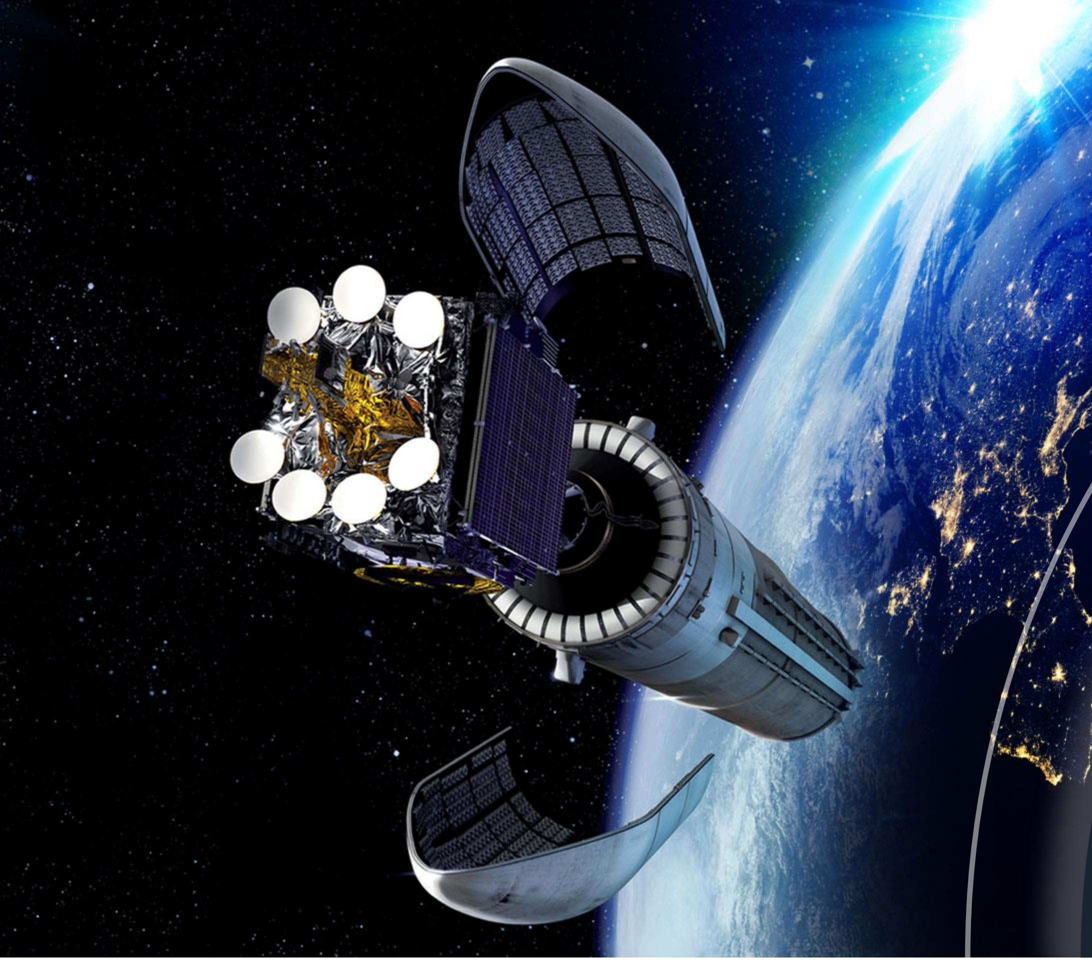


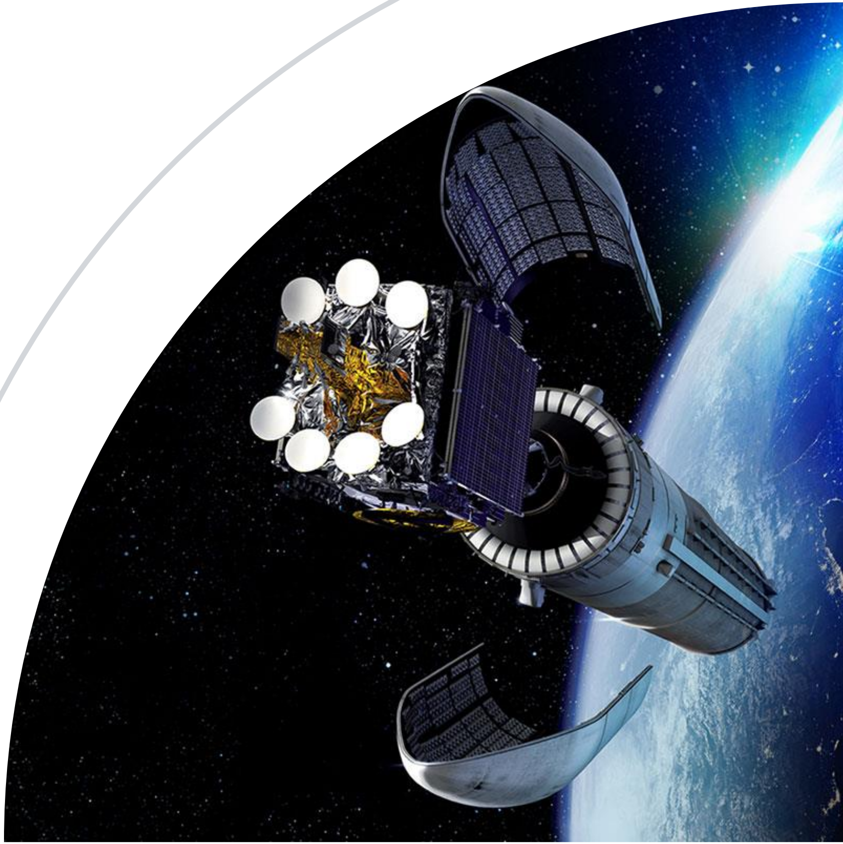
LEO platforms Space Debris Mitigation strategy

Nicolas Thiry (nicolas.thiry@thalesaleniaspace.com)

ThalesAlenia Space
a Thales / Leonardo company

Table of contents

Introduction



