Polyhymnia Space Mission

Group E

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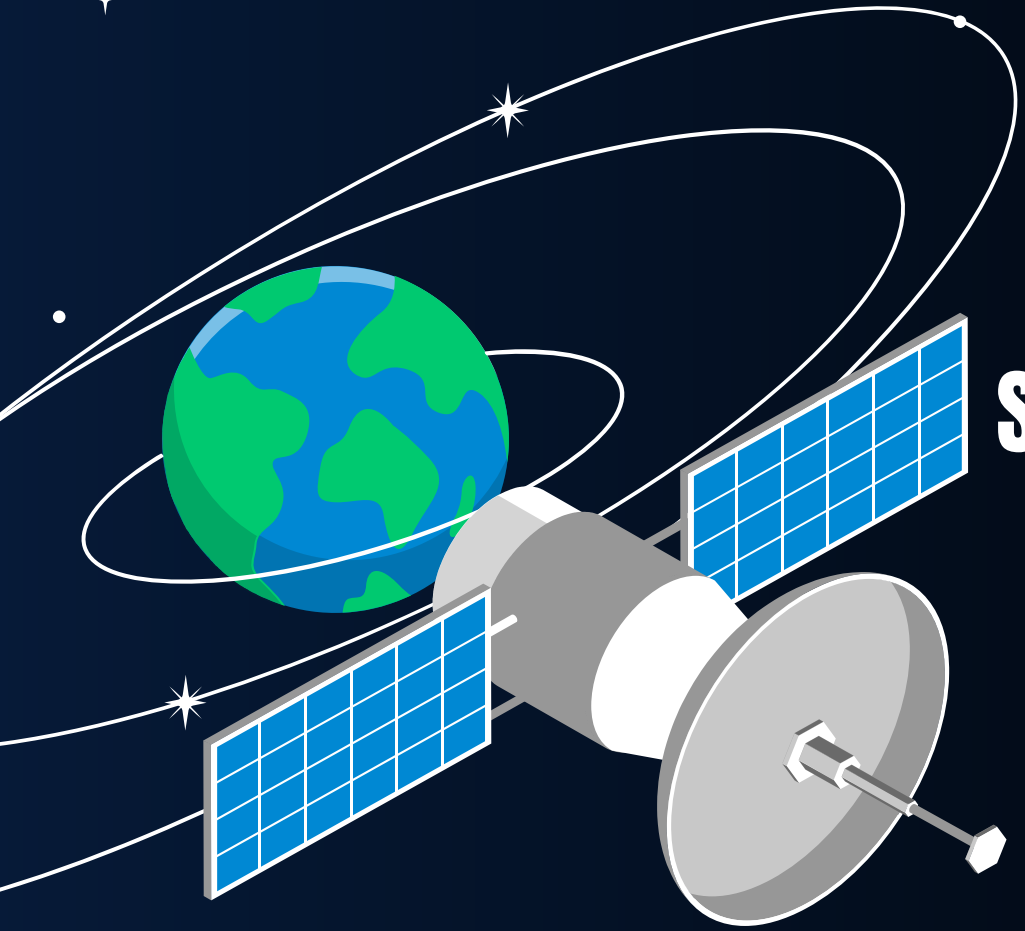
Friday, September 13, 2024

ESA Academy

Summary of our task

1. Space debris mitigation requirements
2. Mission profile
3. Representative model of the satellite
4. Impact risk of micrometeoroids and space debris
5. Collision avoidance strategy
6. Disposal plan
7. Results



01
SPACE DEBRIS MITIGATION REQUIREMENTS

Space Debris mitigation requirements 1/2

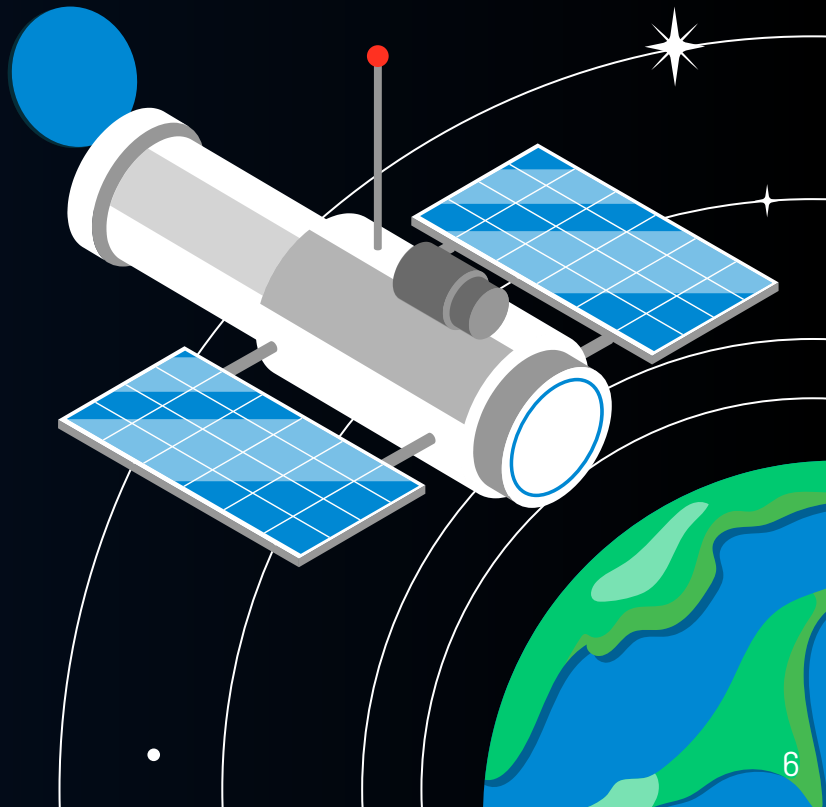
Requirement type	Requirement number	Description
Disposal	REQ-010	The satellite shall clear its orbit in maximum of 5 years after the end of its functional lifetime
Disposal	REQ-020	Probability of successful disposal of at least 90%
Disposal	REQ-070	Propellant residual volume shall be less than 1% of the tank capacity
Disposal	REQ-080	Casualty risk of better than 10^-4 from uncontrolled entry; can be worse than 10^-4 for controlled re-entry

Space Debris mitigation requirements 2/2

Requirement type	Requirement number	Description
Design	REQ-050	The spacecraft fuel tank pressurant shall be less than 5 bars
Design	REQ-060	The spacecraft propellant tank pressure shall be less than 5.5 – 6 bar
Collision	REQ-030	Cumulative collision probability better than 10^-3 for objects that are greater than 1 cm in size
Operations	REQ-040	The mission operations shall ensure the reduction of the risk of accidental break-up and consequent generation of space debris, caused by on-board sources of energy or failure of mechanical parts

02

MISSION PROFILE



Mission timeline

2024

IN-ORBIT

1. the impact risk of micrometeoroids and space debris
2. collision avoidance strategy

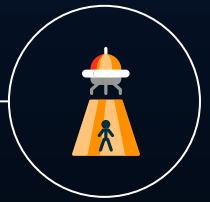
2034

DISPOSAL

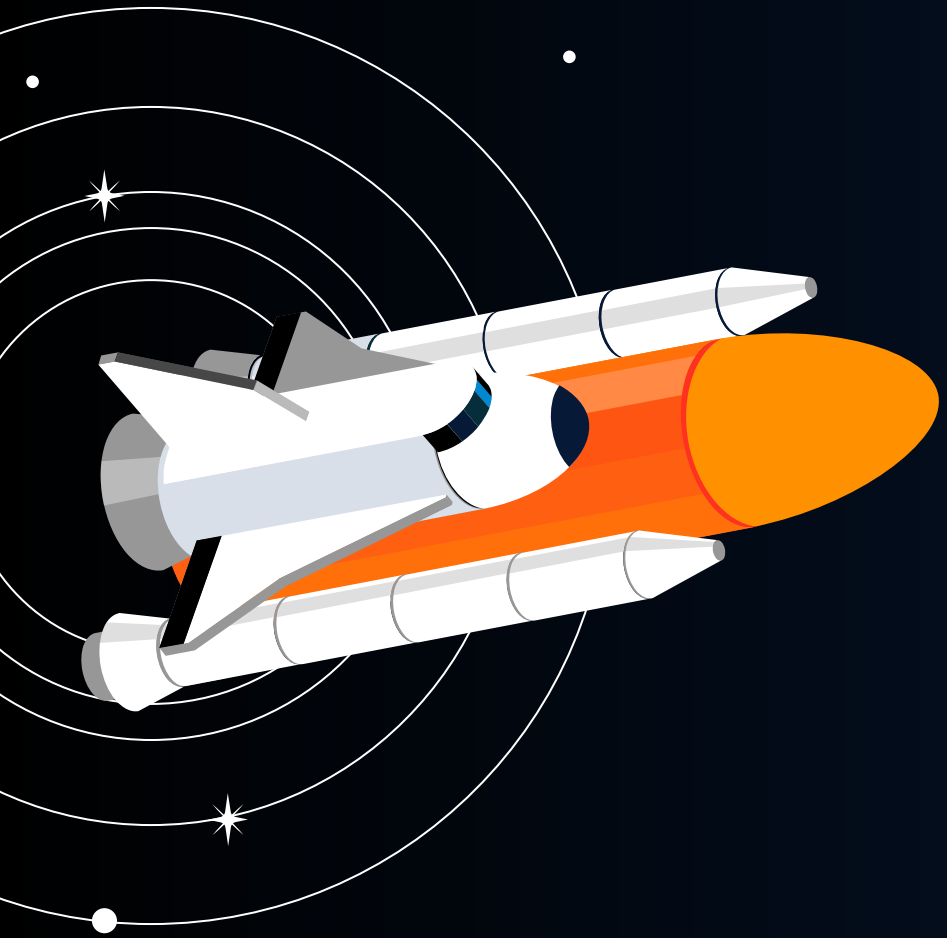
3 strategies:

