END-OF-LIFE CONSIDERATIONS FOR CUBESATS

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- LEO clearance vs. mission lifetime
- Probability of successful disposal
- Re-entry casualty risk
- Zero debris by 2030

LEO CLEARANCE VS. MISSION LIFETIME (1)

- A typical CubeSat does not have any propulsion and relies on passive compliance
- How can LEO clearance requirement and mission lifetime requirements be balanced?

Parameter	LEO clearance re-entry time	Mission lifetime
Requirement	< 25 years	> 4 years
Serves as?	Defines upper bound of launch altitude	Defines lower bound of launch altitude
Mass	Highest: 23.1 kg (incl. system margin)	Lowest: 19.3 kg (excl. system margin)
Drag coefficient	Lowest: 2.2	Highest: 3.0
Cross-sectional area	Lowest: 0.101 m^2 (dead-on-arrival, tumbling with no deployed surfaces)	0.159 m^2 (operational average)
Atmospheric model	ESA latest estimation	ECSS Sample Cycle (solar cycle 23)
Result	Max 555 km, when including +/- 15 km injection uncertainty, the **maximum launch altitude is 540 km** ↔	**Minimum 560 km launch altitude** to reach 4 year operational lifetime (passively)

LEO CLEARANCE VS. MISSION LIFETIME (2)

Parameter	LEO clearance re-entry time		Mission lifetime
Result	Maximum launch altitude is 540 km	↔	Minimum 560 km launch altitude

- The most important requirement is 25 years LEO clearance: if not compliant, launch is skipped
- There are several **mitigations** to improve mission lifetime:
  - Playing with satellite **mass** (adding dummy mass to improve lifetime)
  - Playing with **drag** area in the conops (implementing a low drag attitude)
  - Adding **propulsion** to increase altitude once operational
    - Launcher uncertainty (~ +/-15km) is cleared once the satellite is operational
    - Solar arrays and/or other stowed surfaces are deployed leading to increased drag area
    - This leads to a higher maximum allowed altitude
    - BUT: increases complexity and costs
  - **Acceptance** of short lifetime

***Don't forget**; a CubeSat is usually not the main passenger and cannot define launch altitude!*

PROBABILITY OF SUCCESSFUL DISPOSAL

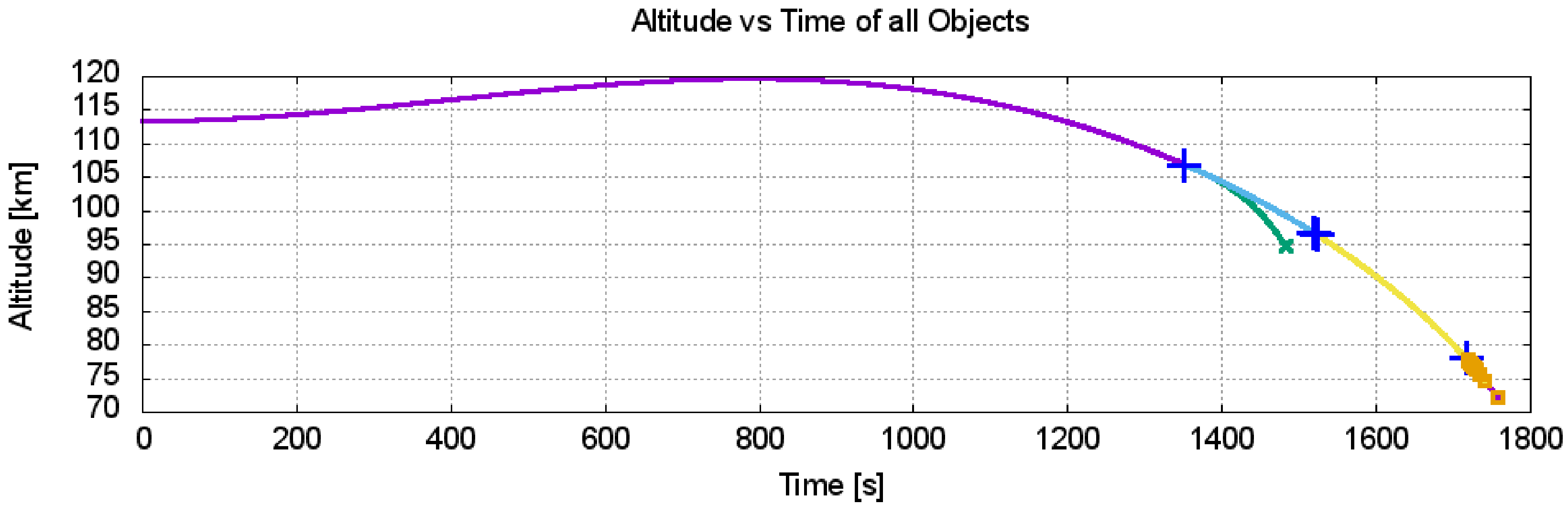
The probability of successful disposal of a spacecraft shall be at least 0,9 through to the end of life.

