# HYBRID PROPULSION SOLUTIONS FOR SPACE DEBRIS REMEDIATION APPLICATIONS

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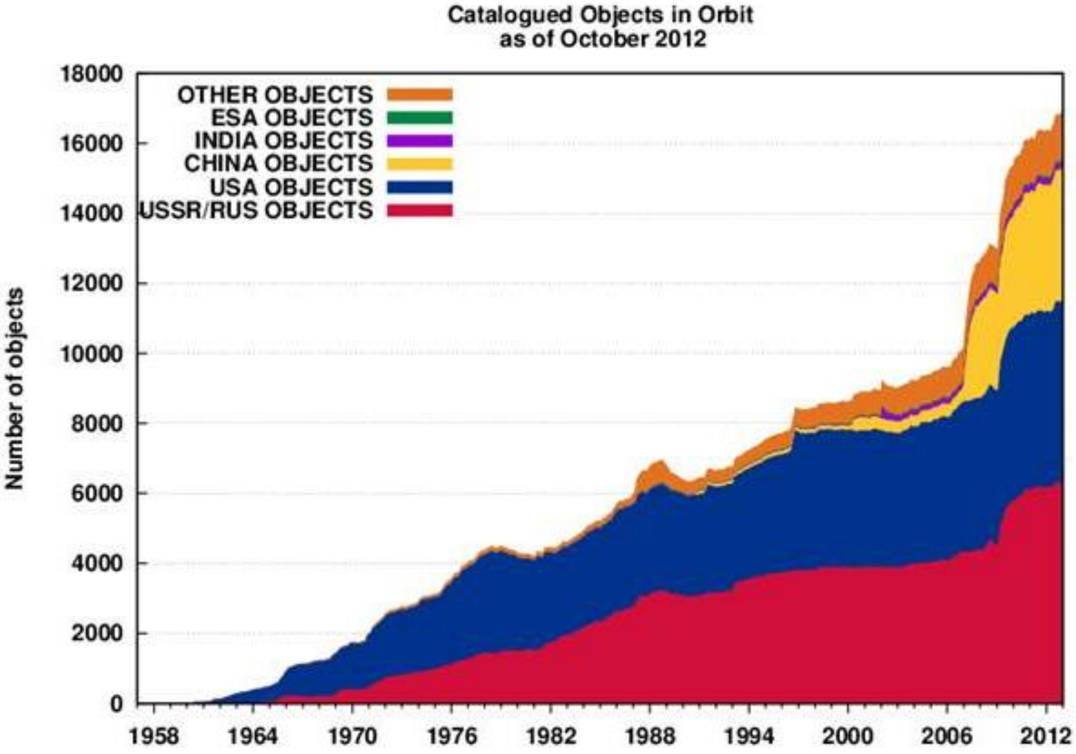
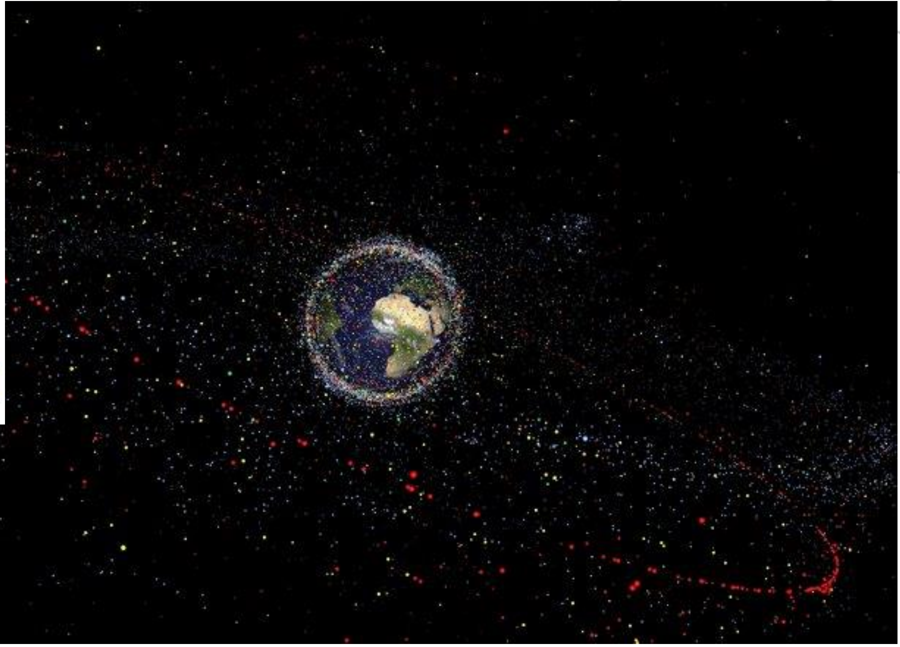
# Motivation



