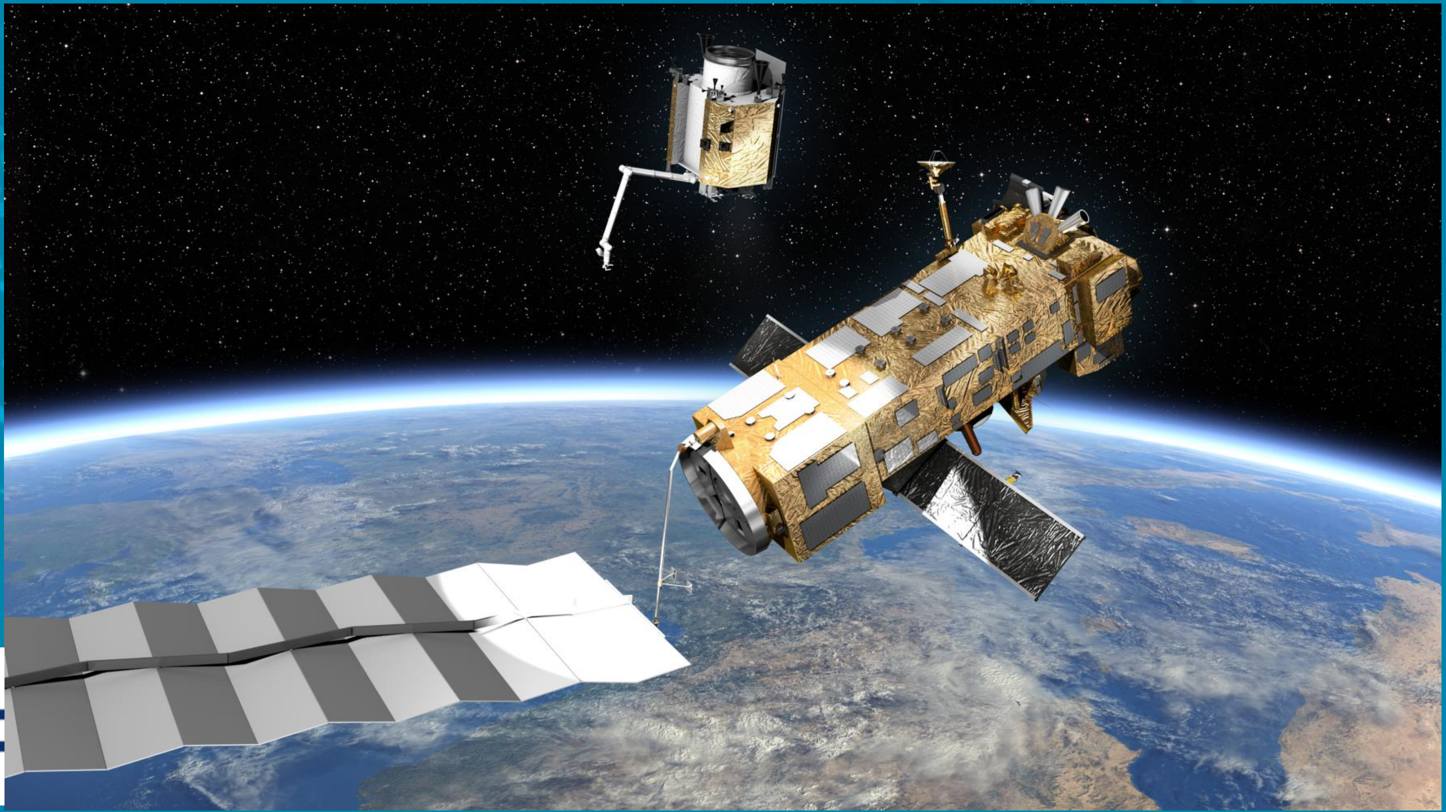


# Envisat removal by robotic capture means. Results of the Airbus DS led e.Deorbit Phase B1 ESA study

Clean Space Industrial Days, 24.05.2016, ESTEC

EDEB1-RIBRE-PRE-0004-16

# Last news on space debris

## Cupola windows hit by space debris…

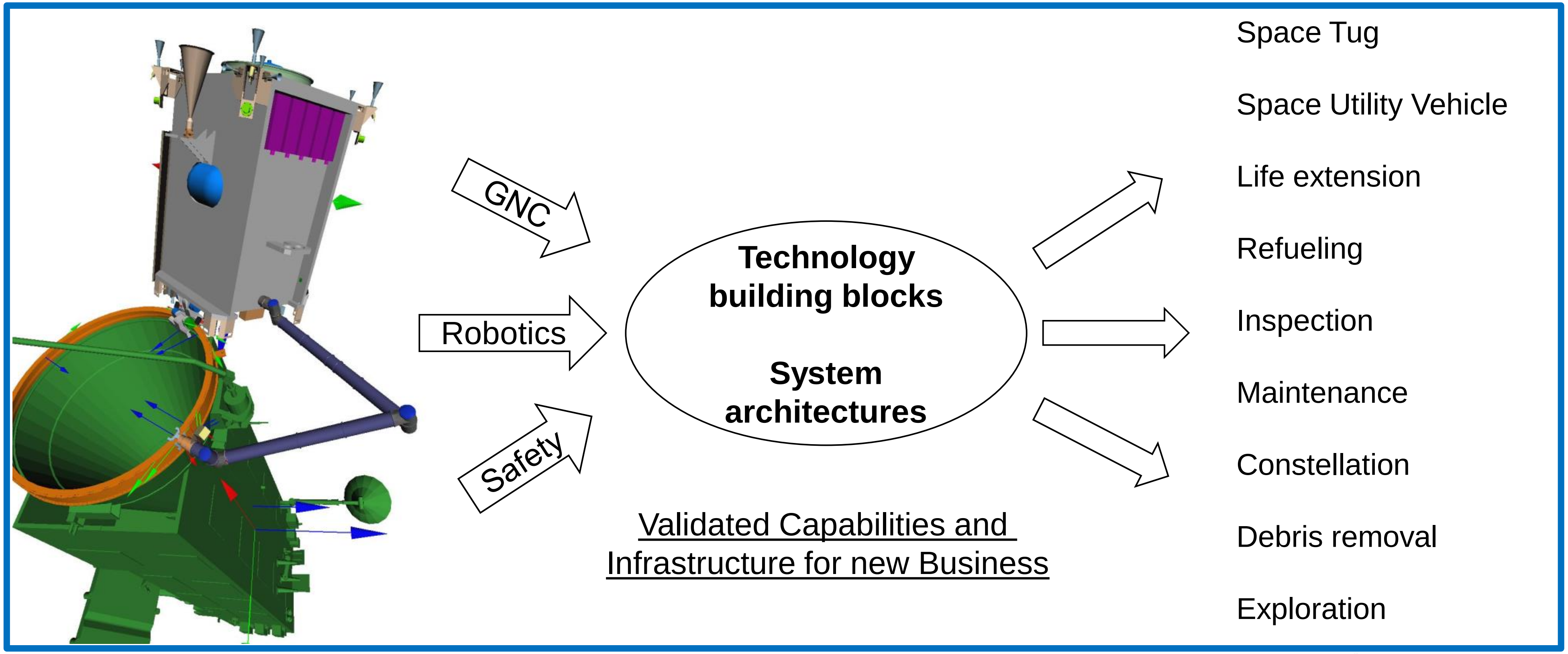
**ISS on duty** a partagé la **photo** de **Tim Peake**.
2 h •