1. controlled re-entry
2. uncontrolled re-entry - 7 year passive
3. hybrid-controlled re-entry - delayed 2.3 years

2039



GROUND RISK ASSESSMENT



03

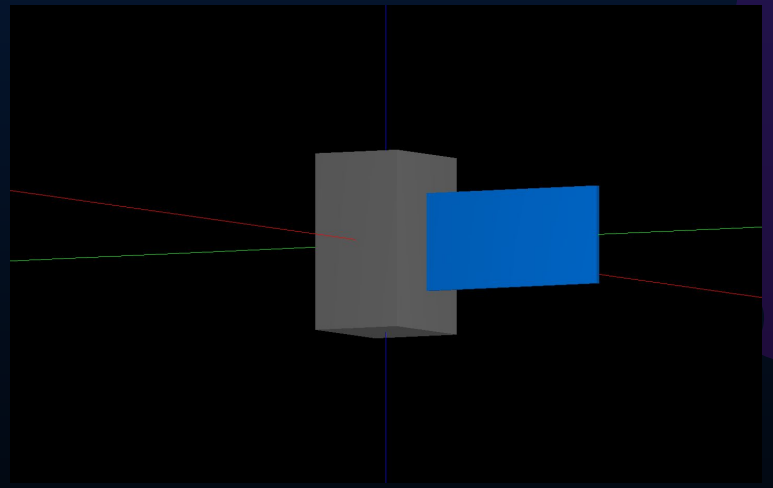
REPRESENTATIVE MODEL

Representative Model - Croc

Parameters used in the DRAMA tools:

- Spacecraft:
  - 3.4 m height, 1.8 m width, 2.35 m depth
  - Solar panels: 1.88 m height, 3.76 m depth (surface area of 7.1 m^2 - Sentinel-2 model)
  - General drag coefficient 2.2 (constant)
  - Operational lifetime 10 years
  - Dry Mass 1000 kg
  - SMA 780 km
- Space Environment
  - LEO environment
- Orbit Parameters

Average Cross Section: 12 m^2

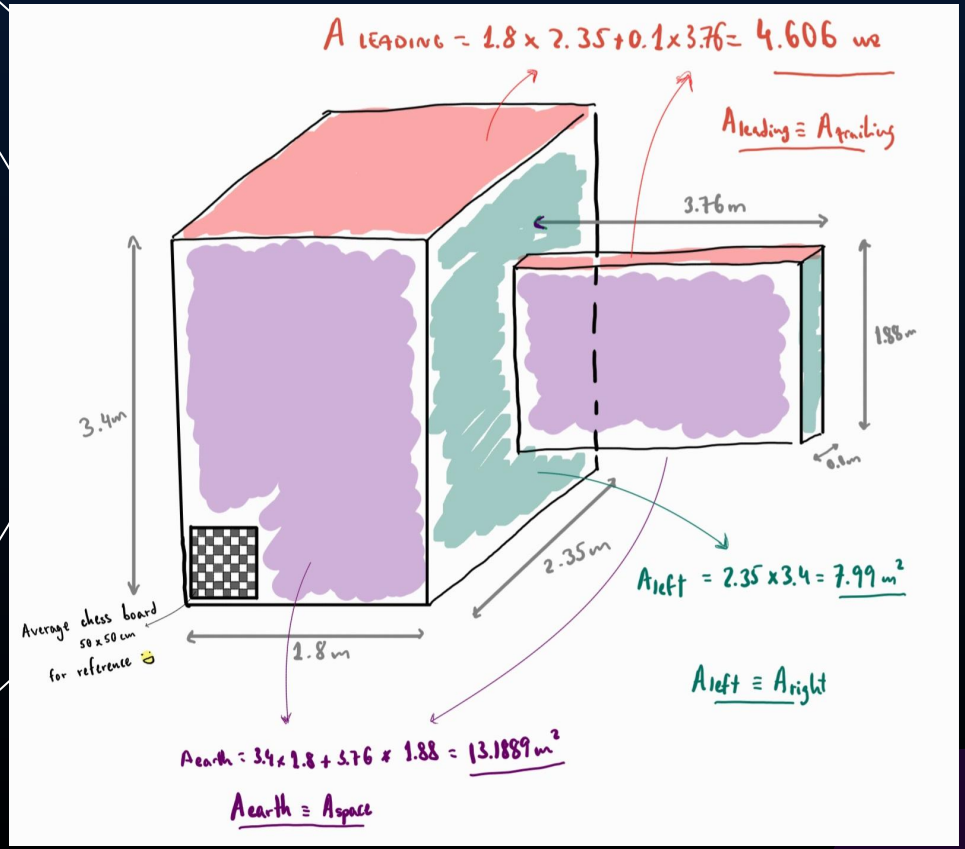


Single Averaged Elements	
Semi-major axis / km	7151.0
Eccentricity / -	8.25E-5
Inclination / deg	98.6
Right asc. of asc. node / deg	60
Argument of perigee / deg	80

04

IMPACT RISK WITH MICROMETEORITES AND SPACE DEBRIS

MIDAS ANALYSIS



Surface Definition

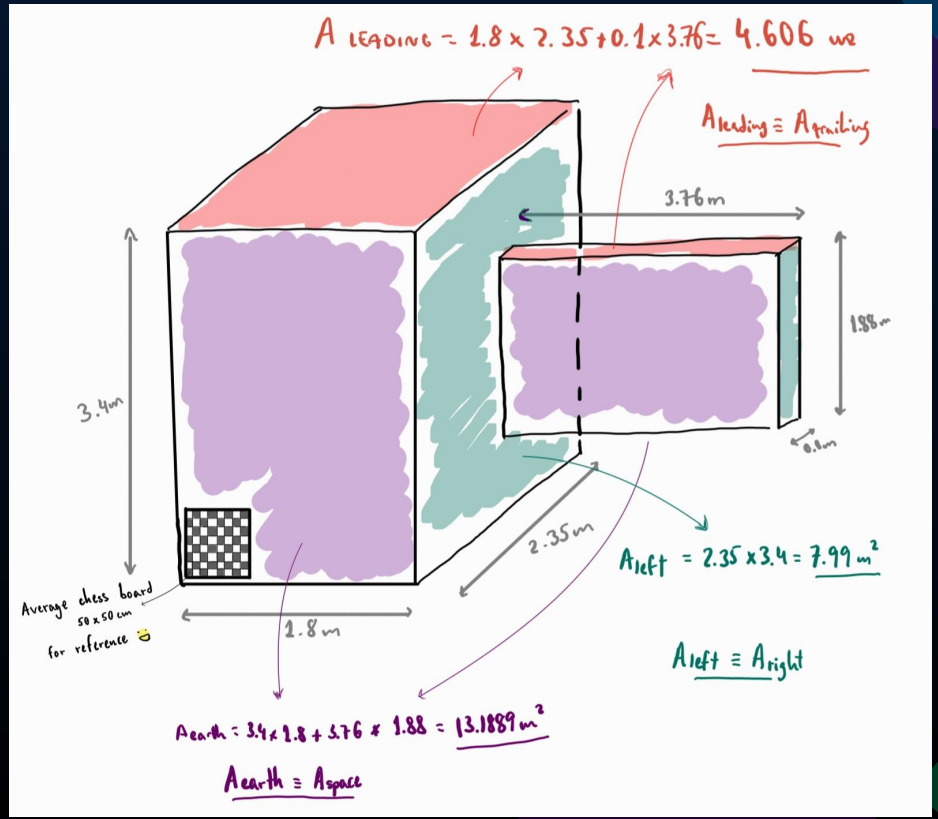
Switch (On/Off)	Earth-oriented
Azimuth [deg]	0.0
Elevation [deg]	90.0
Surface area / m^2	13.1889
Surface designation	Space

