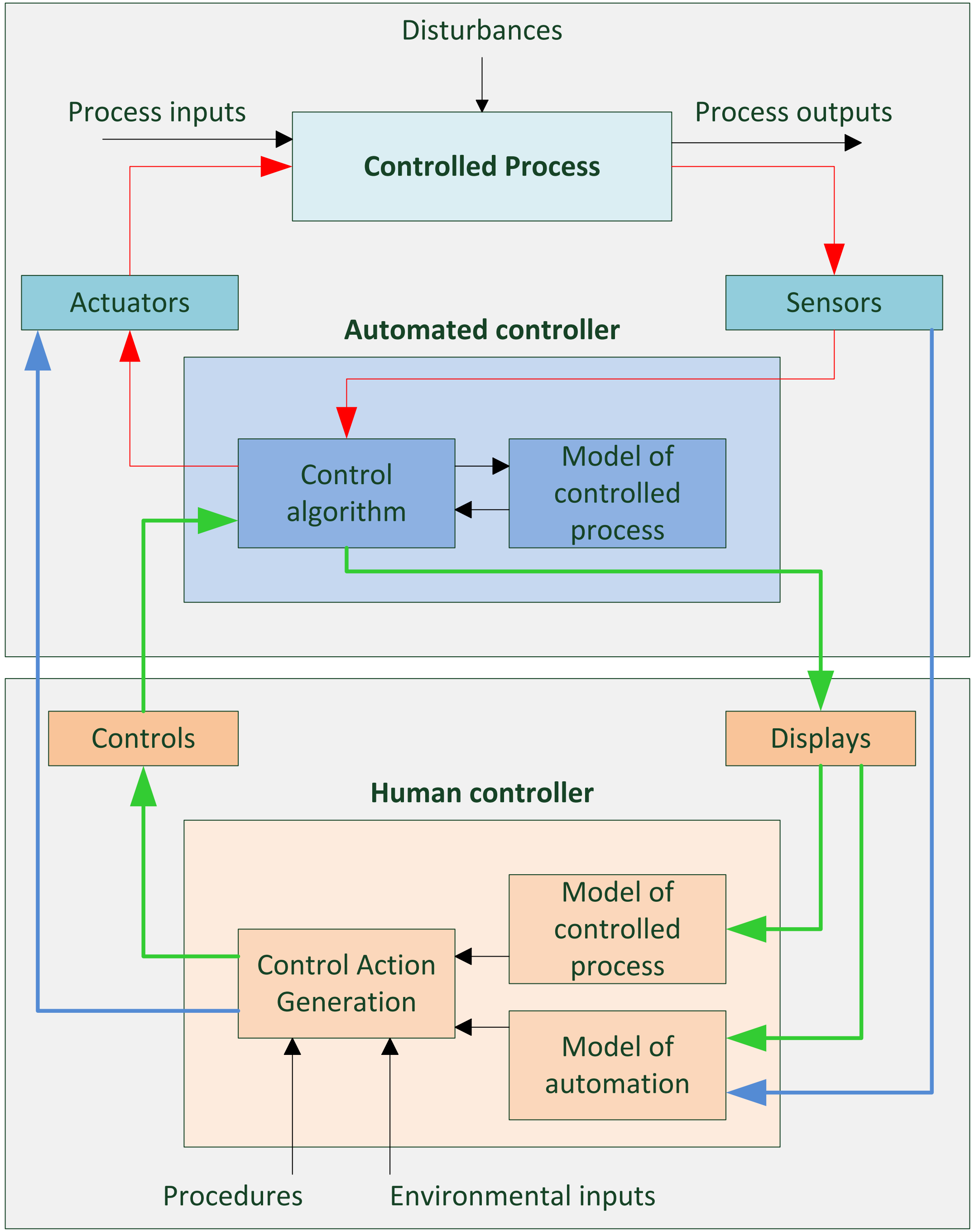
System safety in a complex system

System safety property will emerge from the coherent control of constraints at different system levels