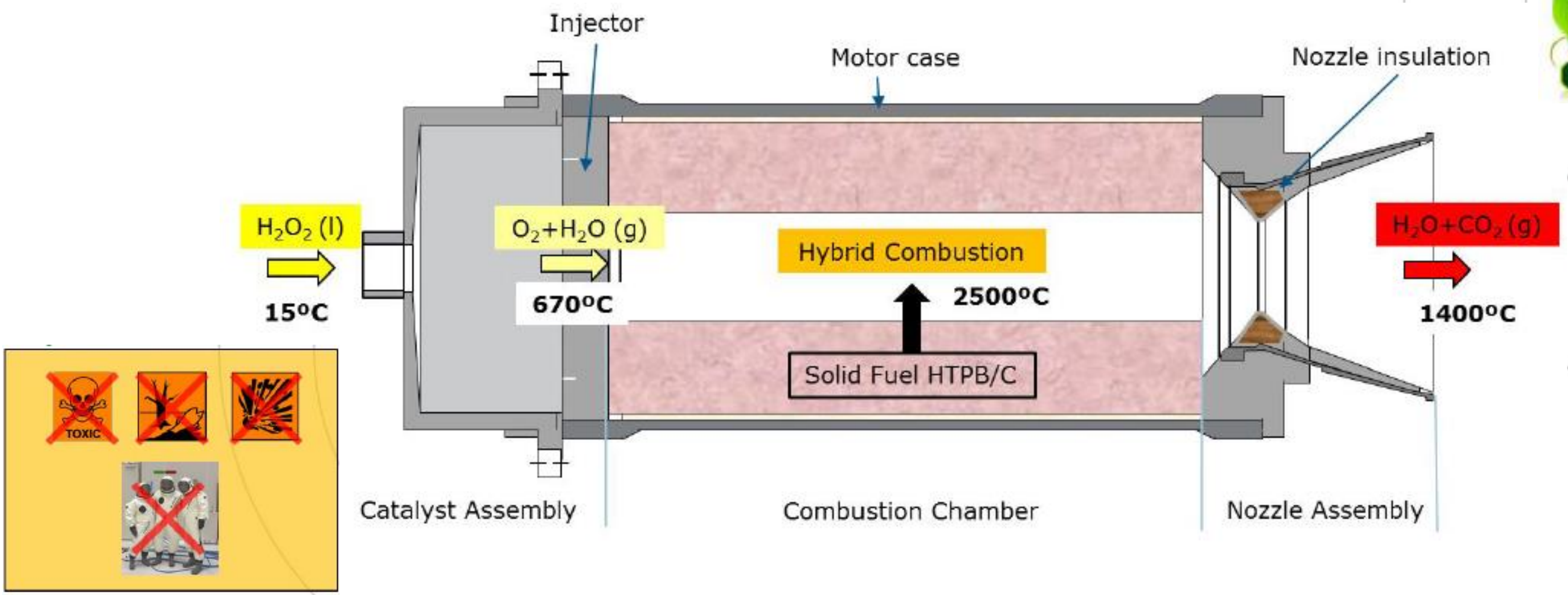
Catalogued Objects in Orbit
as of October 2012



# Framework

- 1 year study carried out by Nammo Raufoss and Elecnor Deimos.
- Funded under the ESA General Studies Programme (GSP).
- Project end: beginning of July 2016.
- Main objective of the study: investigating the implementation of a propulsion system based on hybrid rocket technology for active debris remediation (ADR) missions, and preliminary assessing its design, performance metrics and required delta-development (TRL).
- Interest in considering alternative solutions to conventional bi-propellant systems that could address the need for the recurrent use of a ADR dedicated system.
- Hybrid propulsion systems are based on non-toxic and particles-free propellants and have already proved to be competitive and reliable in the thrust range compatible with space debris remediation missions.