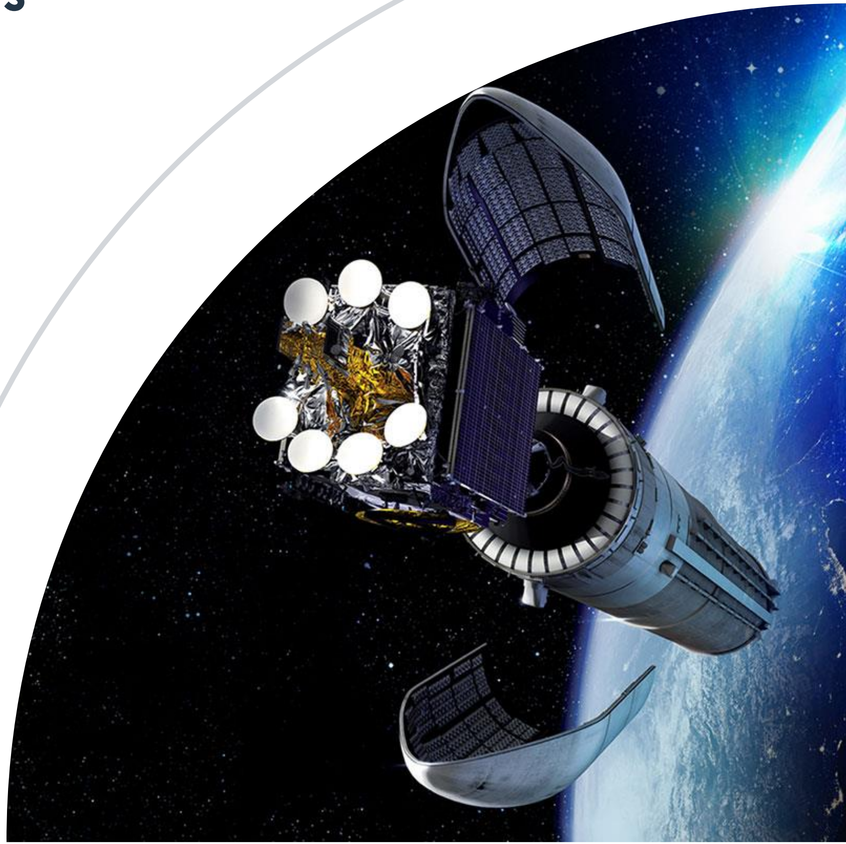
Overview of the different activities

The aim of this study is to support compliance with these new requirements by taking a coordinated approach with new technology developments for controlled and uncontrolled re-entry systems.