The system control structure involves different levels:

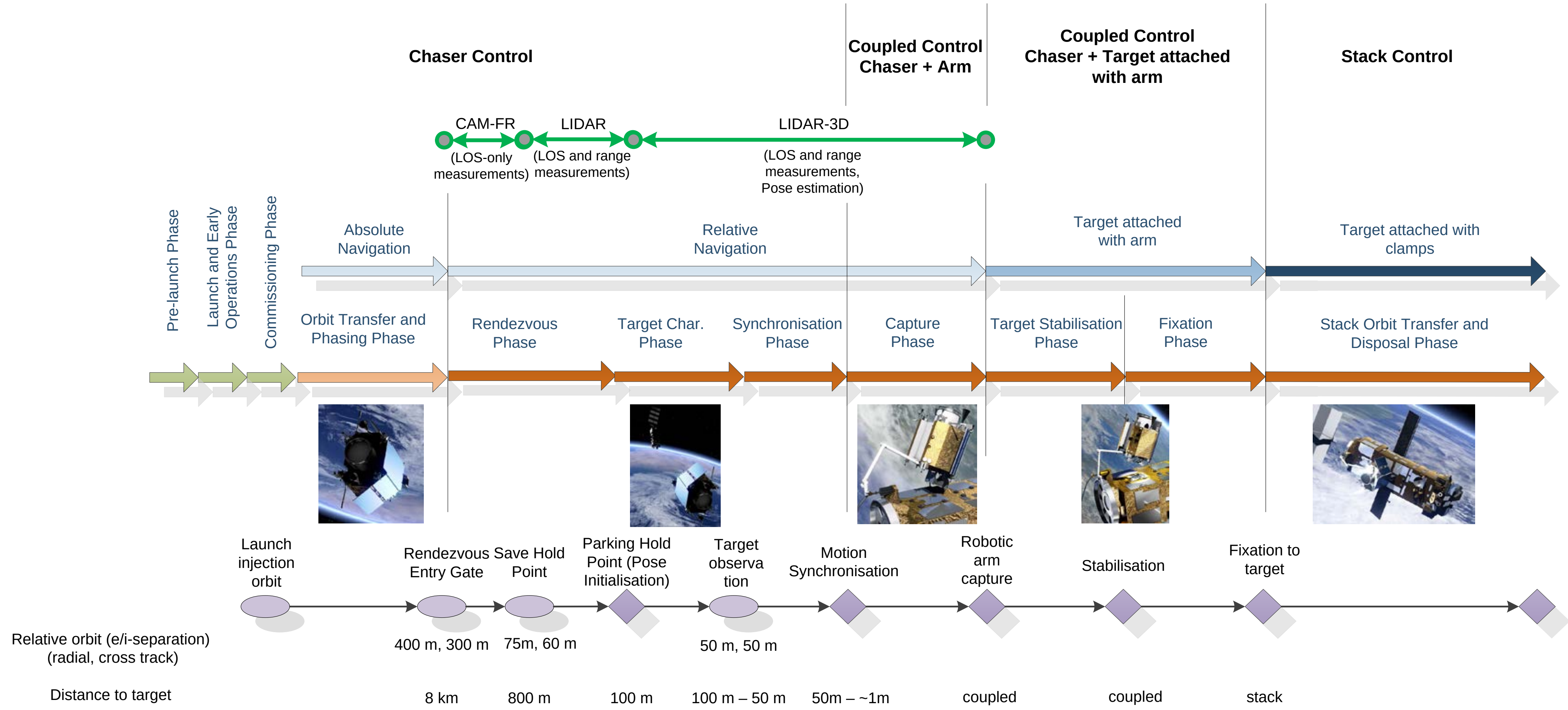
- **Onboard monitoring**: Permanently check system health status and dynamic state (relative pose to Target, speed, rate) w.r.t. the reference program. In case of violation of the program constraints the Chaser has to interrupt or abort autonomously the current operations.
- **Onboard generation of CAM and robot arm retreat trajectories**: The escape trajectories for the platform (CAM) and the robot arm (retreat) are generated onboard at each GNC cycle based on the object geometries and the current relative poses.