**Tim Peake**
3 h •

Often asked if the **International Space Station** is hit by space debris. Yes – this is the chip in one of our Cupola windows, glad it is quadruple glazed! http://www.esa.int/spaceinimages/Images/2016/05/Impact_chip

# The removal of envisat with e.Deorbit is an opportunity for qualifying key technologies and opening new business

- Envisat removal is a one-off mission to solve a real concern in LEO
- 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



GNC

Robotics

Safety

**Technology building blocks**

**System architectures**

Space Tug

Space Utility Vehicle

Life extension

Refueling

Inspection

Maintenance

Constellation

Debris removal

Exploration

<u>Validated Capabilities and Infrastructure for new Business</u>

# Content

1. Industrial team
2. Objectives, Mission Environment and Needs
3. Architectures
4. Selection of the appropriate level of safety for the mission
5. Conclusions

# Industrial team

# e.Deorbit Phase B1 Team

## Integrated team working in concurrent engineering sessions with model-based SE

| 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.<br>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 (DLR-RM**, **D**), Robotic arm analyses, design and configuration.<br>Bring the expertise in robotics and in rigid link based capture. |
| SENER | **SENER (POL)**, definition of the chaser to target mechanical interface.<br>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.<br>Highly capable in complex GNC analyses and simulation, including proficiency on the GNCDE tool. |

# Objectives, Mission Environment and Needs

# Study objectives

## Mission, operations and chaser definition, requirements dev. and risk mitigation

**Main objective of the Phase B1**

- Definition of the e.deorbit mission implementation concept at Phase B1 level
- Derive a baseline concept, to define its technical specifications and interfaces
- Assess the preliminary verification plan in line with the applicable ECSS standards.
- Project management, engineering and PA plans, master schedule and cost report.

**Detailed risk analysis** including a fault analysis is expected.

**Study Technical Objective**: To mitigate e.deorbit risks and establish the system preliminary definition up to SRR level. There are 6 Goals:

1. Perform a phase B1 design
2. Mitigate collision risk between the chaser and target
3. Mitigate casualty risk on-ground
4. Mitigate risk of unsuccessful capture
5. Mitigate risk of debris generation
6. Mitigate schedule risk

# Mission scenarios

## Three rotational scenarios shall be considered for the ENVISAT rotational state

**Scenario 1**

Spin axis in body frame is aligned with the +Ys axis.

Spin axis in LVLH frame is aligned with the +H-bar axis.

Spin rate is 3.5 deg/s.

**Scenario 2**

Spin axis in body frame is along a direction contained in the YsZs plane at 45 degrees w.r.t. +Ys and +Zs.

Spin axis in LVLH frame is aligned with the +H-bar axis.

Spin rate is 5 deg/s.

**Scenario 3**

Spin axis in body frame is aligned with the +Zs axis.

Spin axis in LVLH frame is at an angle of 45 degrees with respect to the +H-bar axis and is contained in the H-bar/R-bar plane.

Spin rate is 5 deg/s.

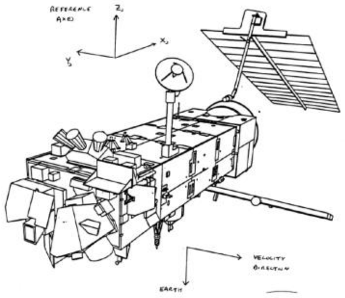


Figure 10-1. ENVISAT body reference frame

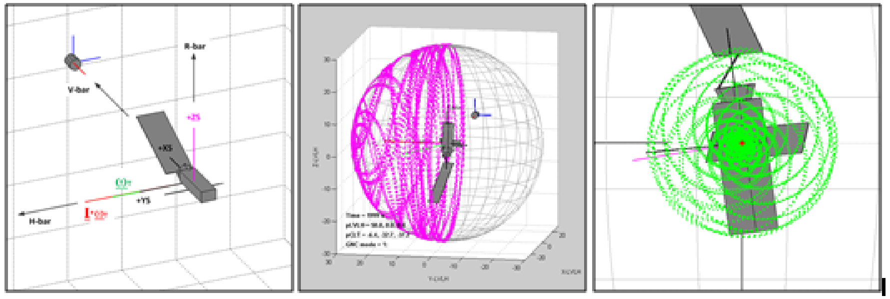


Figure 8-8: Scenario 1 results in a +/-90° cone containing the ZS figure axis motion (middle) w.r.t. LVLH and a +/-25° cone for the spin vector (right). The angular momentum vector stays very close to the H-bar

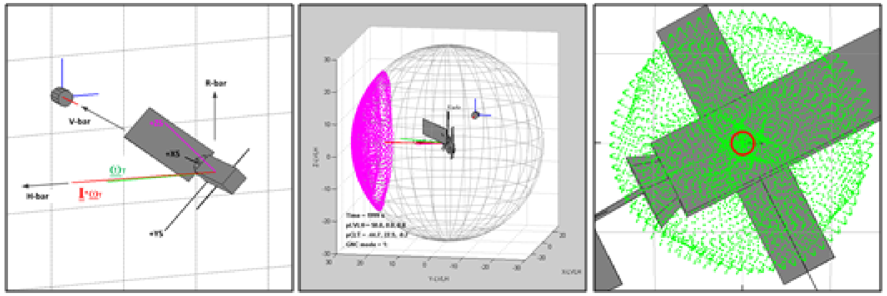


Figure 8-9: Scenario 2 results in a +/-45° cone containing the ZS figure axis motion w.r.t. LVLH and a +/-18° cone for the spin vector. The angular momentum vector stays very close to the H-bar