# Hybrid Propulsion



# Study Content

- Competences in mission analysis (Deimos) and hybrid propulsion (Nammo) have been combined to perform the study.
- Mission analysis:
  - Detailed survey of ESA and European LEO missions
  - Orbital maneuvers sizing:
    - Transfer to target orbit
    - Approach to target
    - De-orbit and re-entry
- Propulsion system assessment:
  - Implementation of models:
    - Simplified mass budget estimation → Tsiolkovsky
    - Detailed modeling
  - Sizing of selected scenarios
  - Comparison with bipropellant system
  - Assessment of TRL and missing development required to flight qualification

# General Requirements

- Functions: a dedicated satellite, the chaser, is sent to target, capture and deorbit a single object in space. So the chaser is fully independent once released by the launcher in its injection orbit.
- Launcher: Vega.
- Maximum acceleration: a strict requirement is enforced.

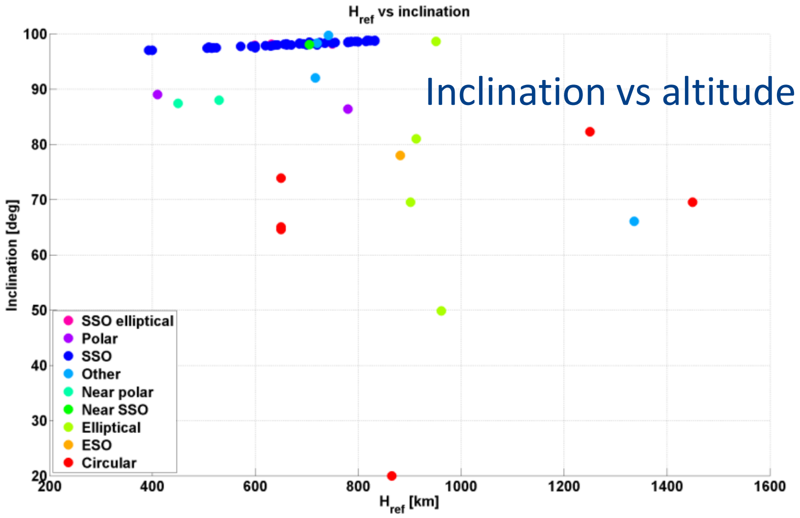
  In compliance with ESA approach, this study considers a value of 0.04g.
- Propulsion system:

| Function # | ID name | Description |
|---|---|---|
| F1 | Targeting | Hybrid<br>87.5% H2O2-HTPB/HDPE |
| F2 | RDV | Monopropellant<br>87.5% H2O2 |
| F3 | Deorbiting | Hybrid<br>87.5% H2O2- HTPB/HDPE |
| F4 | RCS | Monopropellant<br>87.5% H2O2 |

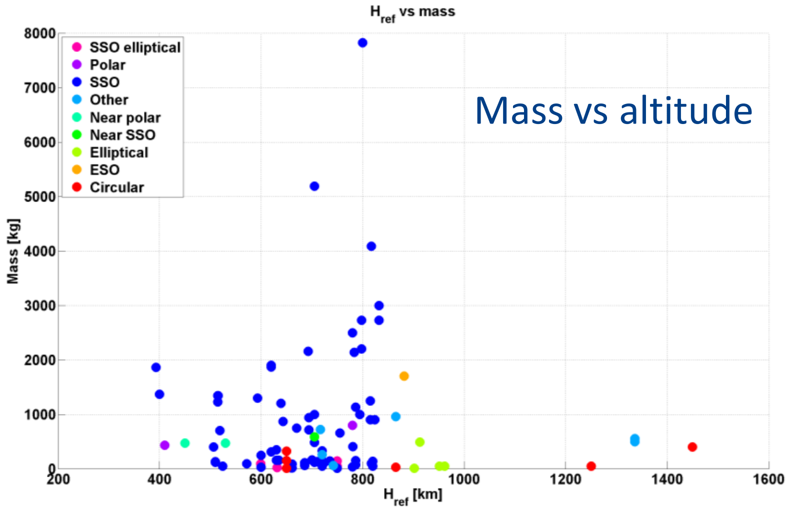
- Margins are applied both to ΔVs and dry masses in proportion to the level of uncertainty.