- **Ground supervision**: The system is checked for plausibility/consistency on ground at mission transitions and reconfigurations and during operations.
- **Failure recovery on ground**: Reference data with markers are not available for uncooperative Targets. Operator interaction on ground to correct the onboard visual navigation data in case of mismatch of the sensor data with the model.
- **Tele-operation**: To continue the mission in case of malfunction of the robotic subsystem, the system shall be able to command manually the robot arm from ground in a tele-operation mode.



Chaser control modes

Various control modes for the platform AOCS, GNC, robot arm and their coupling.



Chaser main functions

The Chaser functions are shared between the platform and the robotic payload.

Chaser Platform functions:

- BL01_01_SUSTAIN_BUS_OPERATIONS
- BL01_02_PERFORM_ GNC_BUS
- BL01_03_PERFORM_PLATFORM_FDIR
- BL01_04_MANAGE_MISSION

The platform functions manage the platform bus from LEOP to the end of the **absolute navigation** at the Entry Gate and during the disposal and re-entry mission phases. These are the **mission phases where GNC-BUS for orbit and attitude control without GNC-RVC is active**, either for the chaser alone or in the stack configuration after fixation.

Robotic Payload functions:

- BL01_05_PERFORM_GNC_RVC
- BL01_06_CONTROL_ROBOTIC
- BL01_07_PERFORM_PAYLOAD_FDIR

The payload functions manage the **relative navigation phases** from the Entry Gate to the Capture Point, the **capture phase** with the robot arm and the gripper where **coupled-control is active**, the **stabilisation** and the **fixation**.

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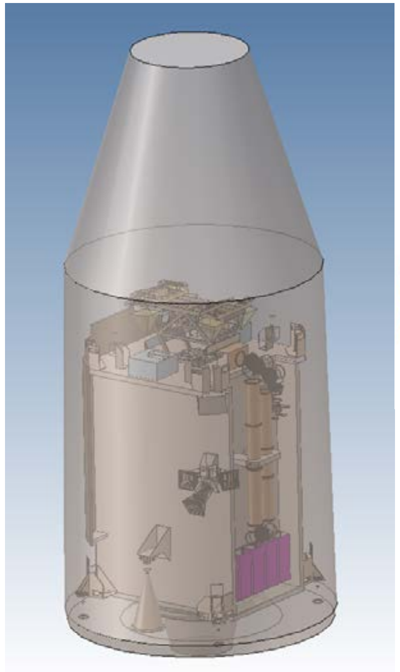
Chaser configuration

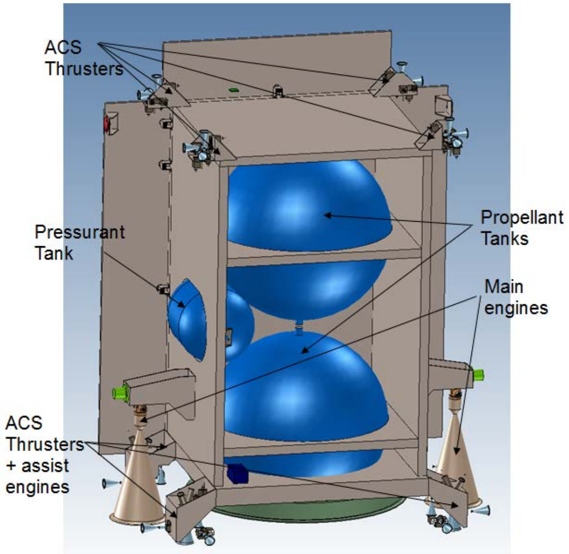
No standard platform but equip. reuse

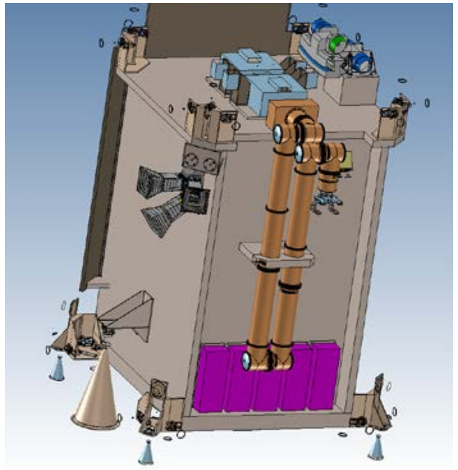
Vega-C acc.