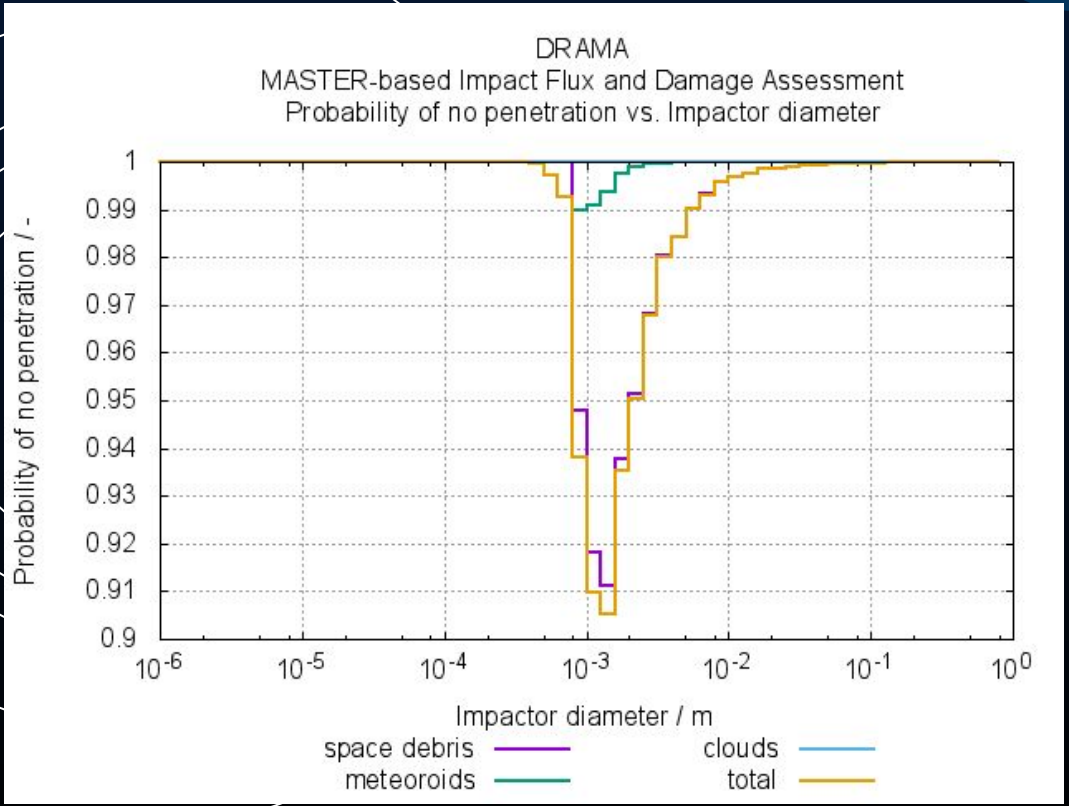
Surface Definition

Switch (On/Off)	Earth-oriented
Azimuth [deg]	0.0
Elevation [deg]	0.0
Surface area / m^2	4.606
Surface designation	Leading

Surface Definition

Switch (On/Off)	Earth-oriented
Azimuth [deg]	-90.0
Elevation [deg]	0.0
Surface area / m^2	7.99
Surface designation	Left

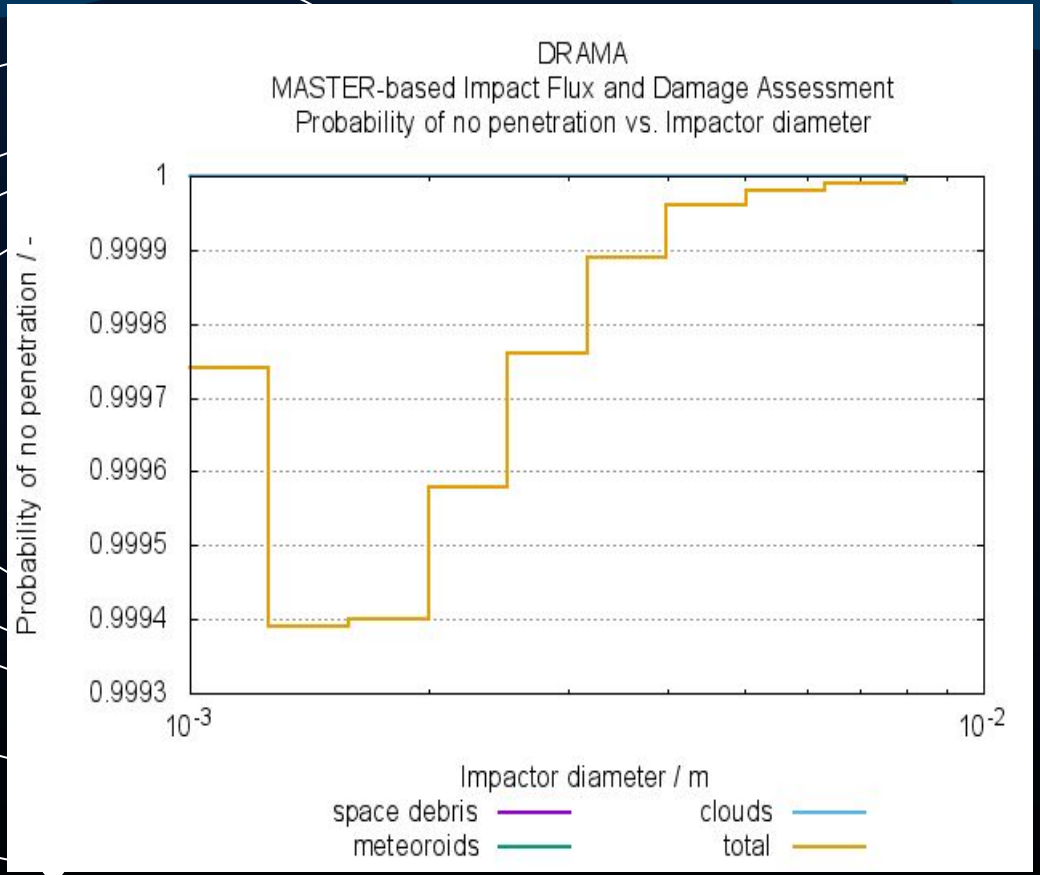




First iteration:

- Full computation of the lifetime (10 years)
- Every object between 10^-6 and 1 m diameter taken into account
- 6 surfaces with equal walls:
  - Aluminium walls (*Cour-Palais thin plate*)
  - 0.5cm thickness

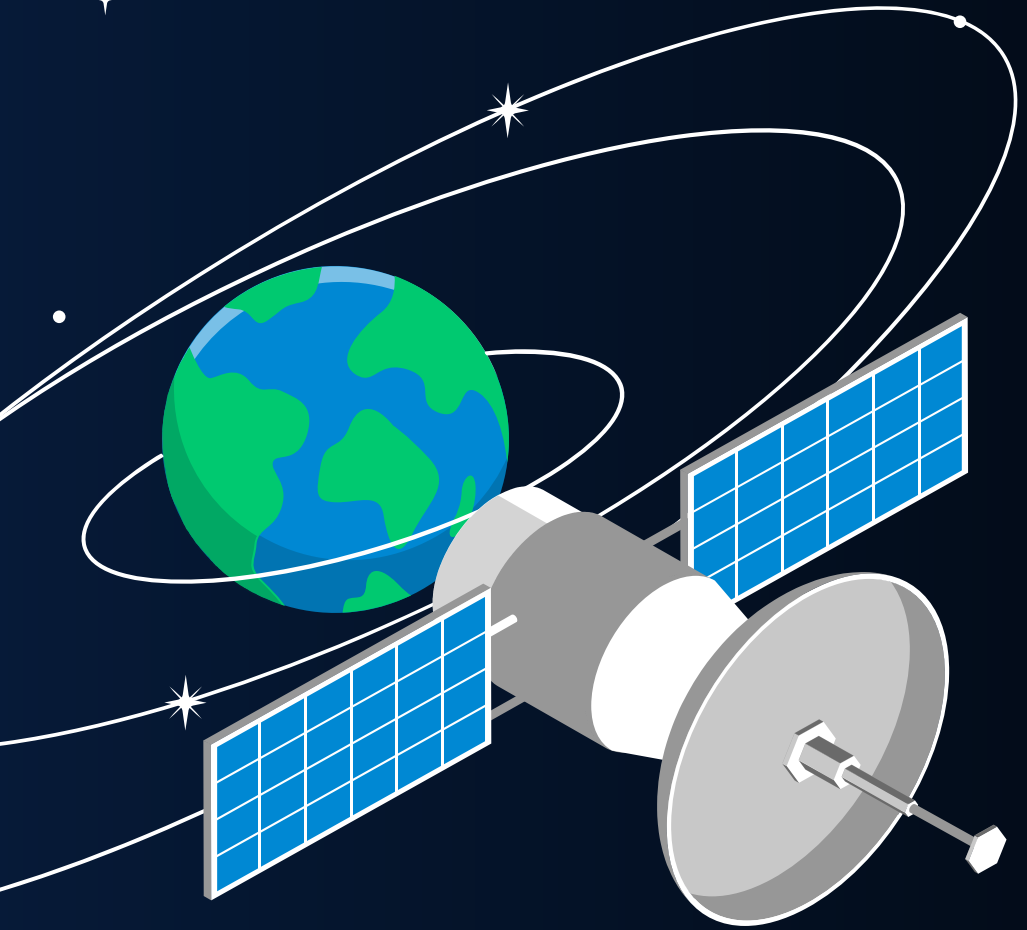
Leading face ~10% penetration
Cross faces (Earth, Space, Left, Right) ~1% penetration
Trailing face ~0.014% penetration



