Reliability model and criteria supporting decision-making to safely dispose a satellite

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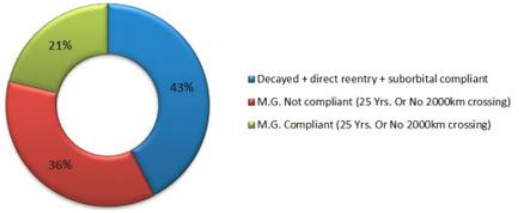
Introduction

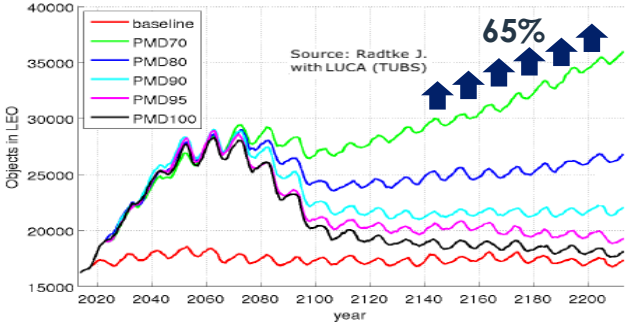
Background

- Space Debris Mitigation requirements have been established
  - To avoid intentional release of objects and break-ups in orbit
  - To evaluate and limit the collision risk and the total casualty risk
  - To remove spacecraft from LEO and GEO protected regions
  - To succeed the disposal with a given probability
- Despite the introduction of SDM standards and regulations, globally a low success rate of the disposal is currently observed in orbit *(source IADC 54th UN COPUOS STSC).*
  - Satellites not designed to be disposed before the SDM standards
  - Recommendations and not regulations (except for French law : LOS)
  - Disposal not attempted or later decision :
    - decision mainly based on consumables (e.g. propellant mass),
    - less on the risk of losing the disposal capability because of already occurred or possible future failures
- The population of space debris in LEO is expected to grow :
  - because of satellites left in orbit or lost after the occurrence of failures
  - and especially because of the future mega-constellations whose Post Mission Disposal success rate is the driving factor for the evolution of space objects



Only 65% of LEO objects are currently compliant

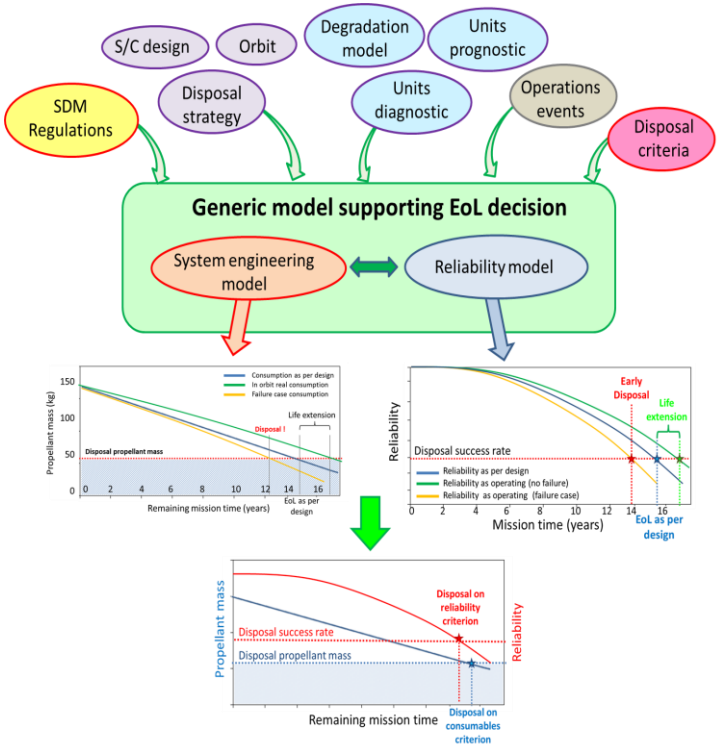
- *43% were already at altitudes with a natural orbit decay within 25 years,*
- *21% realized the necessary orbit lowering maneuvers*
- *36% special measures would have to be used or were not available.*