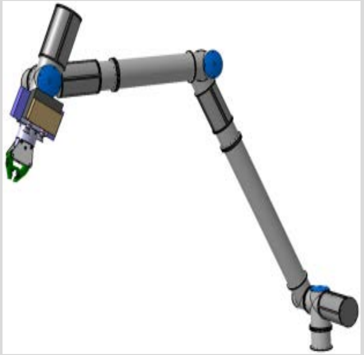
Size: 2.0 x 1,6 x 2.8 m

Platform





Robotic Payload



Robot arm

Gripper (MDA)

Clamp

Payload computer

Cameras

LIDAR

	Chaser budgets
Wet mass	1660 kg Target wet mass = 1573 kg (TBC)
Dry mass	744 kg (incl. 20% system margin)
Propellant	778 m/s in total or 913 kg (incl. all mission contingencies)
Power	1287W max peak consumption during arm rigidization phase
Data link	4.05 Mbps max real-time downlink data rate during Target capture and stabilization phase
GNC accuracy budget	For relative navigation during capture: Relative attitude: 2 deg Relative angular rate: 0,5 deg/s Relative position: 0,05 m Relative velocity: 0,01 m/s

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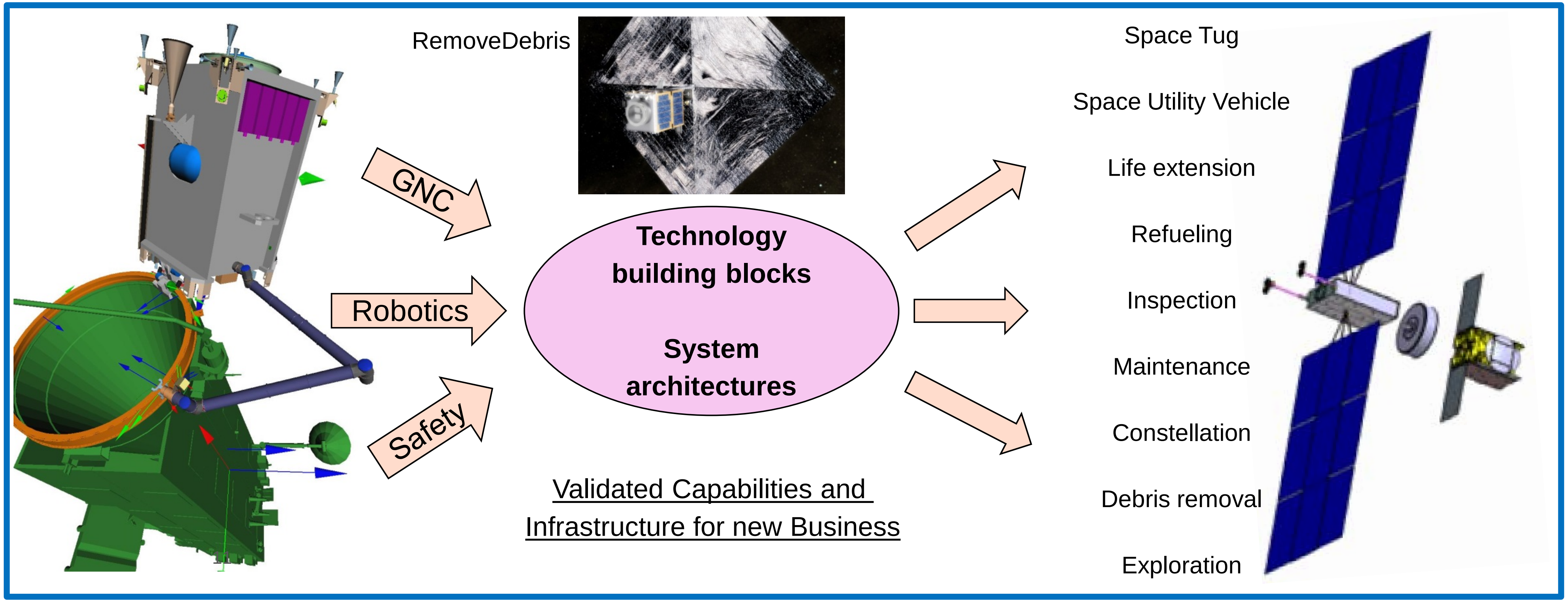
e.Deorbit: much more than only a debris removal mission