The Study is divided into 3 phases:

- **Phase 1** aims at defining **LEO platform classes** and select their targetted **re-entry strategy according to their mission profile** from **system level trade-offs.** Based on this, a **mapping** can be done **between** the **LEO platform** classes considered and the **Buildings blocks** needed. This phase is concluded by a **prioritization of the Building Blocks.**
- **Phase 2** aims at **defining high level functional and interface requirements for each Building Blocks retained** after the first phase. The definition of the requirements will rely upon system level simulations and trade-off. Following this, a Harmonization meeting is foreseen at ESA between all stakeholders
- **Phase 3** concern the **development of the Building Blocks** themselves based on the harmonized requirements. The developments are funded through separate ESA contracts and will run over 2 years. **Thales Alenia Space will actively participate in the development reviews** and perform an iterative refinement of the interface requirements in parallel whenever necessary.

SDM Requirements and Design Drivers



SDM Requirements: ISO 24113

Req. 6.3.3.2 (Re-entry options)

The removal of a spacecraft or launch vehicle orbital stage from the LEO protected region shall be accomplished by one or more of the following means (in order of preference):

a) retrieving it safely to Earth, or

b) performing a controlled re-entry with a well-defined impact footprint on the surface of the Earth to limit the possibility of human casualty, or

c) allowing its orbit to decay naturally in accordance with the specified 25-year limit for orbit lifetime, or

d) manoeuvring it in a controlled manner to reduce the remaining time in orbit so as to comply with the specified 25-year limit for orbit lifetime, or

e) augmenting its orbital decay by deploying a device to reduce the remaining time in orbit so as to comply with the specified 25-year limit for orbit lifetime.

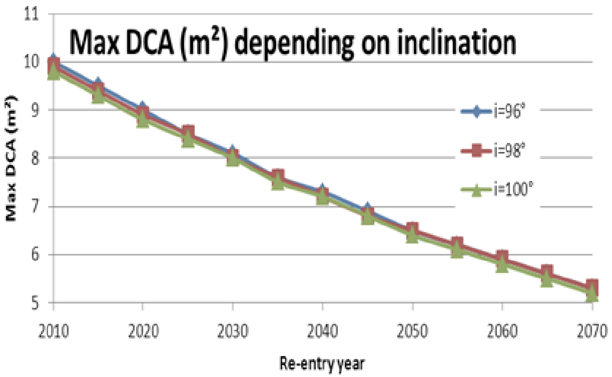
Req. 6.3.4.1 (option choice based on safety requirement)

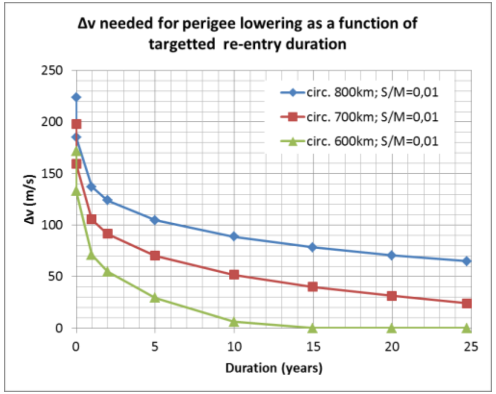
Specific re-entry safety requirements imposed contractually, voluntarily or by national or international authorities shall be identified and applied.

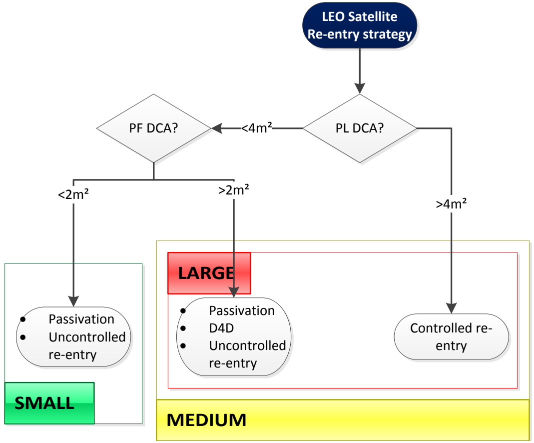
SDM Requirements: ISO24113

ESA/ADMIN/IPOL(2014)2 Section 2 (similar criterion in French LOS):

(…) the casualty risk shall not exceed 1 in 10'000 for any re-entry event (controlled or uncontrolled) (…)







Problems:

1) Different reference tools to compute the DCA between CNES or ESA projects → Risk of the same platform being only compliant for Scarab but not Debrisk or vice-versa.