Introduction

Activity objectives and general approach

- **Some improvements are needed in order to be able to dispose the satellite in a reliable manner and especially at the right time !**
  - Satellite design and disposal strategies
  - Reliability standards and models
  - SDM requirements
  - The decision-making process
- A generic model supporting decision-making on satellite life extension and safe disposal is proposed.
- This initial proof-of-concept will be deployed experimentally in support of missions developed/operated by ESA or by a third party.
- The final goal is to support the decision on how and especially when a satellite has to be disposed !
- This tool could also support other applications :
  - launch date / constellation replenishment strategy
  - In-orbit refueling – servicing (maintenance) missions
    - Does it make sense to refuel and already old (less reliable) S/C?
    - Which are the HW more likely to be replaced ? And when ?



How to improve the satellite reliability and the success of the disposal ?

- How to improve the reliability of the satellite design ?
- How to improve the accuracy/representativeness of the reliability models?
  - What are the main sources of uncertainty in current reliability models ?
  - What are the possible improvements ?
  - What are the needed information, methods and tools ?
  - What are the expected benefits for the life extension and EoL disposal ?
- Do SDM standards / regulations need to be further improved ?
  - More stringent requirement on PMD success rate ?
  - What could be the real benefits on the evolution of the population of space debris?
  - What the impacts on the satellite design and competiveness of the European space industry?
- How to improve the current decision-making process ?
  - How to evaluate/anticipate the impact of failures on the disposal capability?
  - How to evaluate the risk of not succeeding the disposal maneuvers ?
  - How dependability engineers could provide useful / understandable results to decision-makers ?

How to improve the satellite reliability and the success of the disposal ?

How to improve the reliability of the satellite design ?

- The EoL disposal reliability depends on :
  - The functional chains / hardware needed for the disposal (EoL strategy) and the mission duration
  - The redundancy schemes selected for these units
  - The quality of the selected components and the corresponding quality assurance process
  - The operating conditions of the units (T°, electrical stress, duty cycles, etc.)
- Past/Current approach :
  - EoL strategies not always defined or only for nominal cases
  - Cross-trapped and redundant designs
  - High reliability (Hi-Rel) and radiation hardened (Rad-hard) components / extensive qualification & tests
  - Derating rules, design margins, etc.

So why only 65% ?

- Current/Future trend (New Space) :
  - EoL strategies to be defined before launch / Several R&D studies defining a minimum set of functions needed for the disposal
  - Limitation/elimination of redundancies because of mass, volume and costs constraints
  - Massive use of COTS and no longer (not always) Hi-Rel EEE / "Launch and test in orbit" approach !
  - Lower technical margins in order to reduce mass/costs/time to market

How to achieve the 90% ?

Satellite designers and RAMS engineers to collaborate even further to make future missions reliable !!

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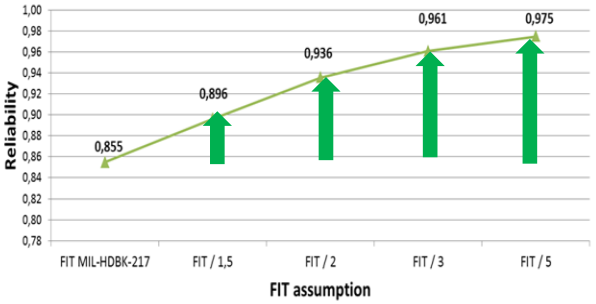
How to improve the satellite reliability and the success of the disposal ?

How to improve the accuracy/representativeness of the reliability models?