# Mission Scenarios: Debris Population

- Focus on ESA, ESA member states and ESA cooperating states LEO missions, considering in-orbit, under current design and future missions.
- 80% of the missions are in SSO, polar orbits or near to them.
- Focused scenarios: SSO between 350 km and 850 km with satellite masses from 10 kg to 8000 kg. → 130 missions identified to be potential object of study for ADR analyses.
- Information retrieved: mission name, launch date, agency or organization, spacecraft mass and average cross section, orbit type, orbit reference altitude and inclination and propulsion system embarked.



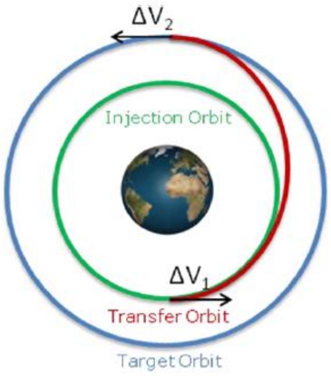
Inclination vs altitude

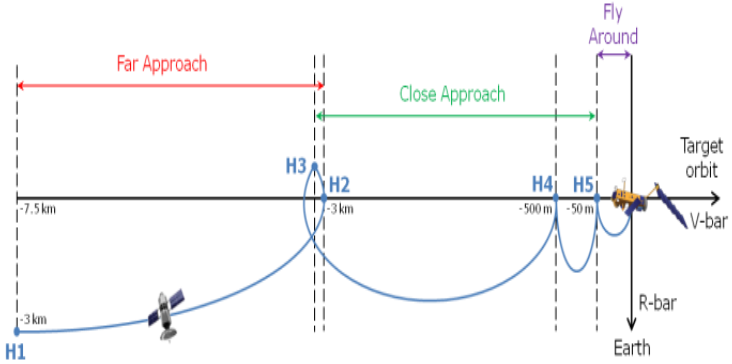


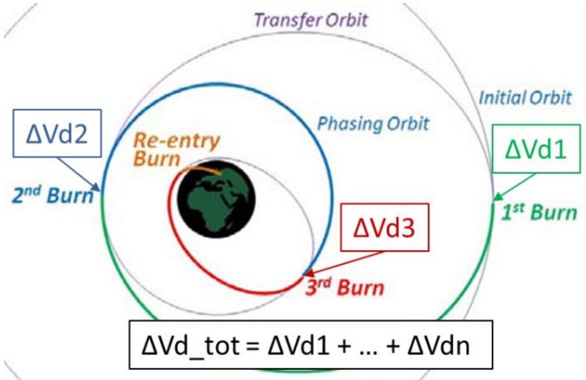
Mass vs altitude

# Mission Scenarios: Maneuvers

- Three different propulsive phases have been considered and sized:
  - Transfer to target orbit, Vega as baseline launcher
    - The highest mass at the target orbit is achieved when the injection altitude is the lowest possible: 300 km
    - Orbital raising to target orbit is performed by the chaser itself.
  - Approach to target:
    - Far range rendezvous;
    - Close range rendezvous.
  - De-orbit and controlled re-entry over SPOA (60 km altitude):
    - For the thrust-to-mass ratios considered in the study, gravity losses are negligible (<1%) and thus the number of maneuvers does not affect significantly the total delta-V expenditure for the disposal phase.