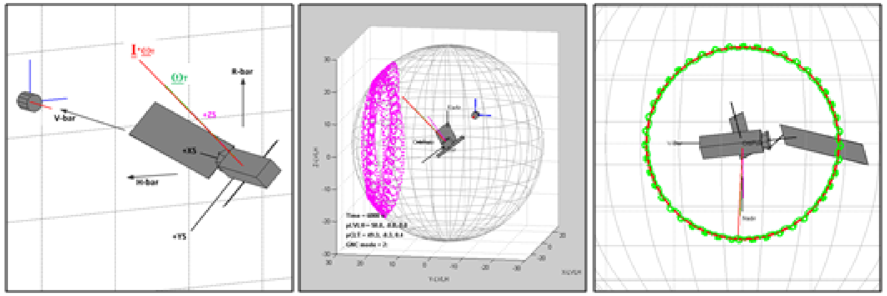
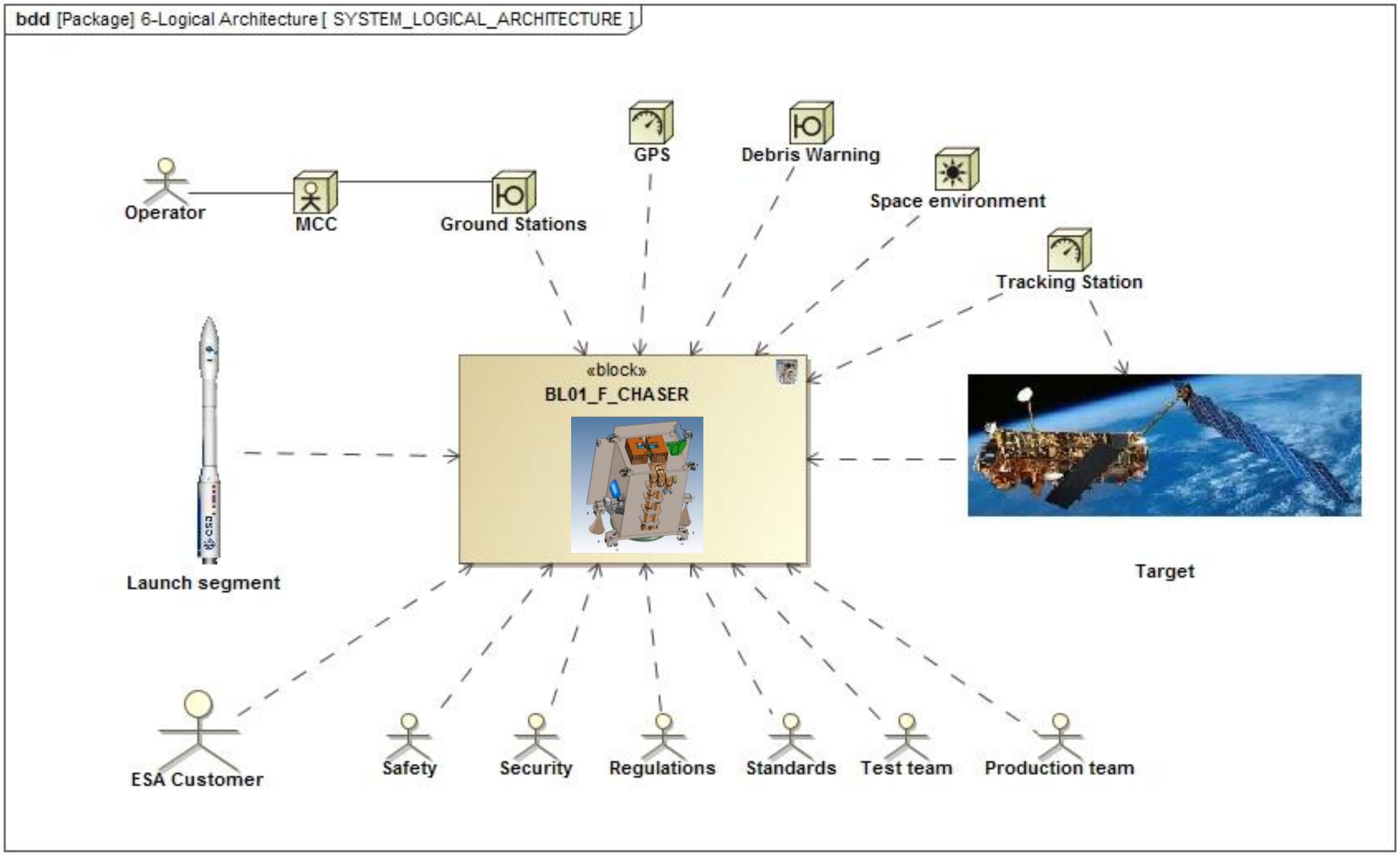


Figure 8-10: Scenario 3 results in a +/-45° virtual precession cone for the angular momentum vector (right, red). Superimposed, a small nutation of both the ZS figure axis (middle) and the spin axis (right, green) is seen

# Mission environment

## The chaser is embedded in a complex environment with many differents aspects



# Main needs for the Envisat capture

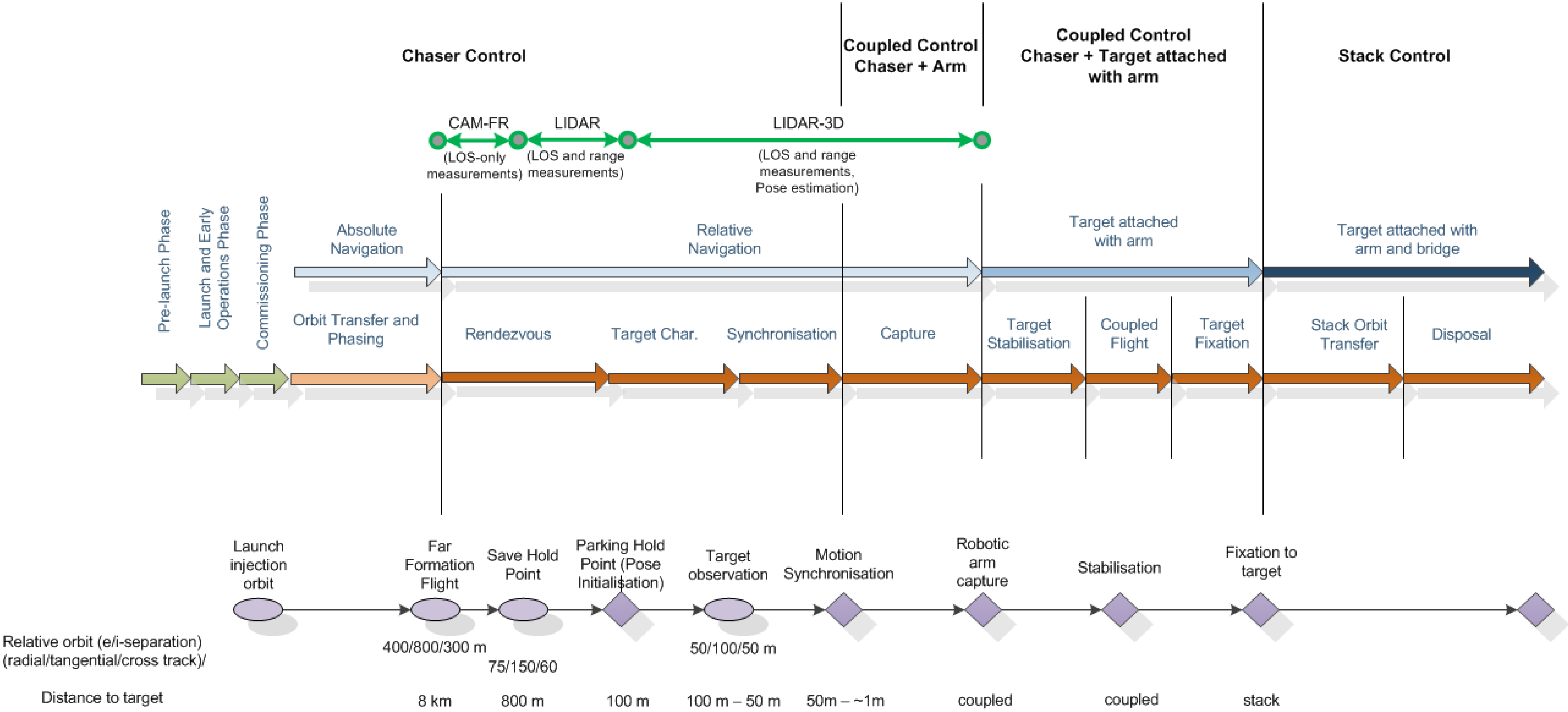
Different needs to be taken into account in harmonized architectures.