- Main sources of uncertainty in reliability prediction stem from
  - The MIL-HDBK-217 standard: conservative results w.r.t. actual in-orbit performance (a factor between 3 and 5)
  - Differences between hypotheses and real operating conditions: (e.g. T°, duty cycles, radiations, etc.)
  - Constant failure rate assumption: infant mortality and wear-out effects not considered
- Promising approaches investigated by Thales Alenia Space
  - New or updated dependability standards
  - REX and Health monitoring with in-orbit data coming from operators
  - Degradation models and prognostic (*based on stochastic models, engineering models, data trends analysis*)
- Examples of application

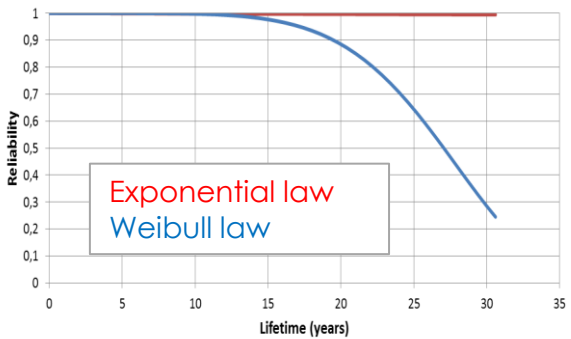


SUBSYSTEMS	Mission (15 years)
AOCS	0,985
PROPULSION	0,998
EPS	0,985
SA	0,999
OBDH (with TTC-RF & STR)	0,934
SDIUs	0,962
THERMAL	0,990
PLATFORM	**0,860**

<0.9

SUBSYSTEMS	Mission (15 years)
AOCS	0,985
PROPULSION	0,998
EPS	0,988
SA	0,999
OBDH (with TTC-RF & STR)	0,973
SDIUs	0,968
THERMAL	0,990
PLATFORM	**0,904**

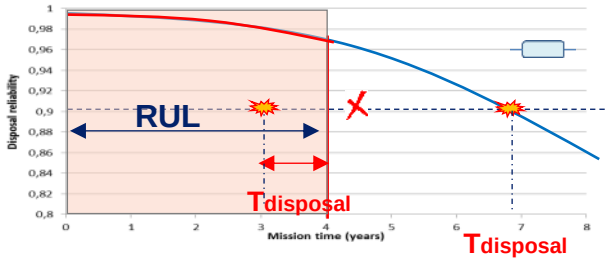
>0.9



How to improve the satellite reliability and the success of the disposal ?

How to improve the accuracy/representativeness of the reliability models?

- Expected benefits :
  - More realistic assumptions and degradations taken into account
    - → Better accuracy/representativeness of the reliability models
  - Higher reliability figures
    - → possible optimization of the satellite redundancy schemes !
  - Health monitoring & Prognostic
    - → To avoid the occurrence of failure via the reconfiguration of the impacted unit
    - → To anticipate the future performance and the Remaining Useful Lifetime (RUL) of satellite units
    - → To derive when the de-orbit has to be started in order to complete the disposal before the loss of a critical function, especially for those units which are already SPF by design or after a previous failure



Satellite designers, operators and RAMS engineers to collaborate even further to make future missions reliable !!

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How to improve the satellite reliability and the success of the disposal ?

Do SDM standards / regulations need to be further improved ?

- Previous requirement on the post mission disposal probability
  - **0.9 and conditional formula** specified in ISO 24113 standard
  - Provides very good results, also for less reliable S/C, therefore
    - Does not really lead to design improvements during the development phase
    - Does not constitute an adequate criterion to correctly decide for the initiation of the disposal phase

- Current requirement on the post mission disposal probability
  - **0.85 absolute** specified in new version of LOS regulation
    - specific S/C design and redundancy schemes to be defined during the development phase
    - neither this requirement constitutes an adequate criterion to decide for a disposal.
  - **0.9 absolute** expected in new version of ISO 24113 standard
  - **0.9 - 0.95 absolute** already proposed or currently being evaluated
    - could represent a show stopper for some missions, thus having an impact on the competitiveness of the European space industry
    - Would it really lead to design improvements and to a higher PMD success rate or only to improvements / 'tuning' of the reliability models to achieve it ?