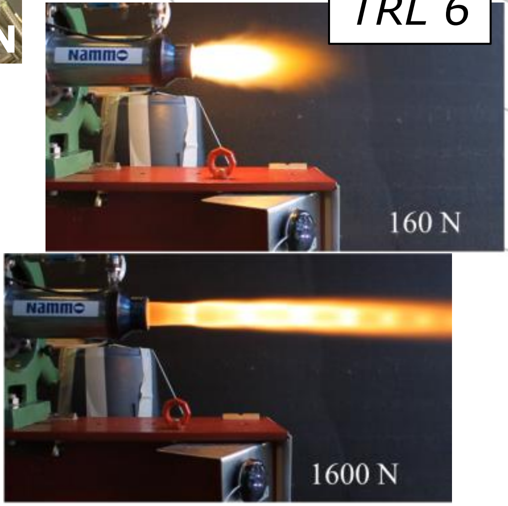


# Propulsion System Architecture

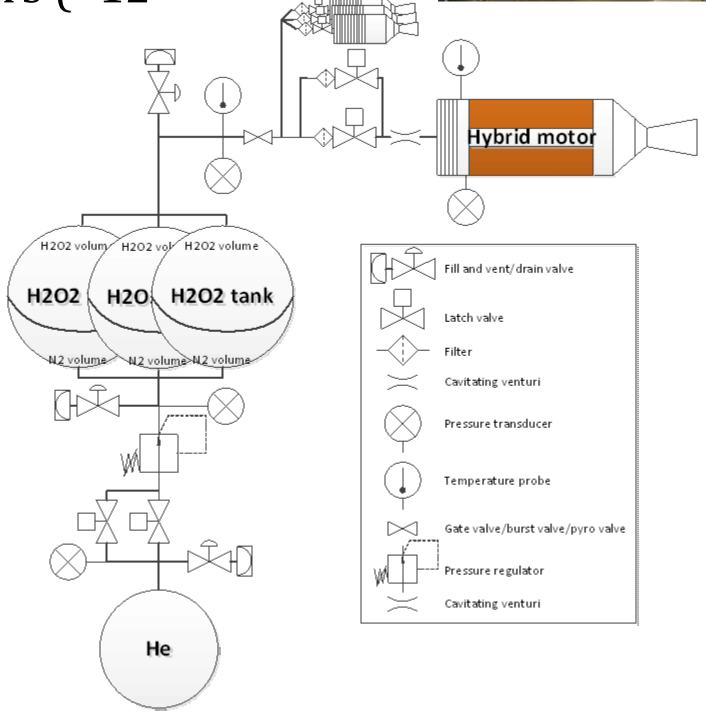
- The main propulsion system is composed by 1 hybrid motor responsible for targeting and deorbiting maneuvers.
- Rendezvous and attitude control are performed by a RCS system composed by 12 monopropellant thrusters (+12 redundant).