- Synchronized flight and stack stabilisation
- Robotics grappling and clamping
- Deorbiting
- Automatic onboard mission execution with onboard monitoring
- Share between onboard monitoring and ground supervision
- Communications architecture
- Mission safety
- Technology and system verification
- Cost effective system
- Modular approach for the development of the technological building blocks

# Architectures

# Mission architecture

## The mission consists of a sequence of different modes with a combination of AOCS, GNC, robotics and bus functions



**Chaser Control**

**Coupled Control Chaser + Arm**

**Coupled Control Chaser + Target attached with arm**

**Stack Control**

CAM-FR (LOS-only measurements)

LIDAR (LOS and range measurements)

LIDAR-3D (LOS and range measurements, Pose estimation)

Absolute Navigation

Relative Navigation

Target attached with arm

Target attached with arm and bridge

Pre-launch Phase

Launch and Early Operations Phase

Commissioning Phase

Orbit Transfer and Phasing

Rendezvous

Target Char.

Synchronisation

Capture

Target Stabilisation

Coupled Flight

Target Fixation

Stack Orbit Transfer

Disposal

Launch injection orbit

Far Formation Flight

Save Hold Point

Parking Hold Point (Pose Initialisation)

Target observation

Motion Synchronisation

Robotic arm capture

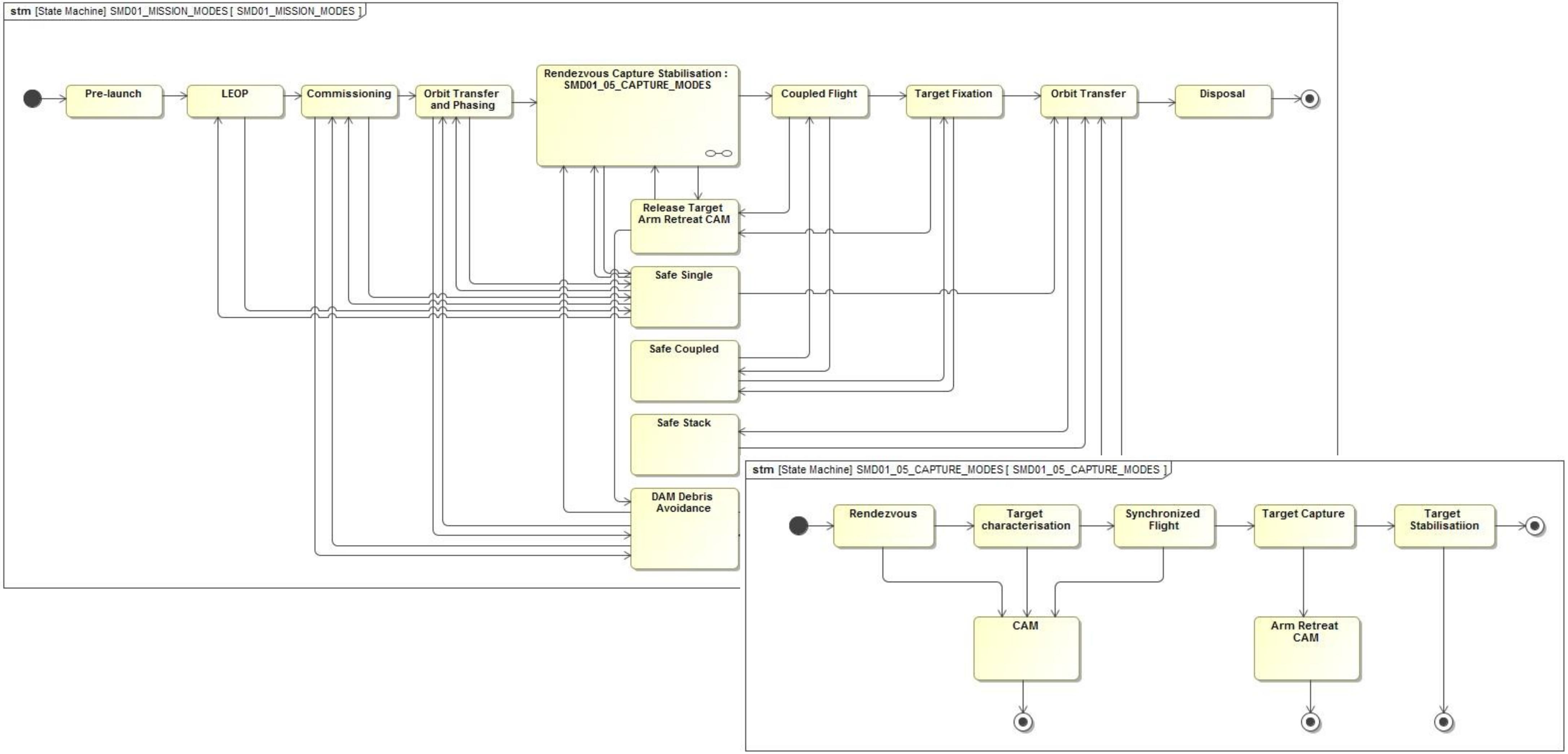
Stabilisation

Fixation to target

| Relative orbit (e/i-separation) (radial/tangential/cross track)/ | 400/800/300 m | 75/150/60 | | 50/100/50 m | | | | |
|---|---|---|---|---|---|---|---|---|
| Distance to target | 8 km | 800 m | 100 m | 100 m – 50 m | 50m – ~1m | coupled | coupled | stack |

# Mission modes

## The mission modes cover the nominal mission activities linked will all the safety states relevant for the simulations, mission operations and verifications