How to improve the satellite reliability and the success of the disposal ?

Do SDM standards / regulations need to be further improved ?

- Future requirement on the post mission disposal probability (con't)
  - New ISO24113 is moving the focus of activities from the **probability of successful disposal** to the **provisions for successful disposal**, i.e.:
    - During the design of a spacecraft an **assessment** shall be made **of the risk** that a space debris or meteoroid impact will prevent the successful disposal
    - Specific **criteria** for initiating the disposal of a spacecraft shall be developed, **evaluated during the mission** and, if met, consequent actions executed.
    - The **condition of a spacecraft** shall be **monitored periodically** during its operation to detect any anomalies that could affect its successful disposal.
    - During the operation of a spacecraft, **if an anomaly is detected** which could affect its successful disposal then **a contingency plan shall be developed** and implemented to mitigate this risk.
    - In case the mission lifetime is to be extended, the capability of a spacecraft to perform **successful disposal shall be reassessed** considering the status of the spacecraft **at the beginning of the mission lifetime extension**.

Current reliability assessment methodology is not adequate to answer to all these requirements !

Some promising approaches and methods have been identified by the study team but they need to be further evaluated in future studies !

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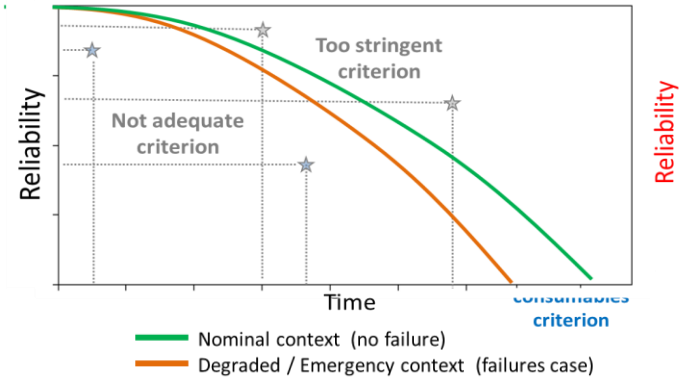
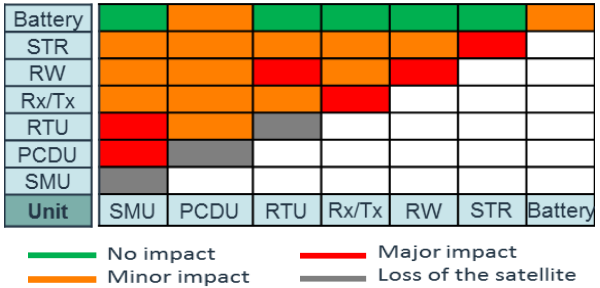
How to improve the satellite reliability and the success of the disposal ?

How to improve the current decision-making process ?

- 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
- A short-term probability requirement should be ideally defined !
- Disposal success rate and reference duration for the reliability computation to be chosen in order to
  - 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
- In addition a **Risk Assessment** based on a double failure FMEA is proposed :
  - To evaluate the impact of combination of failures on the disposal strategy(*nominal, degraded, alternative*) and timeframe (as per design, *life extension, anticipated, emergency*)
  - To identify design weakness and to derive appropriate design or strategy modifications since the early phases
  - To provide during the whole mission a clear picture of the current and future risk, understandable by everyone





These approaches have been seen as very promising but they need to be further evaluated in future studies !