TRL 6

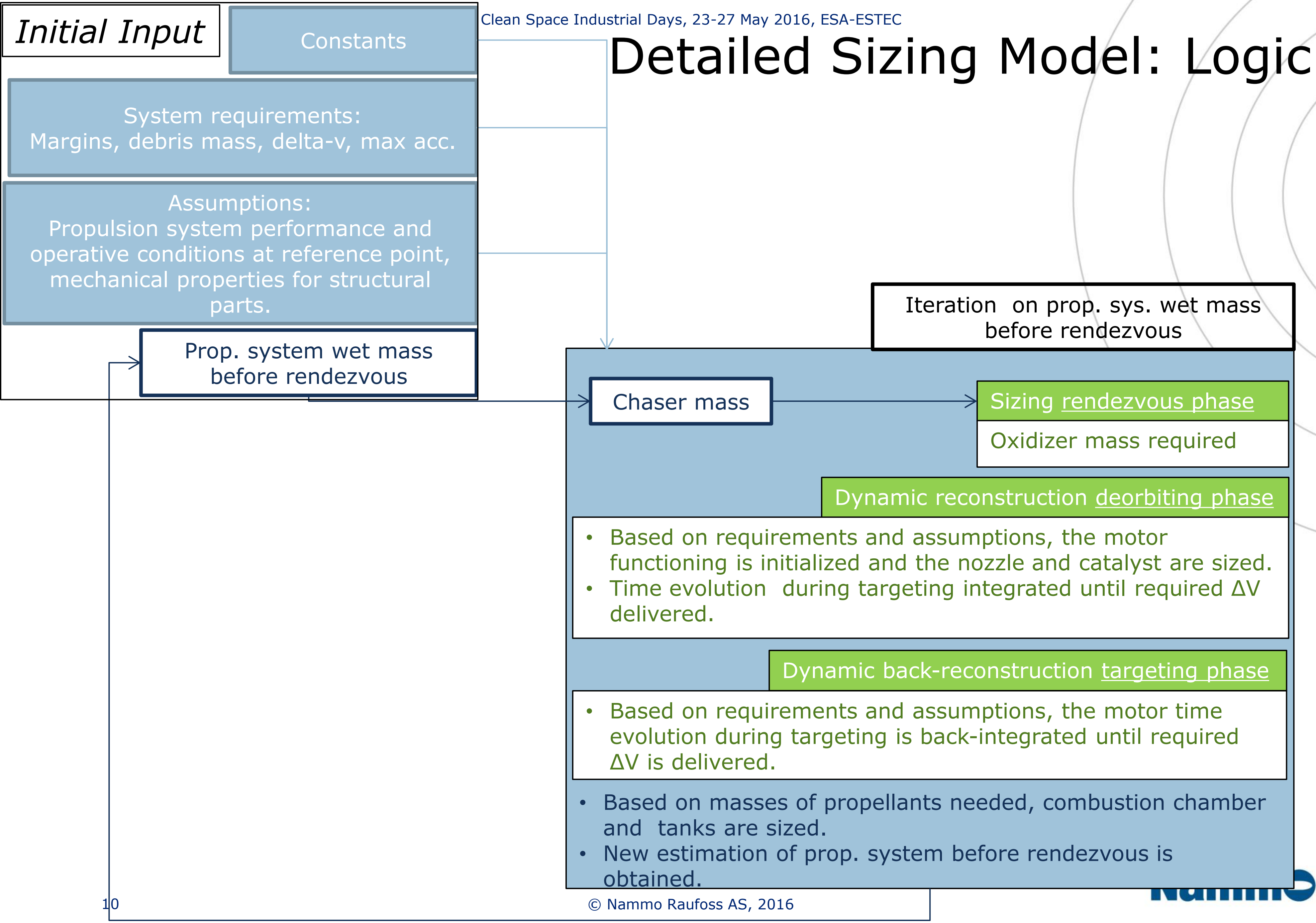
TRL 6



TRL 5



# Detailed Sizing Model: Logic



*Initial Input*

Constants

System requirements:
Margins, debris mass, delta-v, max acc.

Assumptions:
Propulsion system performance and operative conditions at reference point, mechanical properties for structural parts.

Prop. system wet mass before rendezvous

Iteration on prop. sys. wet mass before rendezvous

Chaser mass

**Sizing rendezvous phase**

Oxidizer mass required

**Dynamic reconstruction deorbiting phase**

- Based on requirements and assumptions, the motor functioning is initialized and the nozzle and catalyst are sized.
- Time evolution during targeting integrated until required ΔV delivered.

**Dynamic back-reconstruction targeting phase**

- Based on requirements and assumptions, the motor time evolution during targeting is back-integrated until required ΔV is delivered.

- Based on masses of propellants needed, combustion chamber and tanks are sized.
- New estimation of prop. system before rendezvous is obtained.

# Considered Scenarios

| # | Debris mass [kg] – altitude [km] | ΔVs [m/s] (with margins)<br>• Targeting<br>• RDV and RCS<br>• Deorbiting | Max acc [g] | Thrust class [N] – tot burning time [min] |
|---|---|---|---|---|
| 1 | 1366 - 400 | • 61<br>• 36<br>• 103 | 0.04 | 600 – 4.5 |
| 2 | 2157 - 693 | • 228<br>• 36<br>• 184 | 0.04 | 1000 – 9 |
| 2 b | | | 0.08 | 2000 – 4.5 |
| 3 | 400 - 506 | • 122<br>• 36<br>• 132 | 0.04 | 200 – 7 |
| 4 | 1300 - 593 | • 171<br>• 36<br>• 156 | 0.04 | 600 – 7.5 |

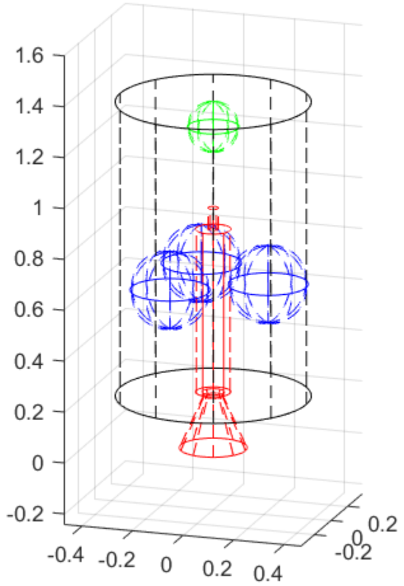
# Example of Output: Scenario 1

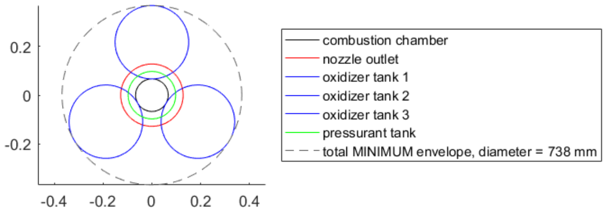
- Debris mass: 1366 kg
- Delta-v targeting: 58 m/s
- Delta-v rendezvous and RCS: 36 m/s
- Delta-v deorbiting: 98 m/s