2) Satellite DCA depends also on the payload, not just the platform → Difficulty to develop a single multi-mission platform covering all the needs, especially for the medium-class category

SDM Requirements: ISO24113

Req. 6.2.2.3

A spacecraft or launch vehicle orbital stage, for which a controlled re-entry has not been planned, shall be passivated in a safe and controlled manner before the end of life.

Rational:

To avoid thermal runaway in batteries or tanks (exothermic reactions in leftover fuel).

- **For batteries**, pervious cleansat activities indicate that thermal runaway can likely be prevented by maintaining battery temperatures <100°C and SoC<50%
- **For propellant**, thruster firing at EoL is done but risks linked with operating thrusters below 5.5 bars (membrane tanks) → Dedicated passivation on pressurant side with pyrovalves allows to get rid of leftover fuel over time

Problem:

- No definition of the terms "safe" and "controlled" → Compliance to this requirement is open to interpretation.
- Pyrovalve lifetime currently limited to 8 years (precursor)

SDM Requirements: ISO24113

Req. 6.3.1.1

The probability of successful disposal of a spacecraft shall be at least 0,85 through to the end of life.

Req. 6.3.1.4

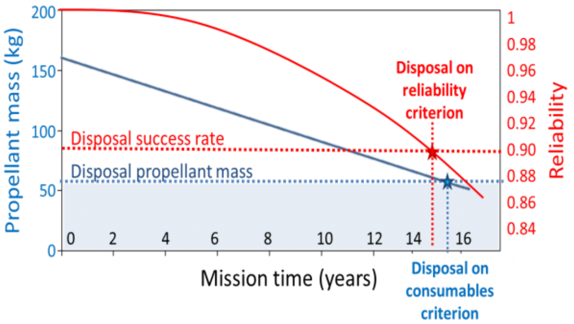
Specific criteria for initiating the disposal of a spacecraft or launch vehicle orbital stage shall be developed, included in a disposal plan, evaluated during the mission and, if met, consequent actions executed

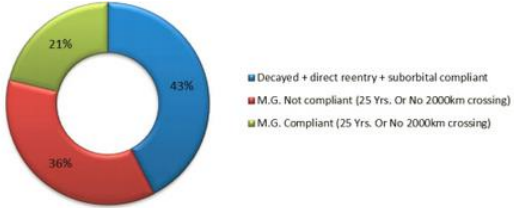
Nota: probability will increase to 0.9 in further issue

Nota: currently the success rate of the EoL disposal is very low, **only 0.65** !
Mainly because :

- being old satellites not designed to be disposed and passivated;
- a disposal decision based mainly on the remaining propellant mass
- a not-attempted start of the EoL manoeuvres or a too late decision, after the occurrence of major failures.

Some improvements are needed for the satellite design, reliability models and for the decision-making approach !