Second Iteration:

- Small computation of the lifetime (1 year)
- Objects between 1 mm and 1 cm
- Slightly different walls:
  - 2 cm thickness for Leading face
  - 1 cm thickness for surrounding cross-faces
  - 0.5 cm thickness for trailing face

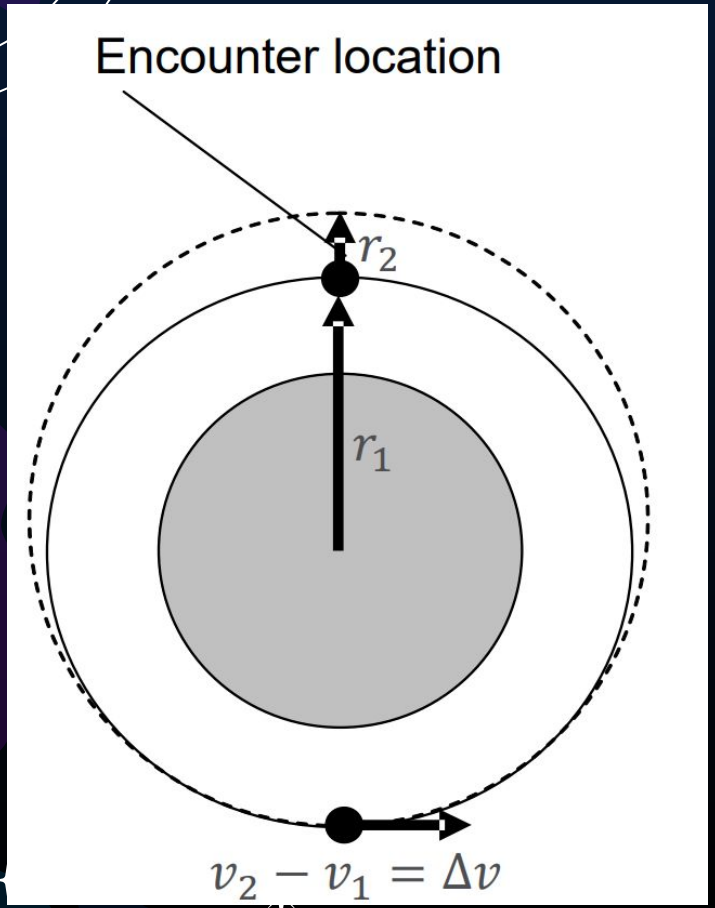
Leading face ~0.06% penetration
Cross faces (Earth, Space, Left, Right) ~0.05% penetration
Trailing face ~0.014% penetration



05

COLLISION AVOIDANCE

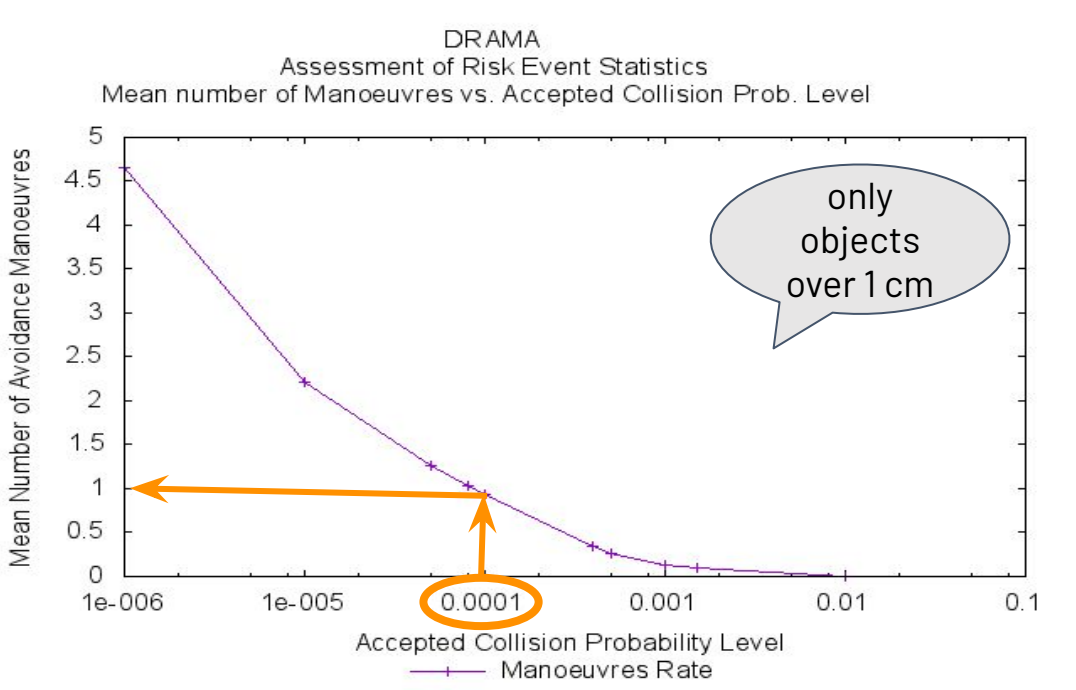
STRATEGY



- **Short-term manoeuvre strategy**:

  Along track Δv half a revolution before TCA
- REQ-030 cumulative collision probability of **at least 10^-4** for objects that are **greater than 1 cm** in size

ARES Analysis

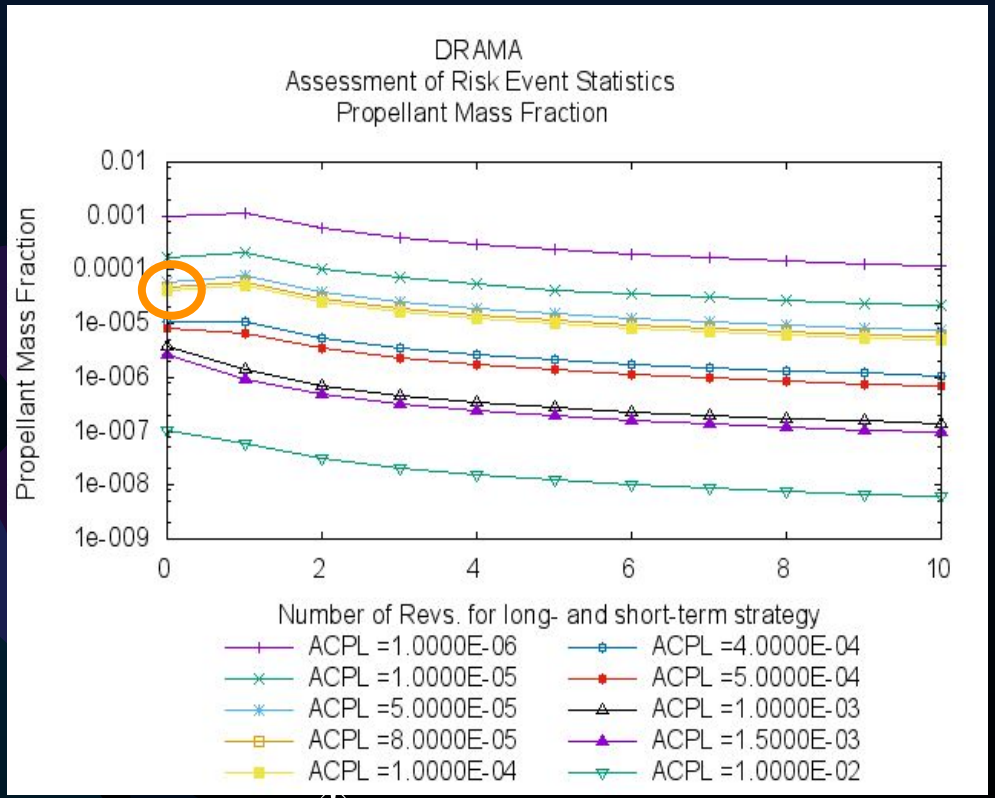


Input assumptions:

- Spacecraft radius : 1.9544 m (CROC)
- Cross-section area: 12 m^2 and using the assumption of a circular area
- Analysis epoch: 2016/11/01 (DRAMA population reference)