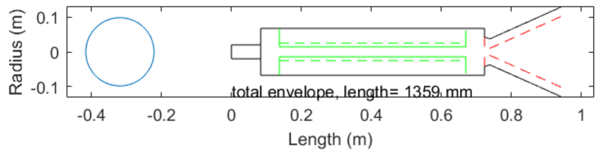
| | Targeting phase | Rendezvous phase | Deorbiting phase |
|---|---|---|---|
| Consumed propellant [kg] | 4 | 5 | 53 |
| Burning time [s] | 21 | 30 | 269 |
| Peak thrust [N] | 614 | 20 | 614 |
| Peak acceleration [m/s$^2$] | 3.03 | 1.19 | 0.39 |
| Initial system mass [kg] | 206 | 202 | 1563 |

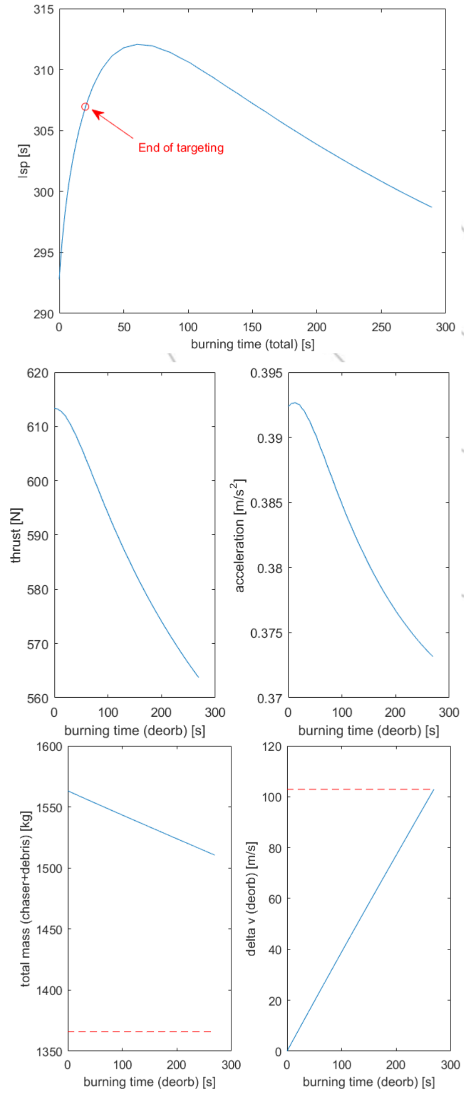
<u>PROPULSION SYSTEM SIZE</u> (margins included):

| | | |
|---|---|---|
| • Propulsion system wet mass: | 81.9 | kg |
| • Propulsion system dry mass: | 20.1 | kg |
| • Hybrid motor total envelope w nozzle (AR 100), DxL: | 0.256x0.943 | m |
| • Hybrid motor total envelope w/o nozzle, DxL: | 0.134x0.724 | m |
| • Oxidizer tank capacity: | 42 | lt |
| • Oxidizer tank outer diameter (x3): | 0.302 | m |
| • Pressurizing gas tank capacity: | 4 | lt |
| • Pressur. gas tank outer diameter: | 0.195 | m |