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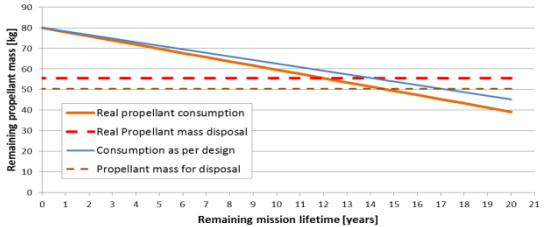
Generic model supporting EoL decision

Overview of the tool and its operational application

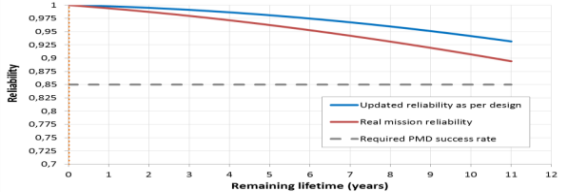
- In the proposed generic model supporting EoL decision, all the nominal events and occurred failures having an impact on the disposal strategy, on the satellite performance and on the redundancy schemes are taken into account.
- The disposal criteria will be monitored during the whole mission and appropriate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

During the mission ….

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

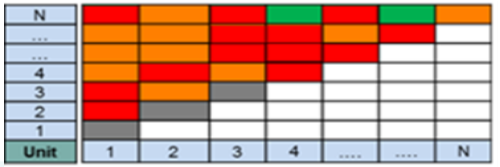


Consumable criterion



Reliability criterion

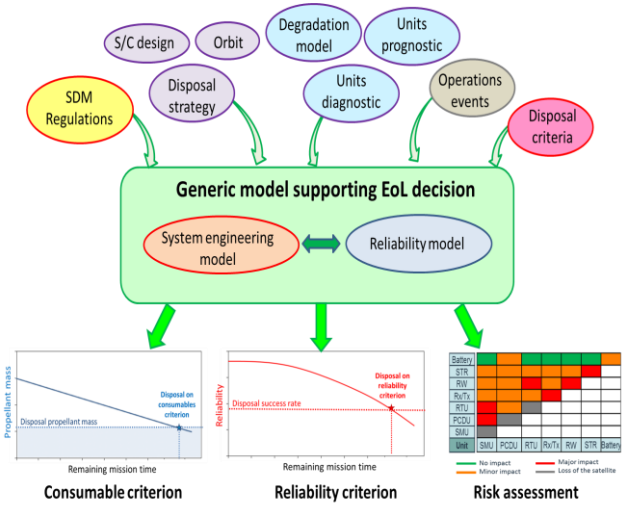
These quantitative and qualitative approaches would lead to a better risk-awarded decision on the EoL and thus to a higher PMD success rate in orbit !

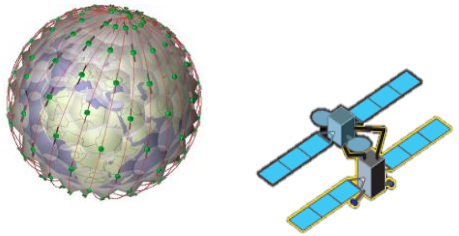


Risk assessment

Conclusions and perspectives

- Some answers have been provided to the question " ***How to improve the satellite reliability and the success of the disposal ?*** "
- A generic model is proposed combining system engineering and reliability aspects by integrating units degradation, diagnostic, prognostic and risk assessment information.
- These approaches could improve the current decision-making process on satellite life extension, safe disposal and other applications as well.
- The reliability criterion and the Risk assessment will be even more important for future missions
  - To comply to new ISO standard
  - or mega-constellations, whose PMD success has been shown to be the major contributor to the future evolution of space objects in LEO
  - the propellant mass criterion could become less adequate or at least useful with future on-orbit refueling and servicing missions
- **Recommendations and way forwards**
  - To define the EoL strategies and the impact of failures since the early phases of the satellite development process
  - Operational data to be systematically shared with dependability engineers and equipment experts in order to apply these methods
  - To further validate these promising approaches on real satellites !
  - To apply these methods and reassess the reliability figures and risk as part of the Yearly Reports !





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THANK YOU FOR YOUR ATTENTION !

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