⇒ Mean number of Avoidance Manoeuvers = 1 / year

ARES Analysis



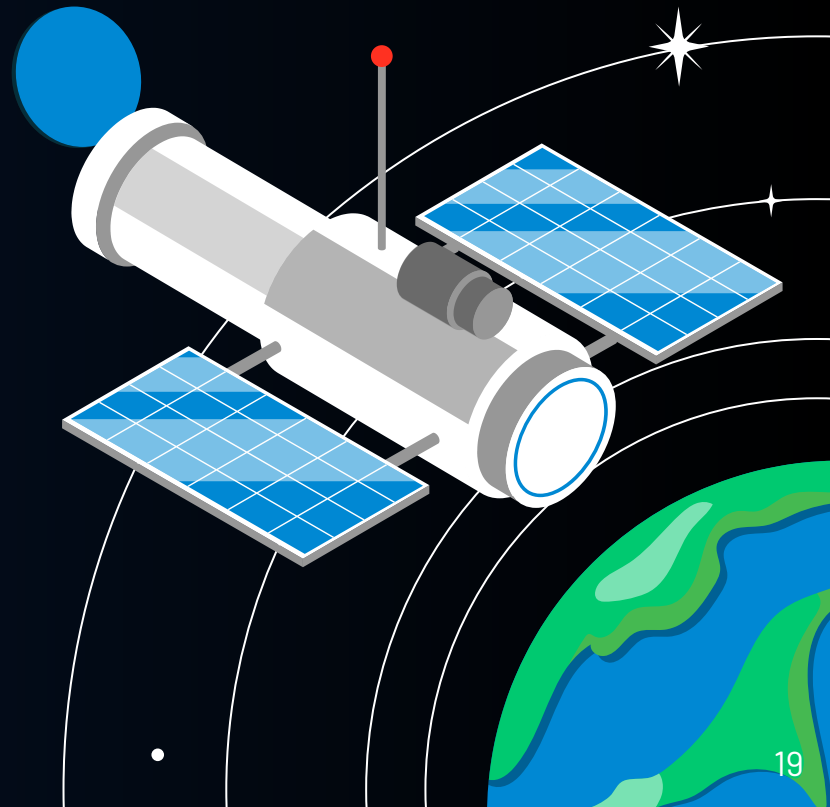
- accepted collision probability = **10^-4** (yellow line)
- short term strategy - manoeuvre performed ½ revolutions before re-entry ⇒ **propellant mass fraction = 0.3989E-04**
- **propellant mass** = 1000 kg * 0.3989E-04 = **39 g / year** to perform 1 avoidance maneuver

! We must return in our desired orbit after each avoidance maneuver ⇒ **78 g propellant / year**

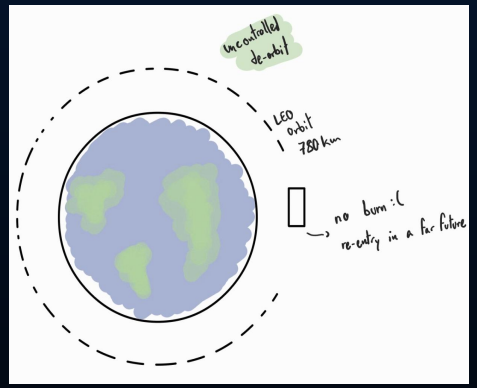
Total: 780 g propellant for collision avoidance in orbit

06

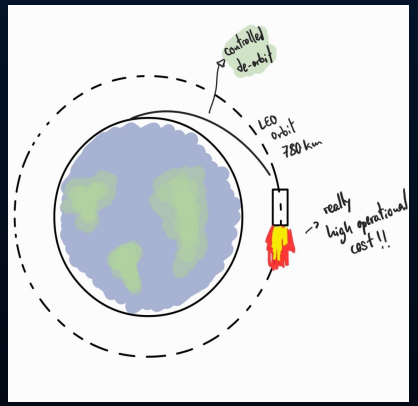
DISPOSAL SCENARIOS



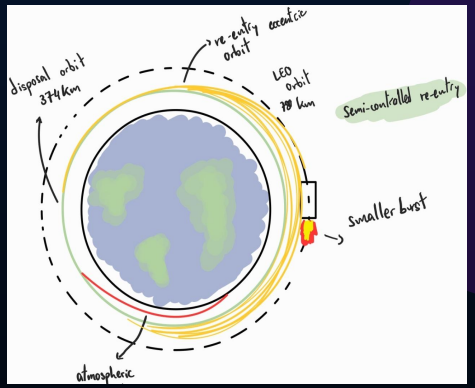
Disposal Scenarios



Scenario 1 - No intervention



Scenario 2 - Direct disposal

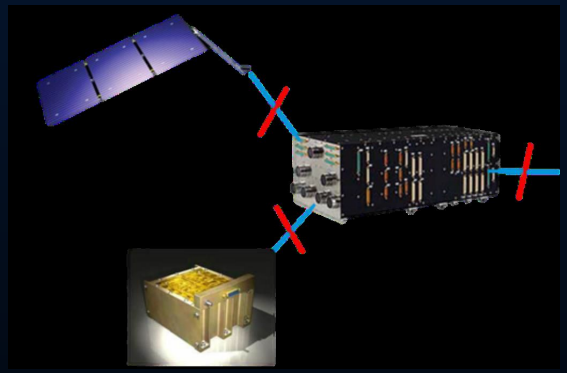


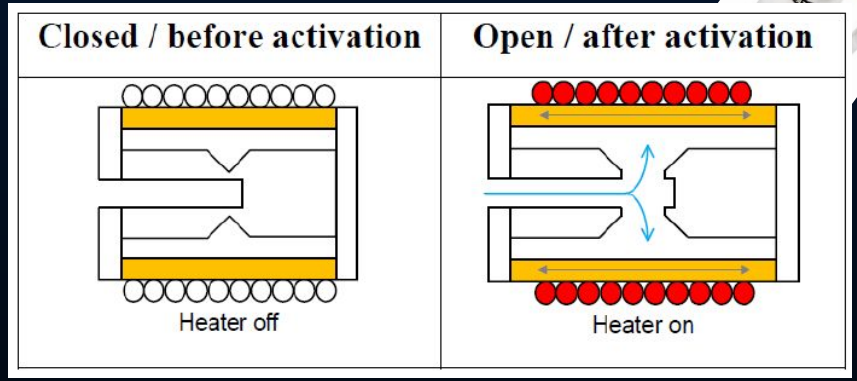
Scenario 3 - Hybrid manoeuver

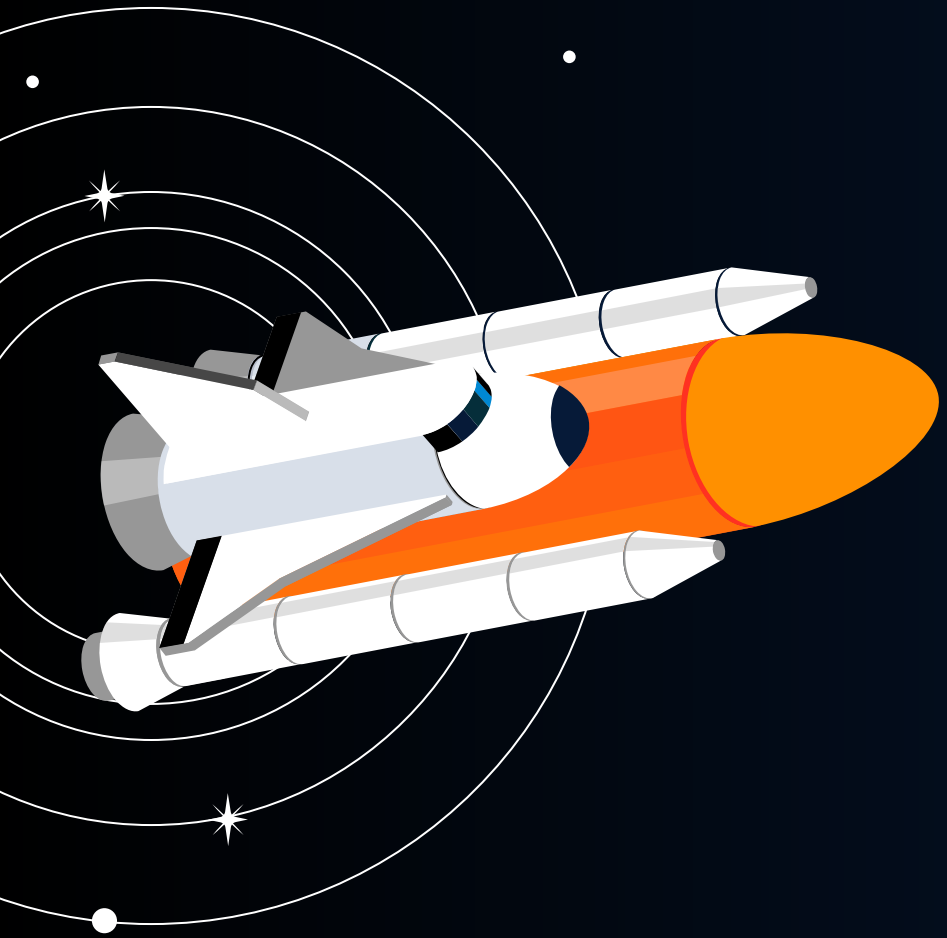
Disposal Scenarios - Oscar

Scenario	Total disposal time	Total Propellant mass (kg)
1 - controlled	45 min	97.17
2 - uncontrolled	>5 years	0.78
3 - hybrid	2.33 years	56.98