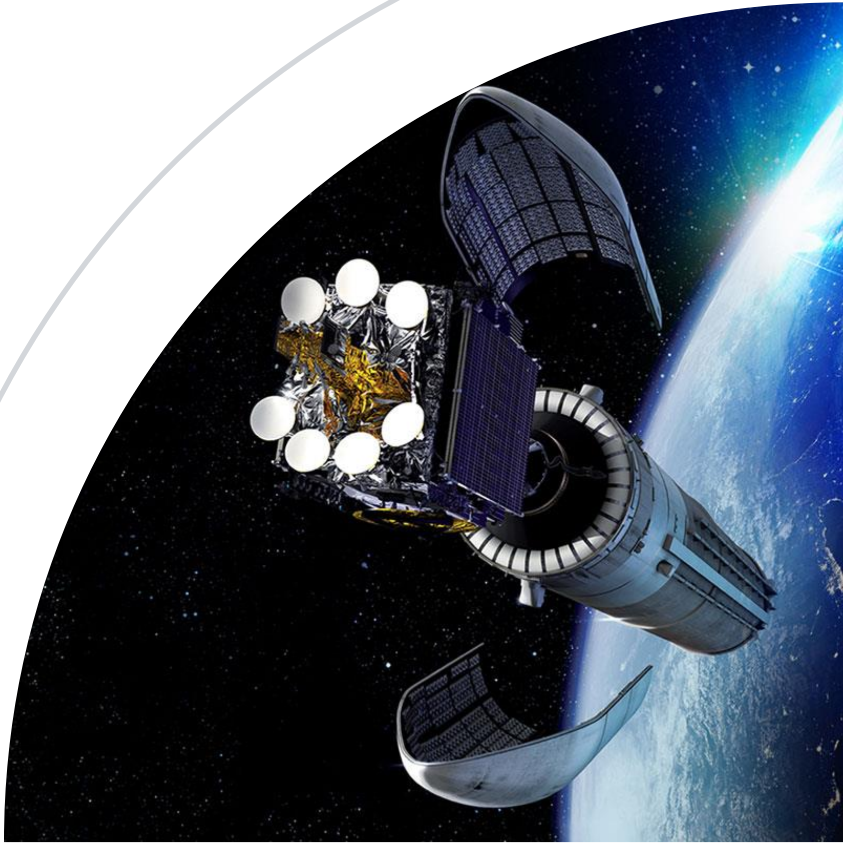




Only 65% of LEO objects are currently compliant

- *43% were already at altitudes with a natural orbit decay within 25 years,*
- *21% realized the necessary orbit lowering maneuvers*
- *36% <u>special measures would have to be used or where not available.</u>*

Prioritization of technology developments to improve SDM compliance status



Controlled re-entry on SWOT

- A NASA/CNES Mission, SWOT (Surface Water & Ocean Topography) is designed to study the topography of oceans and continental bodies of water;

- With a launch date set in 2021, the 2.3T satellite is built to comply with the French LOS and will become the first to perform a **controlled re-entry in 2025;**

- The hydrazine propulsion subsystem, comprising **eight 22 Newtons thrusters**, and **the largest membrane type fuel tank in the world.**

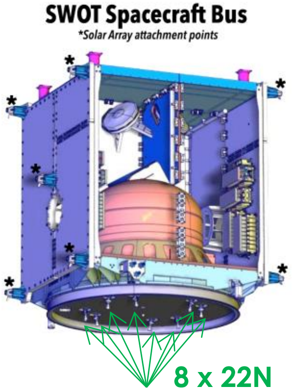
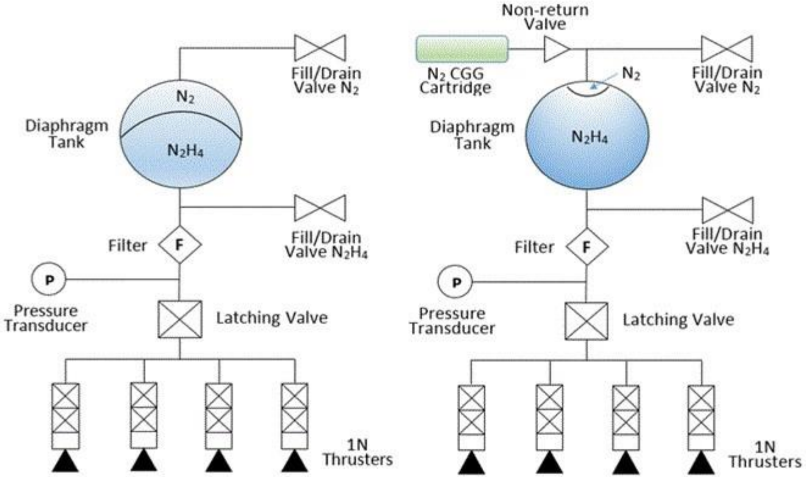


Image: NASA/JPL

Improvement: Solid state re-pressurization module

- CGG have less heritage than COPV tank but have **flown on Proba-2 mission**
- **Upscalable design:** bigger tank can be re-pressurized through additional CGG cartridges on the pressurant side



(Image: ESA ARTES)

(Image: isispace)