- CubeSats are currently **passively compliant**, so the probability of successful disposal is 1.0
  - CubeSats are **low-cost missions** and **less reliable** compared to larger satellite
  - Reliability of a CubeSat for 1 year lifetime is around ~0.6 (based on statistics)
  - This means that CubeSats cannot rely on a probability of successful disposal, but it should be guaranteed
  - **Dead-on-arrival** is the most limiting scenario in terms of altitude

- Passive compliancy will be challenged by Zero Debris in 2030
  - **Propulsion** or **drag augmentation** devices could be used for quicker re-entry
  - How can they be sufficiently **reliable**?

RE-ENTRY CASUALTY RISK

- Current modelling using ESA DRAMA predicts that CubeSats will demise during re-entry and shows a result of **zero risk** on ground (see example below)
- **Changes** to modelling can impact this result so that there is a non-zero casualty risk
- Further understanding of materials and units may generate this change
- Modelling is done on a spacecraft per spacecraft basis rather than **formation or constellation basis**
- Requires **more research**, will become more critical to GomSpace when moving into constellation / microsats



ZERO DEBRIS BY 2030

To achieve Zero Debris by 2030, there are multiple challenges ahead

LEO clearance within 5 years	Guarantee of succesful disposal

Consequences:

- Orbits limited to **max ~430 km altitude**, resulting in a **lifetime less than 1 year** in the worst case scenario
  - Requires propulsion for station keeping
  - Need to stay below certain altitude for the entire mission in case of failure at any point
- CubeSat designs will have to evolve and **costs will increase**
  - Platforms will have to be increased to accomodate thrusters (e.g. from 6U up to 8U)
  - Higher complexity due to thrusters in the design
  - Launch costs increased due to larger platforms
  - Additional operational effort needed for station keeping, also resulting in lower mission availability
  - Added costs will need to be accepted by customers
- **Less debris in LEO**

QUESTIONS?

ZERO DEBRIS BY 2030 – LEO CLEARANCE

“The limit orbit lifetime of a spacecraft or launch vehicle orbital stage in the LEO protected region shall be lower than 5 (TBC) years.”

Parameter	LEO clearance re-entry time	Mission lifetime
Requirement	< 5 years	> 4 years
Serves as?	Defines upper bound of launch altitude	Defines lower bound of launch altitude
Mass	Highest: 23.1 kg (incl. system margin)	Lowest: 19.3 kg (excl. system margin)
Drag coefficient	Lowest: 2.2	Highest: 3.0
Cross-sectional area	Lowest: 0.101 m^2 (tumbling with no deployed surfaces)	0.159 m^2 (operational average)
Atmospheric model	ESA latest estimation	ECSS Sample Cycle (solar cycle 23)
Result	Max 445 km, with +/-15km launcher uncertainty this results in **maximum 430 km launch altitude**	**Minimum 560 km launch altitude** to reach 4 year operational lifetime (passively) At 430 km launch altitude, incl. -15km launch uncertainty, the worst case lifetime is **0.95 year**

Conclusion: add propulsion for station keeping OR accept **very very** short lifetime