Passivation







07

GROUND RISK ASSESSMENT

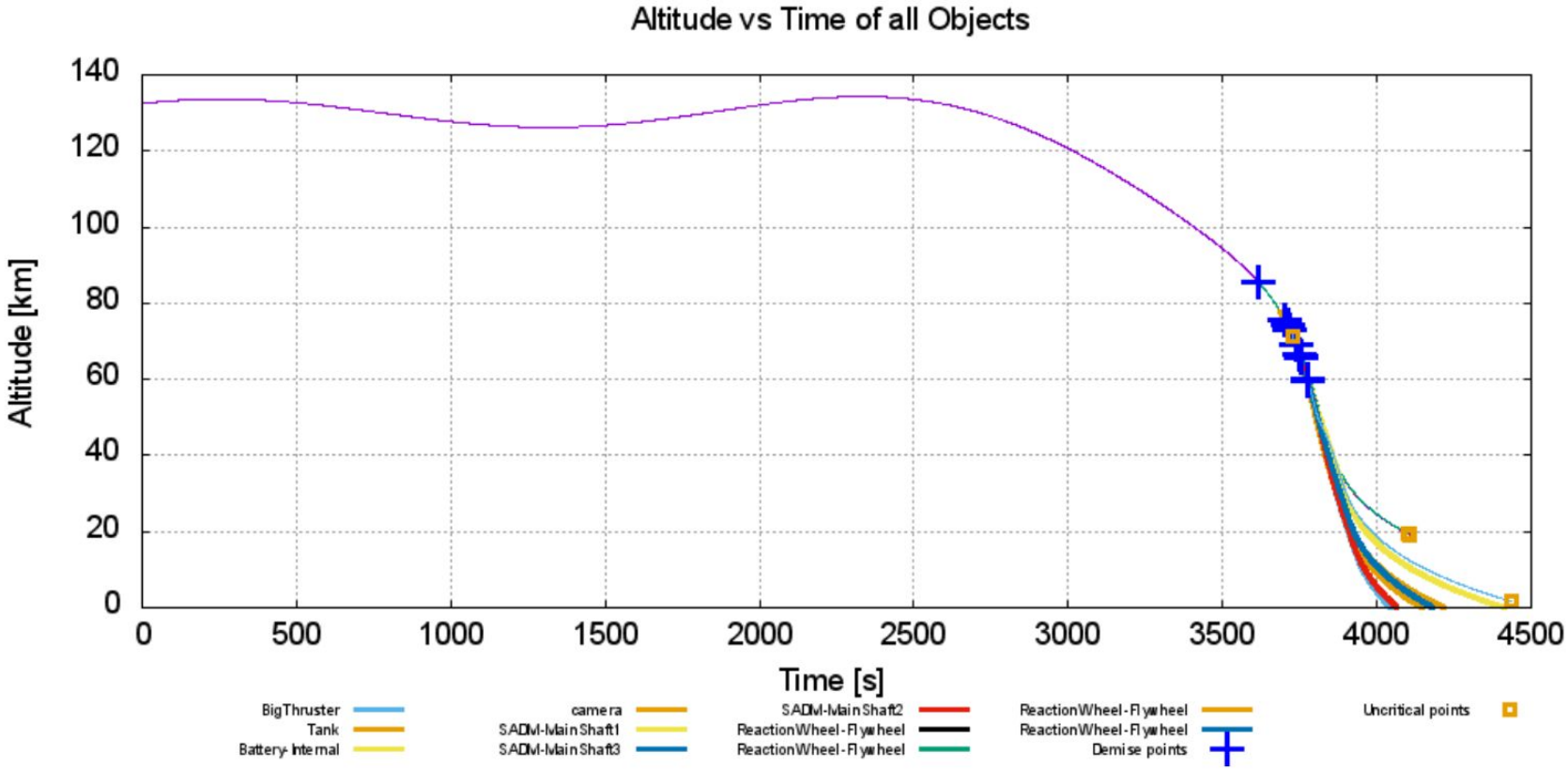
Ground Risk Assessment

SARA simulation was used to estimate the **ground risk associated with reentry (controlled and uncontrolled)**.

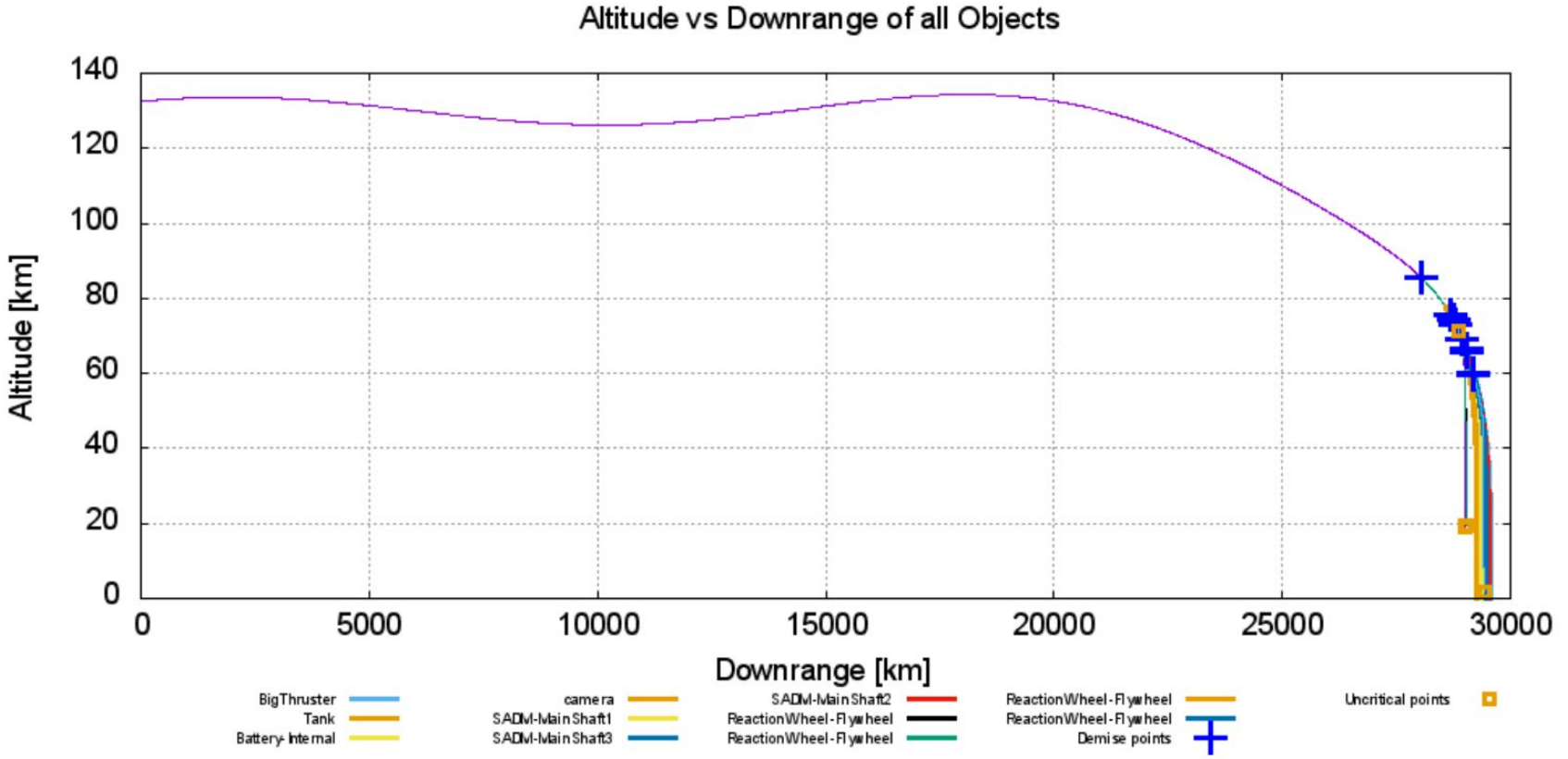
To facilitate reasonable processing times the satellite was deemed to **start at reentry attitude (120 km)**.