Technical data General characteristics of the large space nitrogen cool gas generator CGG-N-800-A1	
Mass	4.4 kg
Gas production	800 Normal liter (1000 grams of nitrogen)
Envelope	Cylindrical with Ø122mm & length of 240mm
Burn time	3 s
Initiation	ESA standard Initiator compatible
Electrical I/F	Flying leads
Gas purity	> 98% nitrogen
Fluidic I/F	M10 threaded pipe
Main materials	Titanium
Mechanical I/F	Clampband
MEOP	90 bars
Temperature range	-10° C to +40° C
Transport classification	Class 1.4S
Vibration environment	Typical ESA launch vehicle vibration environment
Operational Life time	10 years

Alternative: Optional SRM cluster

On the paper, optional SRM engines module could increase the flexibility of the medium class platform by adding an “optional” control-reentry. Important technological limitations shall be noted:

- Need to mount each thruster on **gimbals for thrust vector control**
- **Maximum burn time of 120s**: due to the erosion of the nozzle material
- **Maximum acceleration** of **0.04g** on medium-large spacecraft to ensure the mechanical integrity of some deployable equipment (e.g. SADM).


SRM + TVC
(Image: Institute of Aviation, Warsaw, Poland)

→max Δv ~ 50m/s per SRM engine → cluster of min. 2 or 3 SRMs operated sequentially required for the final burn.

→No obvious advantage in term of mass because the benefits of a higher Isp are offest by a higher dry mass.

→Main advantage : to offer flexibility for the re-entry strategy of medium/large platform design (e.g. optional module)

Alternative: Auxiliary ArcJet thrusters to lower the perigee

AJ thrusters have **twice better Isp** over traditional thrusters but unfortunately, altitude lowering would also consume **twice more Δv** for spiraling descent due to low thrust levels

→ Only interesting option with multiple apogee (>100) maneuvers
→ Increase in operation complexity and cost

$$\Delta v_{spiral} = \sqrt{\frac{\mu_E}{r_2}} - \sqrt{\frac{\mu_E}{r_1}}$$

$$\Delta v_{per.lower} = \sqrt{\frac{\mu_E}{r_1}}\left(\sqrt{\left(\frac{2r_{p1}}{r_{p1}+r_a}\right)} - \sqrt{\left(\frac{2r_{p2}}{r_{p2}+r_a}\right)}\right)$$

	Mission	Perigee lowering	Final burn
Scenario 1 (800 → 500 → 10)			
Δv Chemical only	110 m/s (chem.)	80 m/s (chem.)	142 m/s (chem.)
Δv Hybrid		161 m/s (AJ)	
Scenario 2 (800 → 250 → 10)			
Δv Chemical only	110 m/s (chem.)	150 m/s (chem.)	72 m/s (chem.)
Δv Hybrid		304 m/s (AJ)	

Spiral → 500km

S/C wet Mass	mass ratio Chem. Prop. SS	mass ratio hybrid Chem. + AJ SS
100	31%	41%
200	26%	31%
300	24%	27%
400	23%	25%
500	23%	24%
600	22%	24%
700	22%	23%
800	22%	23%
900	22%	22%
1000	22%	22%
1100	22%	22%
1200	21%	22%
1300	21%	22%
1400	21%	22%
1500	21%	22%
1600	21%	21%
1700	21%	21%
1800	21%	21%
1900	21%	21%
2000	21%	21%

Spiral → 250km

S/C wet Mass	mass ratio Chem. Prop. SS	mass ratio hybrid Chem. + AJ SS
100	31%	40%
200	26%	30%
300	24%	26%
400	23%	24%
500	23%	23%
600	22%	23%
700	22%	22%
800	22%	22%
900	22%	21%
1000	22%	21%
1100	22%	21%
1200	21%	21%
1300	21%	21%
1400	21%	21%
1500	21%	21%
1600	21%	20%
1700	21%	20%
1800	21%	20%
1900	21%	20%
2000	21%	20%

Design for Demise (D4D) Building Blocks prioritization

- Current **small/medium satellite** missions demonstrate **marginal compliance** with respect to SDM **re-entry risk**

- Demisable RWA and tanks are identified with the **highest priority to reduce the platform DCA**
  - **Demisable tanks** will require new materials such as Al-Li alloy or AA2219(AVUM heritage) instead of Titanium alloys
  - **Demisable RWA** can be achieved in 2 different ways:
    - **Small Wheels with Increased motor capacity**:

      Pros: Small wheel already have rim and arms in aluminium

      Cons: Increase in power consumption and micro-vibration levels; Design not optimised for demise (shadowing effect to motor shafts and ball bearing units)
    - **Large Aluminium Flywheel (preferred option)**:

      Design of a current large Stainless steel flywheel (spokes and rim) replaced by a large monoblock aluminium flywheel. According to Cleansat BB11, option feasible with slight increase of mass and operating speed (compatible to current electronics) at iso-performance.
  - **Demisable MTBs** could also be considered in the case of a large demisable platforms

- In complement, an **Early break-up mechanism** shall be considered to ensure satellite break-up **above 78km**

Passivation BB prioritization

A typical passivation sequence includes the following operations:

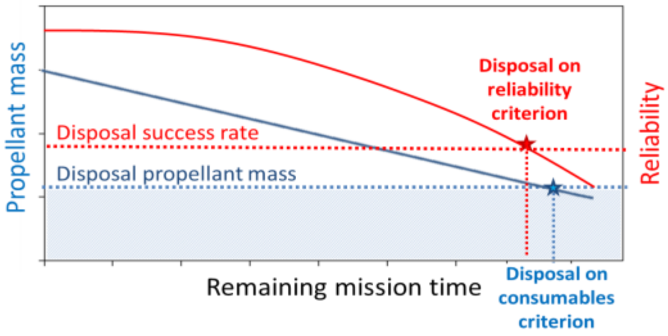
1. P/L equipment switch-off
2. Propellant depletion
3. Pressurant venting → Requires passivation device to free the pressurant trapped upstream of the membrane
4. Battery energy depletion
5. SAW passivation → requires dedicated passivation device
6. COMS switch-off

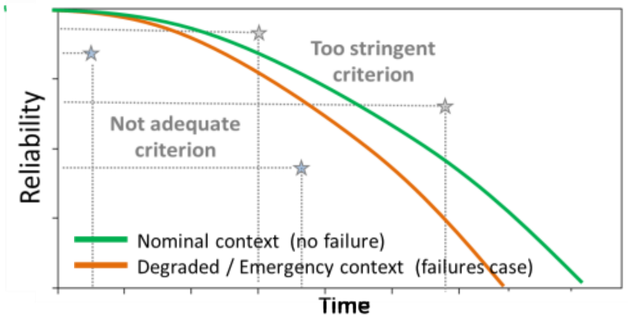
Nota

- **Development of pyrovalves with extended lifetime and micro-perforator are already ongoing**
- **SAW passivation may depend on PCDU type (ongoing ESA development for galvanic isolation concerns MPPT)**

EOL Reliability Tool

- A reliability-based criterion is proposed in addition to the current one based on the remaining propellant mass
- Satellite to be disposed when the first of the two criteria is no longer satisfied
- The probability requirement should be ideally defined such that the post-mission disposal could be performed in a reliable manner and especially started at the right time !
- Disposal success rate and reference duration for the reliability computation to be defined in order to :
  - correctly decide for a disposal initiation when a too high risk of losing the satellite will exist
  - without being too stringent, that is to say avoiding to interrupt a mission that could have been reasonably extended

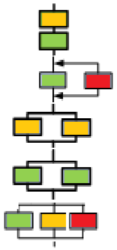


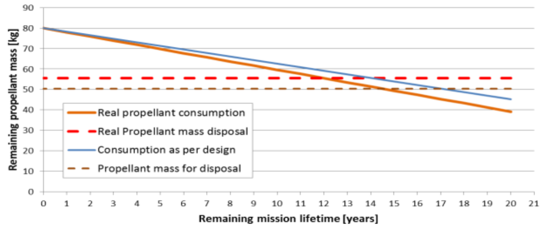


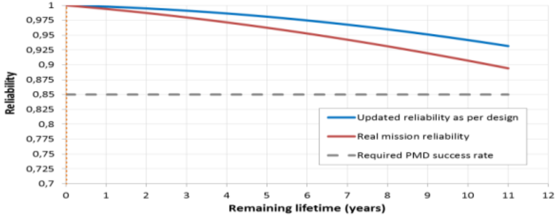
EOL Reliability Tool

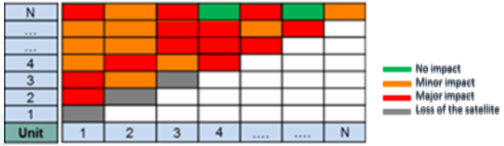
- Once having defined the disposal criteria, they will be monitored during the whole mission and appropriate actions will have to be taken in case threshold reached.
- In the proposed generic model supporting EoL decision, all the nominal events and the occurred failures having an impact on the disposal strategy, on the satellite performance and on the redundancy schemes are taken into account.