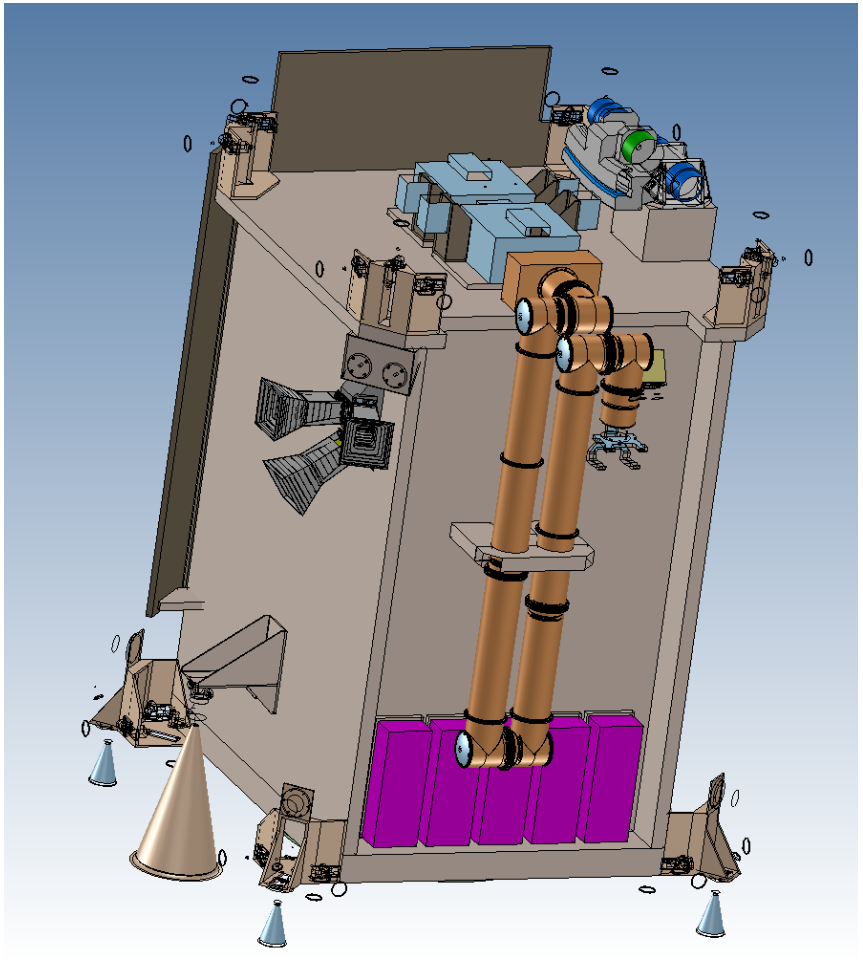
# Chaser design baseline

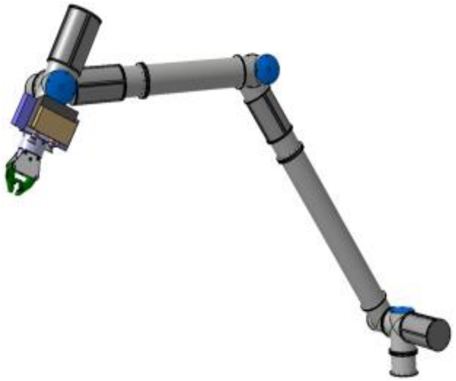
## No standard platform but equip. reuse

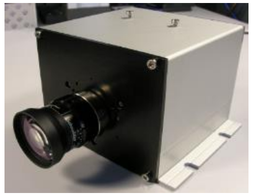
## DEOS payload + new clamp

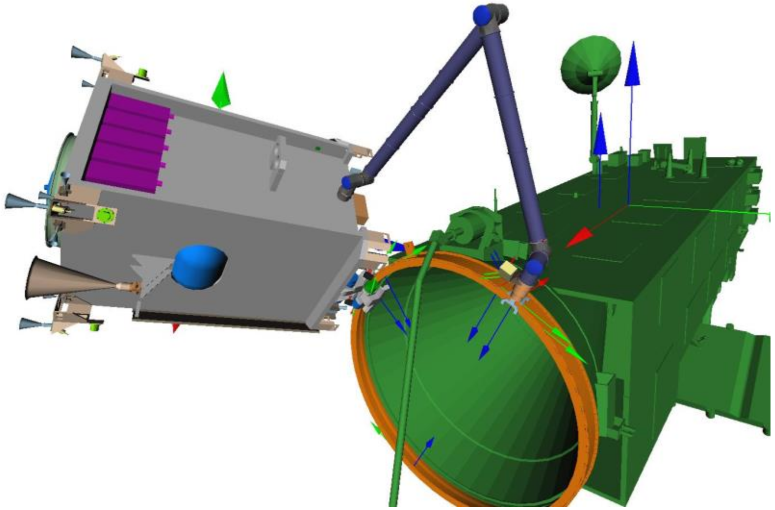
## Vega-C compatible (mass and volume)

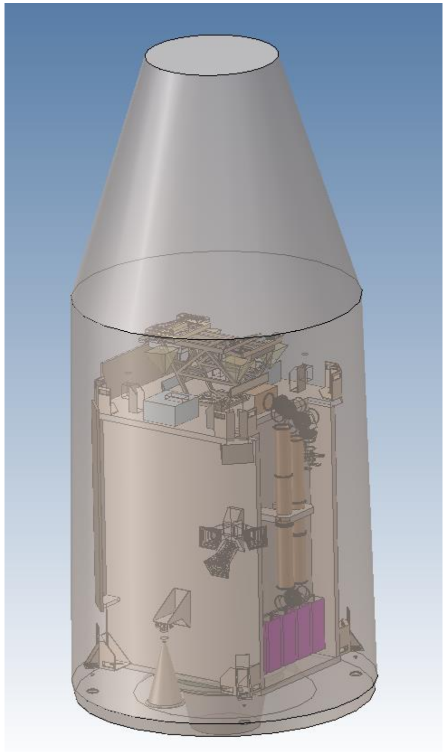
- Wet mass = 1630 kg (incl. mission contingencies)
- Target wet mass = 1650 kg
- Size: 2.0 x 1,6 x 2.8 m
- Power: max peak consumption = 1287W (rigidization phase)
- Data link: 4.05 Mbps real-time downlink data rate, 16.44 Mbps maximum data rate
- 19 min 10 s visibility window for critical operations
- RF link: sufficient margin (7dB downlink, 31dB uplink)











## GNC

GNC architecture

GNCDE simulations (GMV)