Component	Material	Mass
Tank	Titanium covered by Carbon Fiber (CFRP)	30 kg
Battery	Bat-Li	20 kg
Power Control Unit	AA7075	10 kg
SADM	AA7075	10 kg
4 Reaction Wheels	AA7075	34.44 kg
Camera	SiC	100 kg
Solar Panel	Solar Panel Material	100 kg
Big Thruster	Inconel 718	245.46 kg
Small Thruster x 8	Inconel 718	4 kg
Frame	AA7075	450 kg

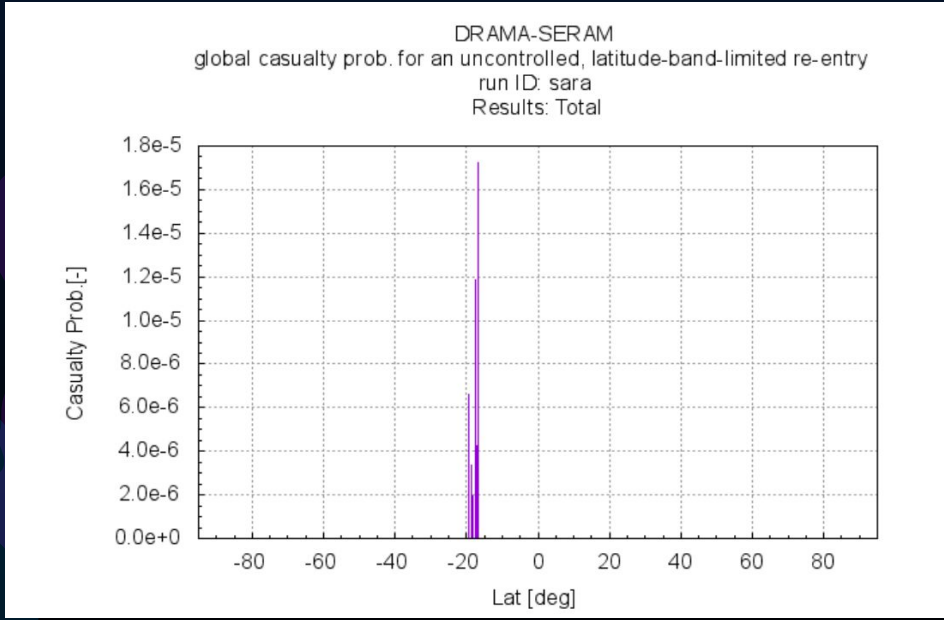
SARA - Altitude vs Time

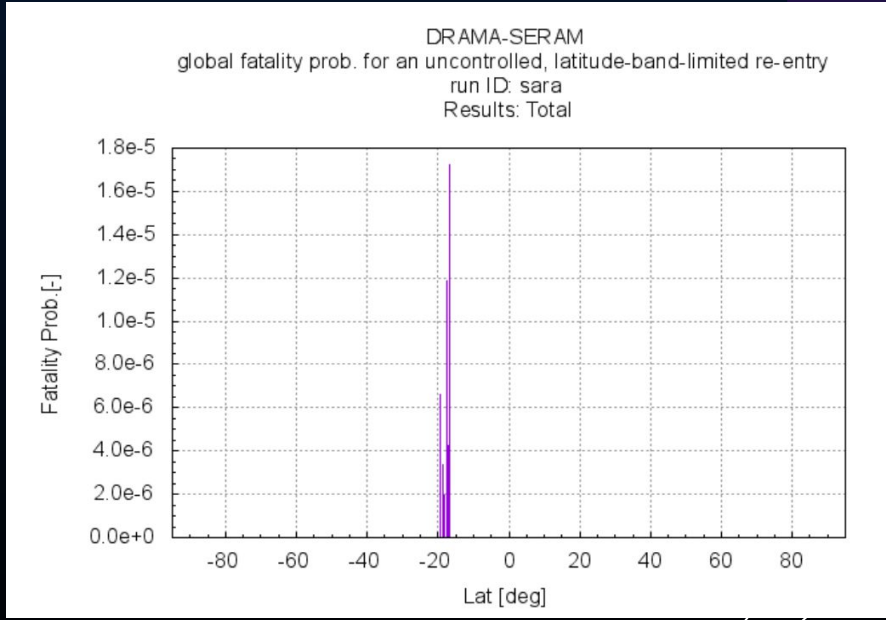


SARA - Altitude vs Downrange



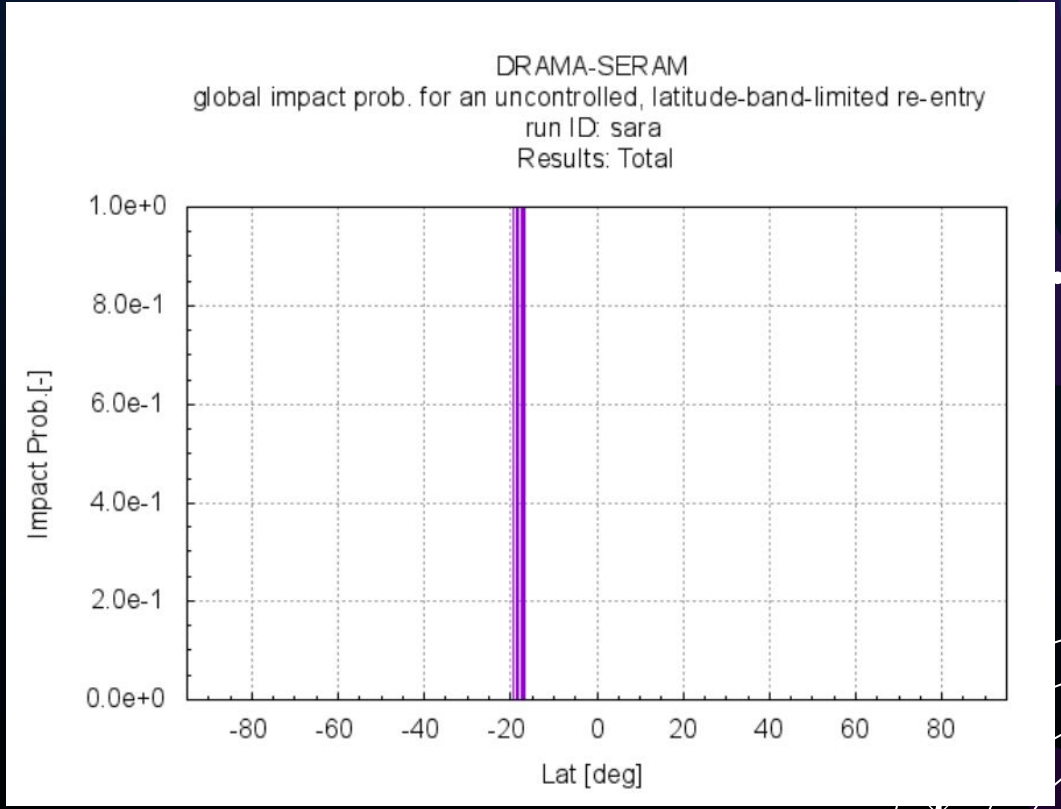
SARA - Casualty & Fatality



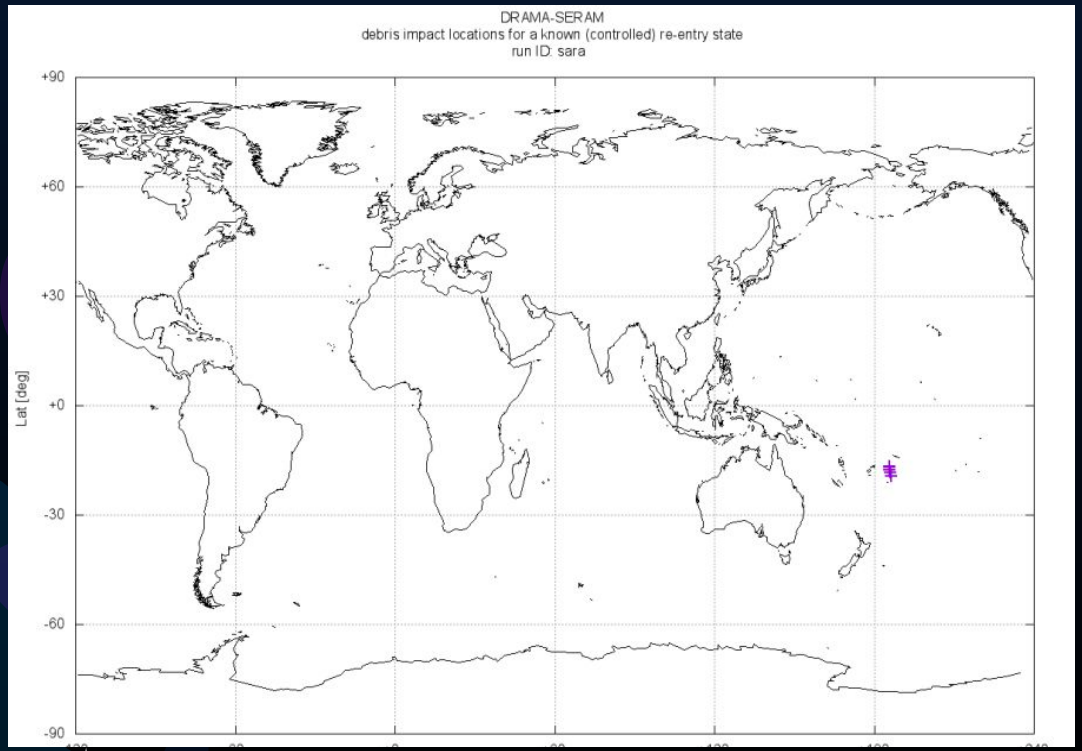


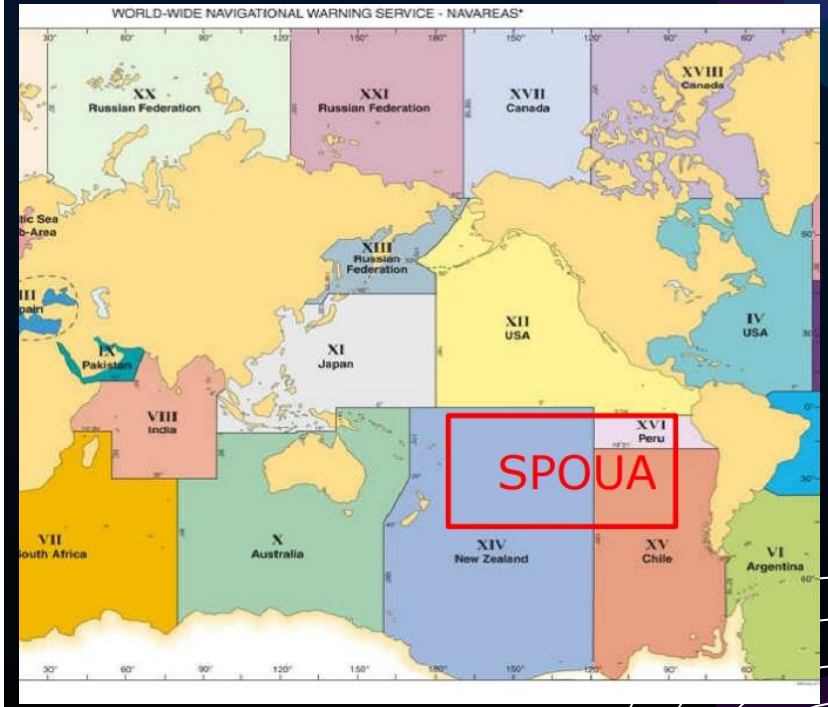
SARA - Impact Probability vs Latitude

This plot visualizes the **impact probability against the latitude** for any debris impacts.



SARA - Impact Location

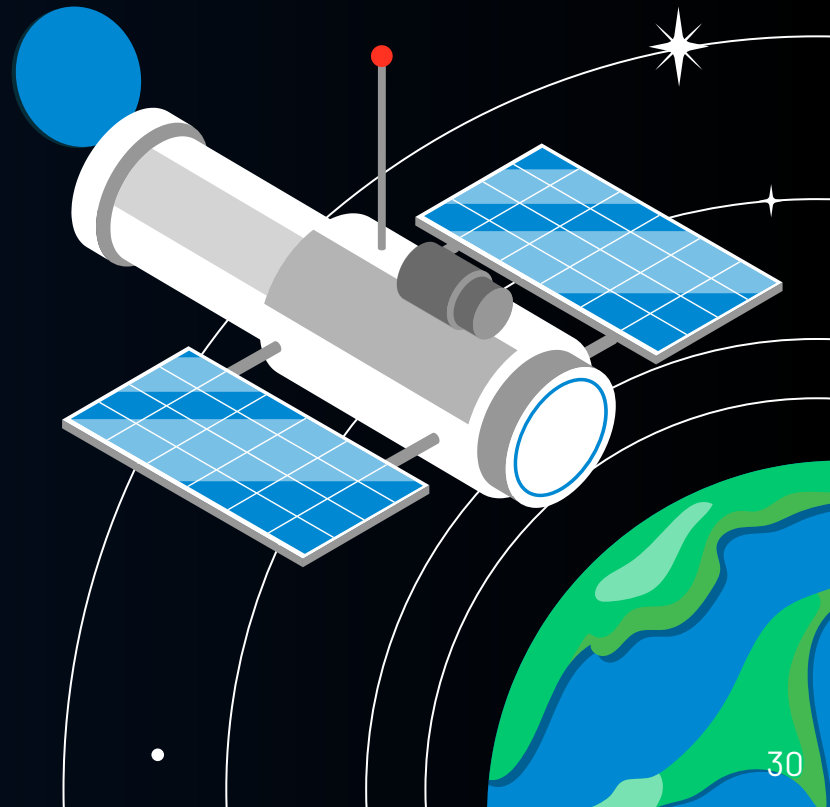




Wide national warning service map [1]