S/System	Equipment	Unit	Current status
Subsystem 1	Hardware 1	HW 1.1	Limited lifetime
		HW 1.2	OK
	Hardware 2	HW 2 Primary	OK
		HW 2 Redundant	Failed
	Hardware 3	HW 3.1	Limited lifetime
		HW 3.2	Limited lifetime
Subsystem 2	Hardware 4	HW 4.1	OK
		HW 4.2	OK
	Hardware 5	HW 5.1	OK
		HW 5.2	Limited lifetime
		HW 5.3	Failed



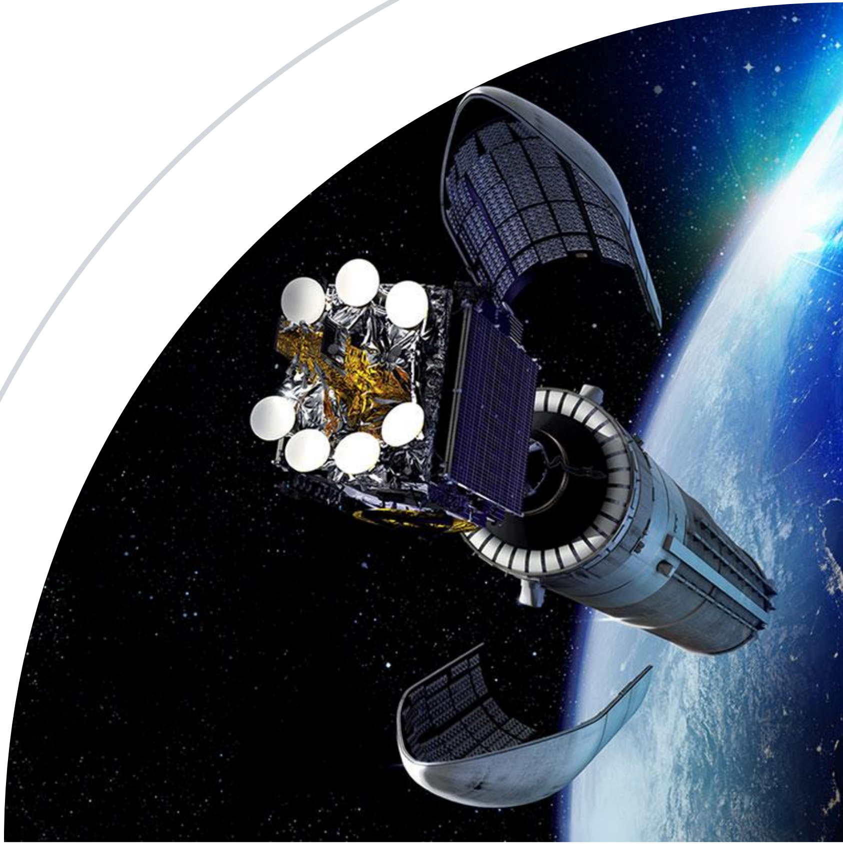






- **This tool could improve the current decision-making approach and thus the success rate of the Post Mission Disposal !**

Conclusions



Conclusion

- Development priorities given to the following Building-Blocks:
  - **Controlled re-entry BB**
    - Low-cost, upscalable re-pressurization module for medium-large platforms
    - Optional SRM cluster for medium-large platforms
  - **D4D BB**
    - Demisable tank (2 versions: 30-50L and 100-200L)
    - Demisable RWAs (Medium)
    - Demisable MTBs (Medium-Large sat.)
    - Early break-up mechanisms
  - **Electrical Passivation BB**
    - S3R passivation
    - MPPT passivation (galvanic isolation)
  - **EOL Reliability tool** to trigger disposal
- Inconsistencies between ESA and CNES verification tools for casualty risk assesment → Risk of some D4D BB being only applicable future ESA missions

ThalesAlenia Space

a Thales / Leonardo company