Synchronized Flight

Coupled control simulations

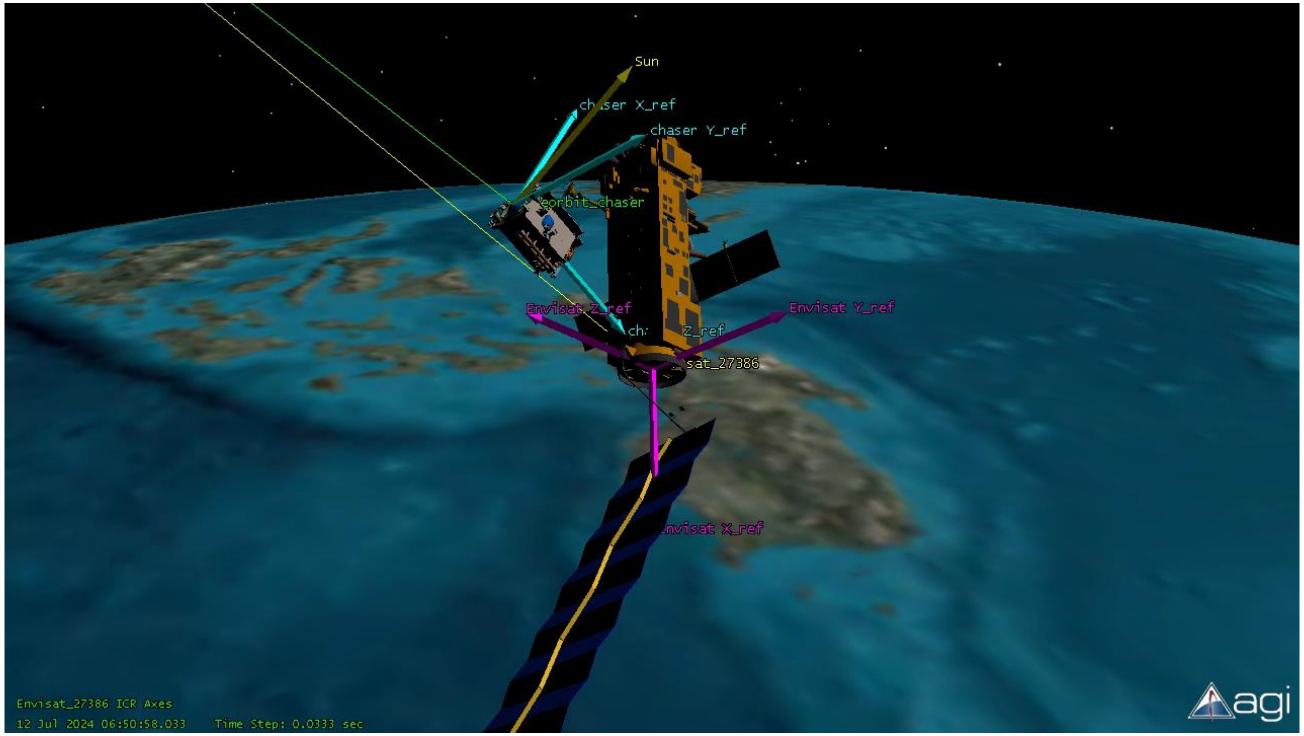
## Robotics

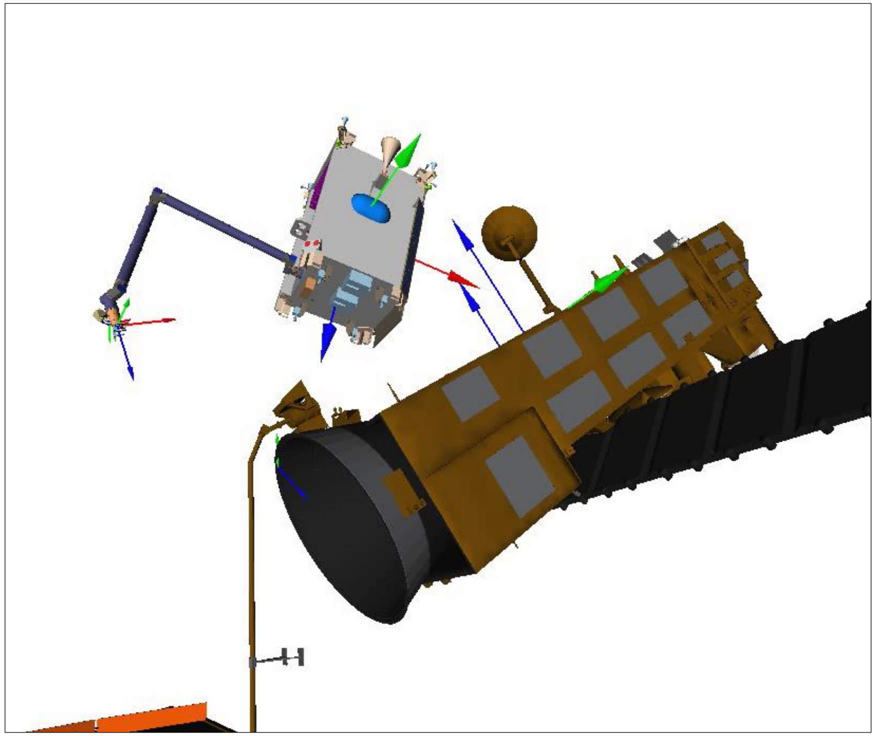
Robotic design (DLR-RM)

Gripper design (DLR-RM)

Clamping design (SENER)