08

CONCLUSIONS



Mission results

IN-ORBIT

1. Impact risk of micrometeoroids and space debris **minimized** through **shielding-material analysis**
2. Collision avoidance strategy - fulfill requirement through **1 maneuver / year** with **78 g of propellant**

DISPOSAL

Best strategy: **hybrid-controlled re-entry**

GROUND RISK ASSESSMENT

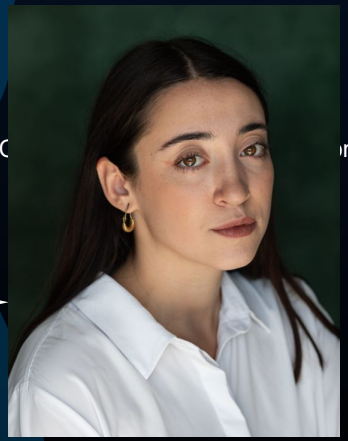
Impact site on the border of SPOUA - **compliance** with requirements about **casualty risks**

Joost Hubbard

Melina Kübler

Iona Popa

OUR TEAM

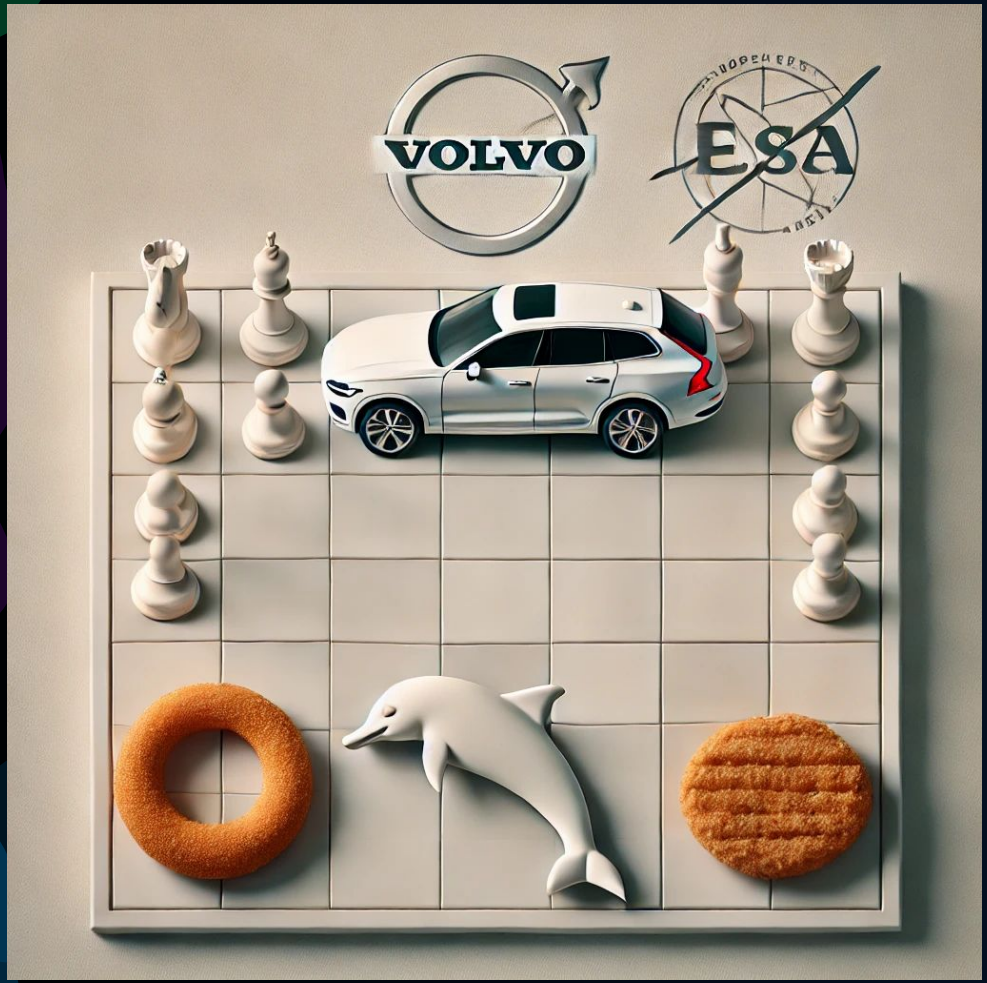


Marta Scherillo

Gurpreet Singh

Jose Triviño

THANK YOU FOR ATTENTION!

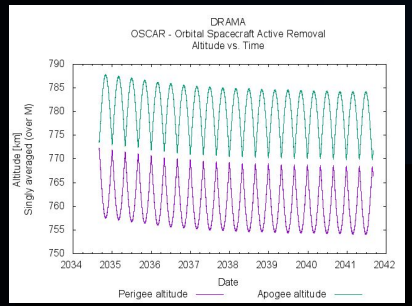


As requested by the esteemed judging department

Backup - Disposal

Scenario 1 - No intervention

CROC



Scenario 2 - Direct disposal

Scenario 3 - Hybrid manoeuver