e.Deorbit has a concrete application: the removal of Envisat

This mission is also a unique opportunity for maturing and qualifying key technologies, and opening new business opportunities:

- Demonstration and validation of technologies for GNC, Robotics, Combined Control and Safety Monitoring
- Delivery of technology building blocks and system architectures for On-Orbit Servicing and new space business



Conclusion

Confirmation at e.Deorbit iSRR that the ENVISAT removal mission is feasible.

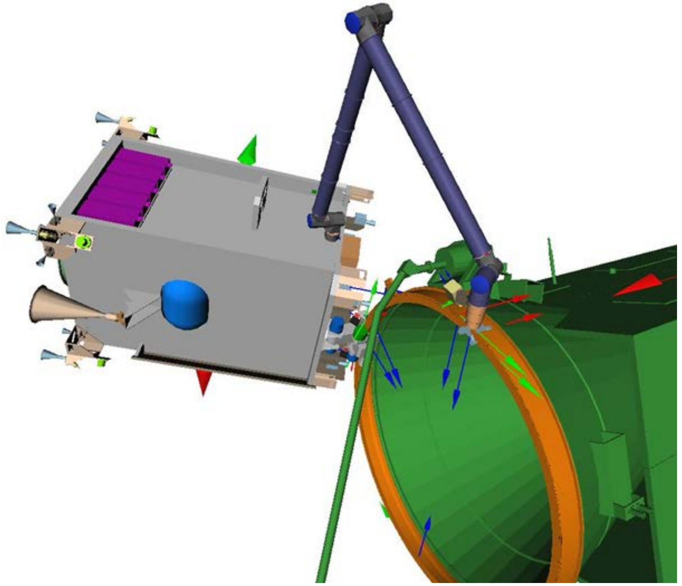
ENVISAT removal mission is feasible w.r.t.:

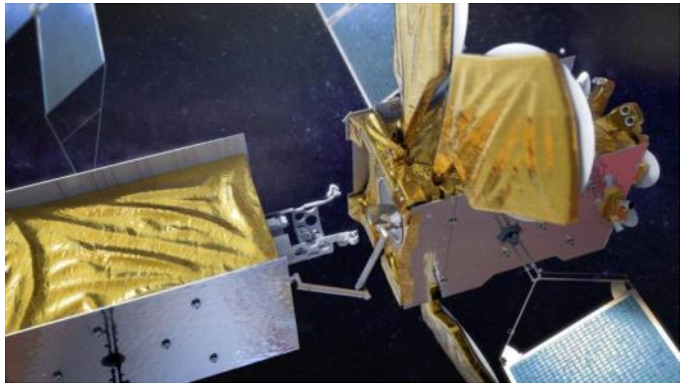
- Cost
- Technologies
- Schedule
- Risks

The defined chaser is

- compatible with launch on VEGA-C
- robust to the state of Envisat
- comprised of elements transferrable to future debris removal and on-orbit servicing (OOS) missions
- devised on the basis of a strong risk mitigation philosophy

e.Deorbit can open new business opportunities on on-orbit servicing for European companies using the building blocks.





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