Grappling and Clamping Simulation



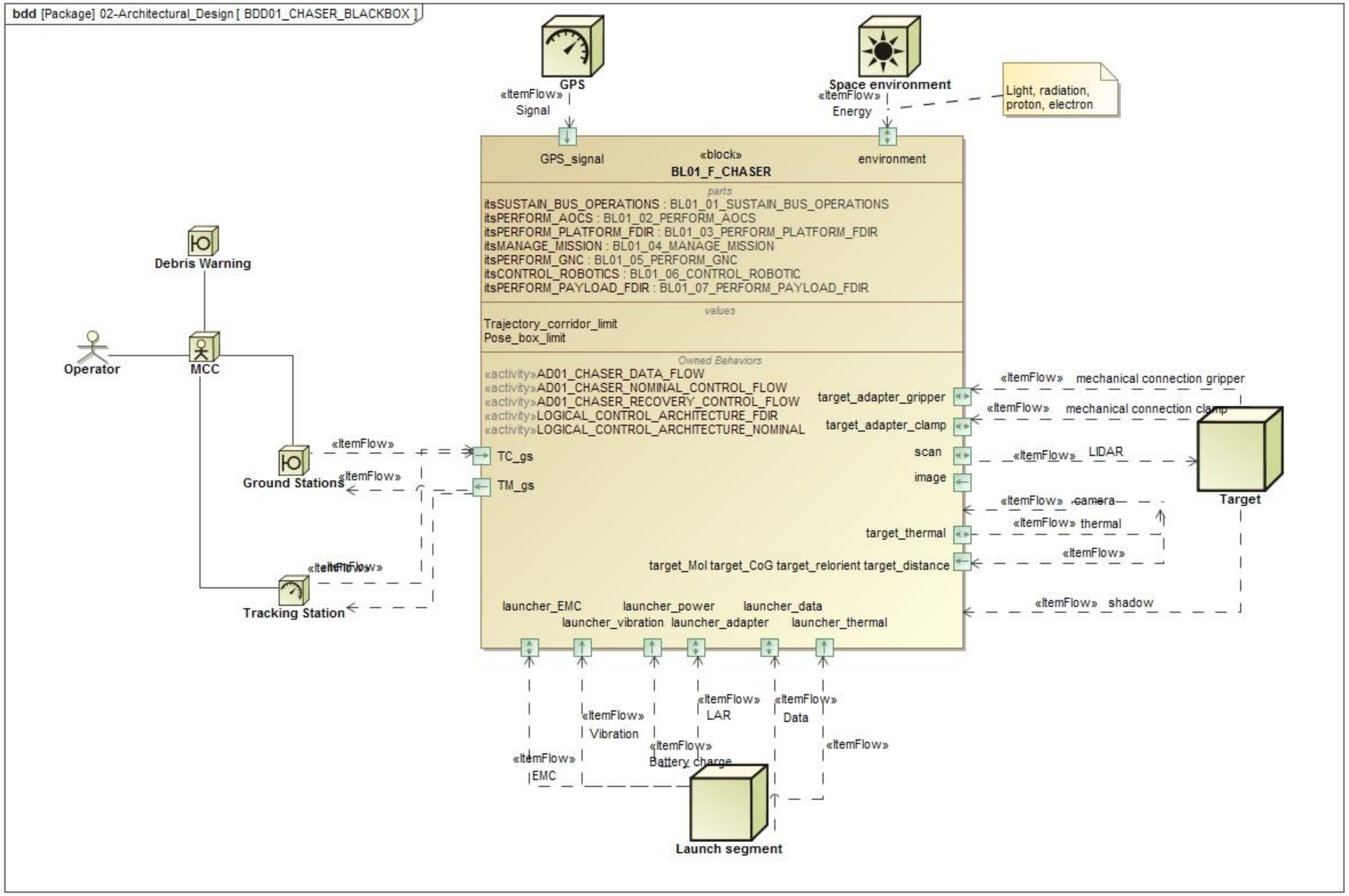


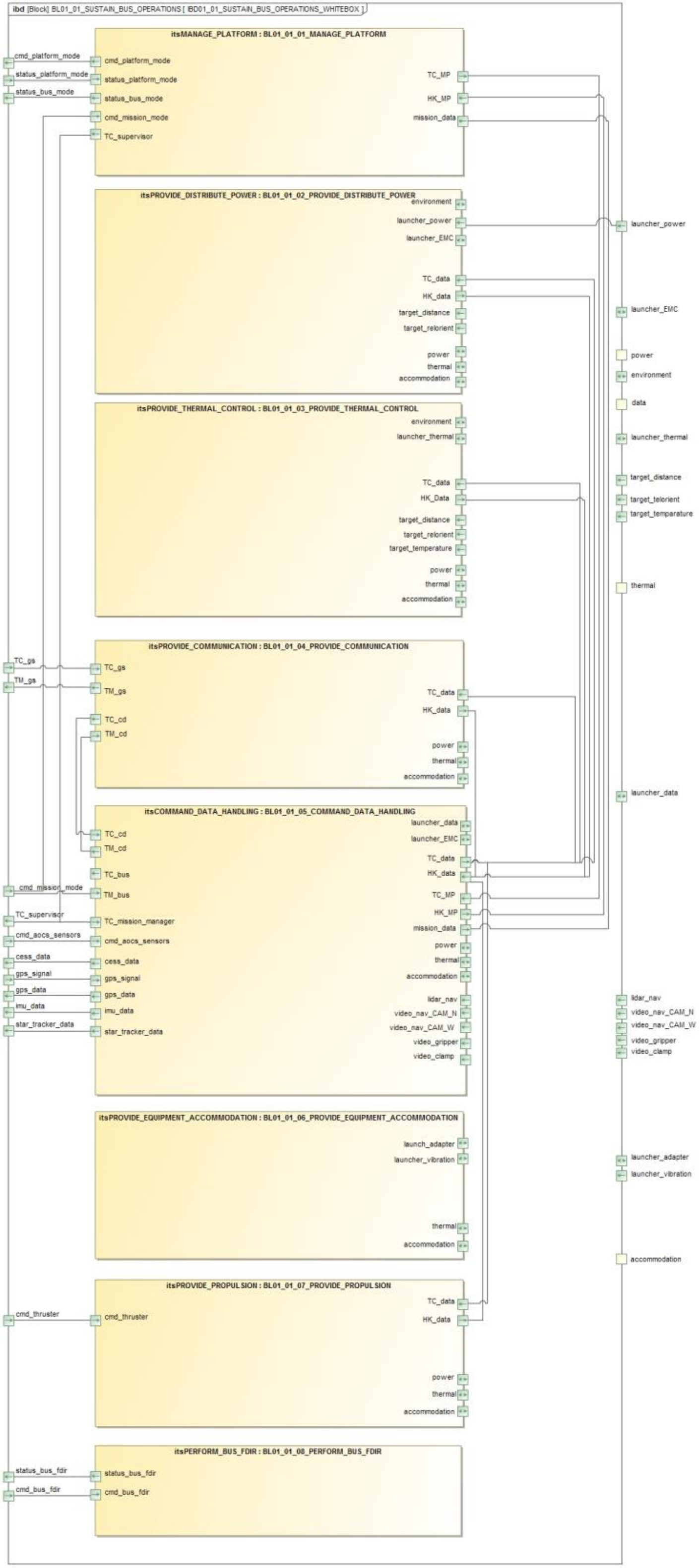
GNC / Robotic architecture and simulations including combined-control will be presented by Jürgen Telaar (Airbus DS) on Wednesday and Thursday

Clamping design will be presented by Marcin Wygachiewicz (SENER Sp. z o.o.) on Wednesday