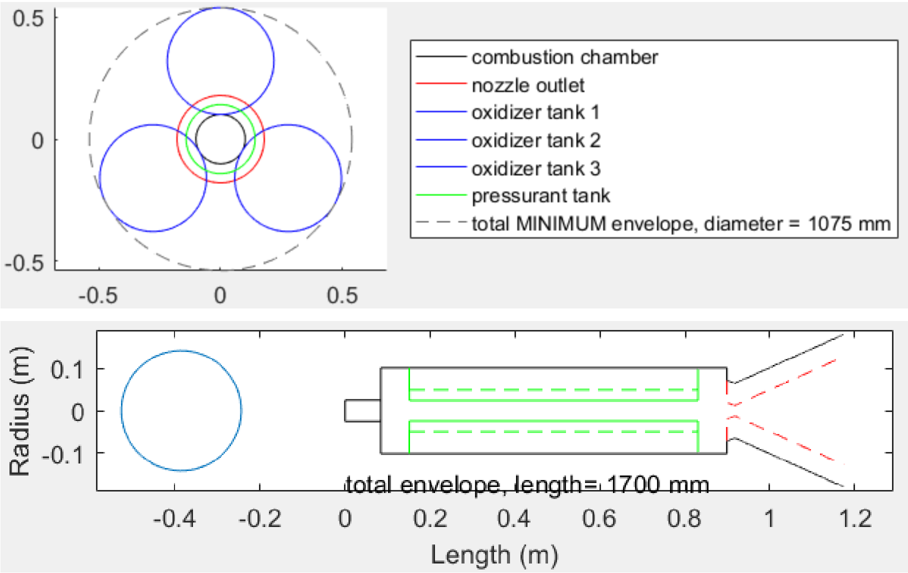




# Scenario 2, Acceleration Comparison

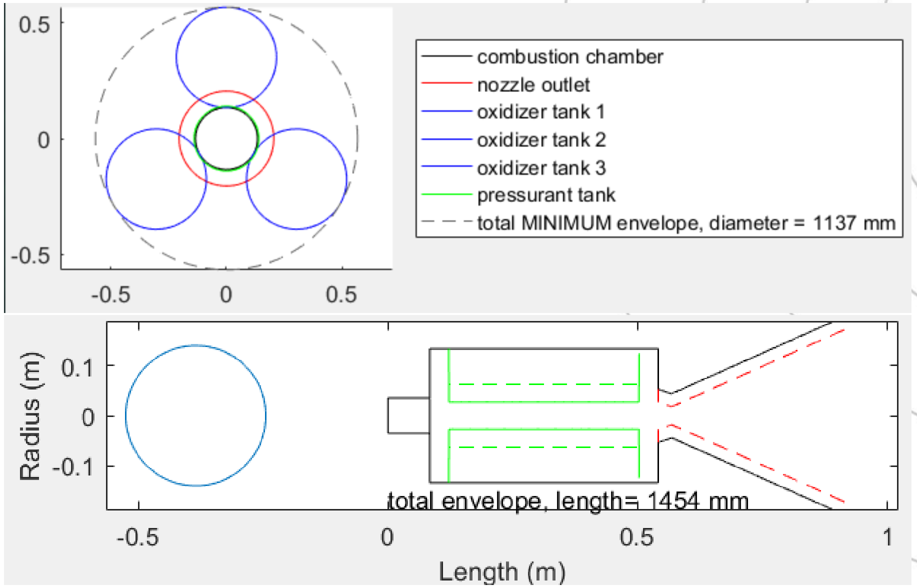
- Debris mass: 2157 kg
- Delta-v targeting: 217 m/s
- Delta-v rendezvous and RCS: 36 m/s
- Delta-v deorbiting: 175 m/s

- Maximum allowed acceleration = 0.04 g:



- PROPULSION SYSTEM SIZE (margins included):
- Propulsion system wet mass: 235.9 kg
- Propulsion system dry mass: 49.3 kg
- Hybrid motor total envelope w nozzle (AR 100), DxL: 0.357 x 1.173 m
- Hybrid motor total envelope w/o nozzle, DxL: 0.202 x 0.899 m
- Oxidizer tank capacity: 129 lt
- Oxidizer tank outer diameter (spherical x3): 0.437 m
- Pressurizing gas tank capacity: 11 lt
- Pressurizing gas tank outer diameter (spherical): 0.282 m

- Maximum allowed acceleration = 0.08 g:



- PROPULSION SYSTEM SIZE (margins included):
- Propulsion system wet mass: 229.5 kg
- Propulsion system dry mass: 45.3 kg
- Hybrid motor total envelope w nozzle (AR 100), DxL: 0.411 x 0.929 m
- Hybrid motor total envelope w/o nozzle, DxL: 0.268 x 0.541 m
- Oxidizer tank capacity: 127 lt
- Oxidizer tank outer diameter (spherical x3): 0.434 m
- Pressurizing gas tank capacity: 11 lt
- Pressurizing gas tank outer diameter (spherical): 0.281 m

# Study Further Tasks

- Further steps in the study, not yet concluded but already ongoing:
  - sizing for ENVISAT;
  - assessing the TRL of the main components and technologies included in the considered hybrid propulsion system and identifying the delta-development effort required to bring them to a ready to flight status;
  - comparing the appraised scenarios based on hybrid propulsion with the corresponding conventional bi-propellant system in order to highlight the benefits of choosing a hybrid system;
  - out looking at the suitability of the considered hybrid propulsion system for upcoming ESA missions as a propulsion kit addressing debris mitigation requirements.

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## Thank you.
## Questions?

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