# Functional decomposition

## Generation of the function tree, interfaces, control behavior and relations to the mission and system requirements

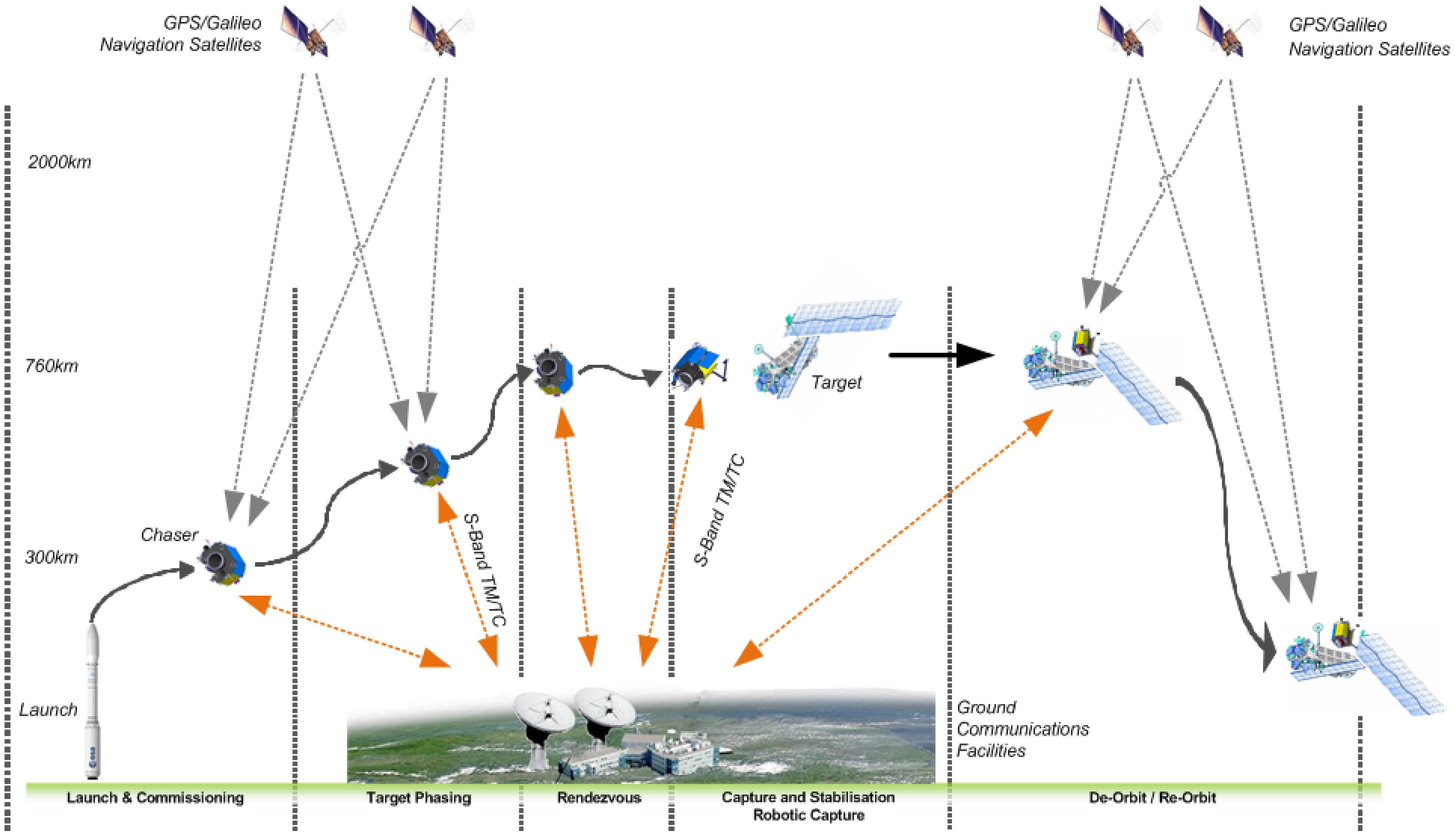


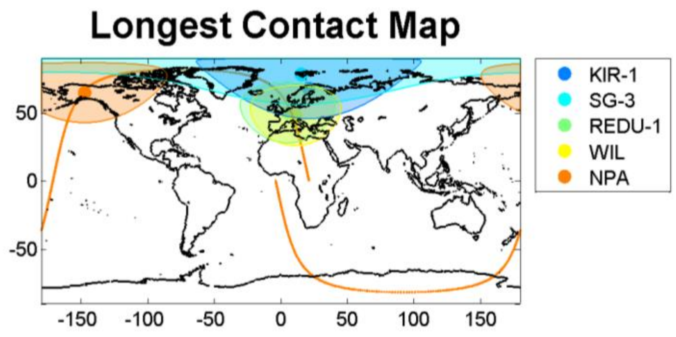


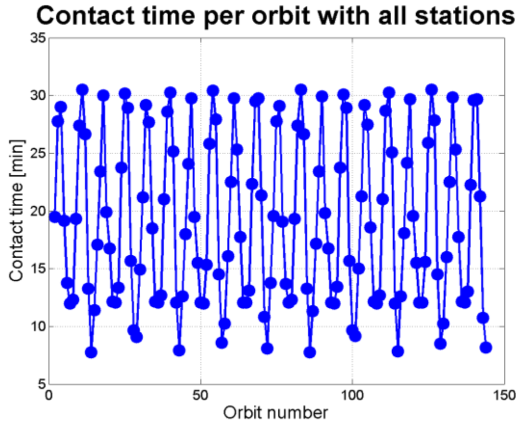
# Communications architecture

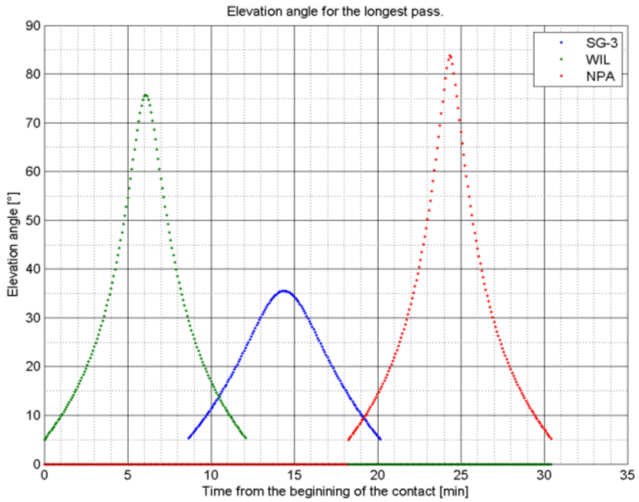
## Mission duration estimated to 3 months nominal, 6 months in total

- Selected ground stations: Weilheim, Redu, Kiruna, Svalbard and one station in the Fairbanks region (e.g. North Pole Alaska).
- Regular communication windows of more than 20 minutes can be provided.
- 10min of blockage free communications during capture can be provided.




Longest Contact Map


Contact time per orbit with all stations


Elevation angle for the longest pass.

AIRBUS DEFENCE & SPACE QinetiQ Space nv DLR SENER gmv INNOVATING SOLUTIONS

# Selection of the appropriate level of safety for the mission

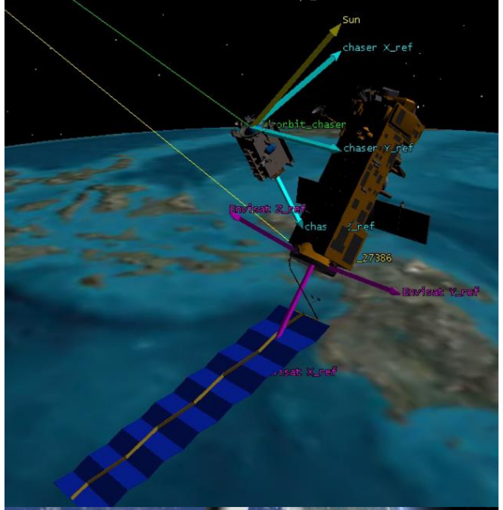
# Safety architecture

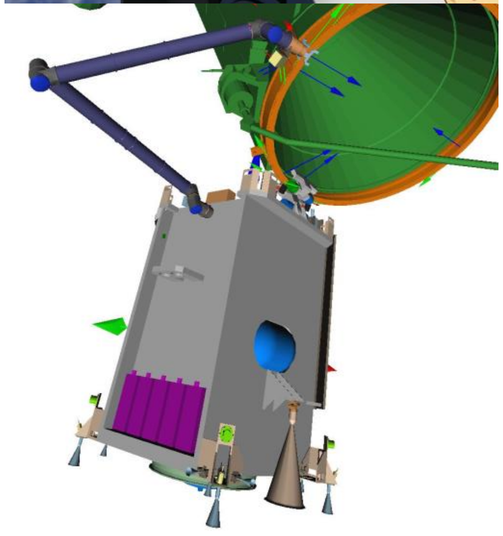
## An architecture has been defined for mitigating the main mission risks to a level compatible with the MSRD and therefore with the proper execution of the mission.

The team is confident that an acceptable level of mission risks can be reached if following combination of architectural decisions is implemented:

- Target status investigated right before the capture phase and system updated accordingly.
- Passive safe chaser trajectories implemented wherever possible.
- LIDAR as navigation primary sensor providing robust navigation data.
- The chaser relies on a high constrained automated vehicle with onboard monitoring for fail-safe behavior.
  All activities required to approach, synchronize, capture, stabilize, fix and deorbit the target can be performed automatically onboard with the associated monitoring functions using independent sensors.
- The share between onboard and ground activities that allows the maximum of mission planning and validation on ground and ground means to recover interactively from onboard failures. Check points are defined at the main transitions between the mission modes for guaranteeing a complete chaser check.
- A communications architecture that can avoid communication blockages during the duration of the grappling.
- Ground supervision and intervention in all critical phases and in particular during the capture with low latency (400ms).
- Extensive verification programme with on ground and in-orbit tests.

# Conclusion





- Further confirmation that the e.Deorbit mission is feasible wrt
  - Cost
  - Technologies
  - Schedule
  - Risk

- The required level of safety for the mission can be reached with a proper combination of the architectures and the definition of strong constraints on the mission

- Visual Navigation and GNC: Proper selection of the navigation cameras

- Robotics: Proper selection of the robot joint wrt torque limits

- Coupled-control approach is showing promising results

- Safety monitoring and FDIR: Further analysis and prototyping needed to establish a sounding baseline

- Communications assessment to be continued to better quantify the interferences

➡ **e.Deorbit can provide generic mission architectures and technology building blocks for reuse in OOS/Tug missions**