Hardware for sustainability

Marnix Verkammen
Engineer at EPFL Space Center

How would you define “space sustainability” ?

Sustainability **from space**

“ Using space as a platform to directly or indirectly address global problems. ”

- Getting space data from earth observation (EO) satellites
- Using space assets for problems on Earth (GNSS)

Sustainability **in space**

“ Viewing space as a natural resource for preservation, exploitation and exploration. ”

- Risk mitigation and management of space debris,
- Preservation of Dark & Quiet Skies

Sustainability **for space**

“ Protecting the terrestrial environment from the impacts of space activities. ”

- Assessing the impacts using Life Cycle (Sustainability) Assessment
- Mitigating impacts using ecodesign

Cited from: Wilson, A. R., & Vasile, M. (2023). The space sustainability paradox. Journal of Cleaner Production. DOI: 10.1016/j.jclepro.2023.138869

What hardware is needed for each pillar?

Sustainability **from space**

Sustainability **in space**

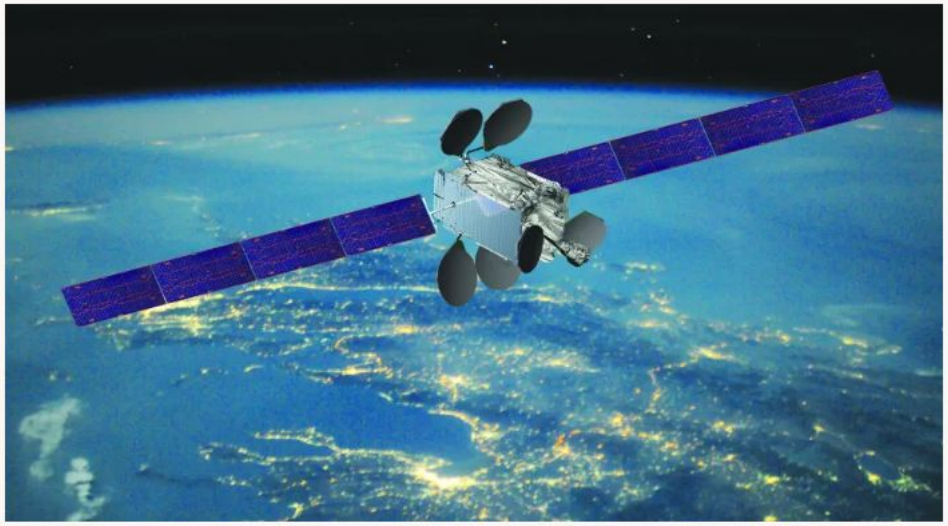
Recently : Fragmentation in GEO !

SPACENEWS 35 YEARS

Commercial

Intelsat 33e breaks up in geostationary orbit

Jason Rainbow October 19, 2024

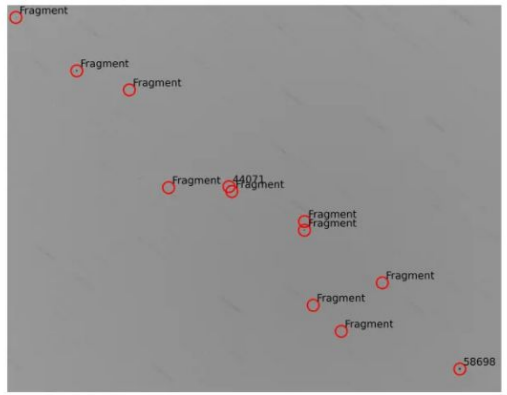


An artist's concept of a Boeing-built Intelsat EpicNG satellite. Credit: Boeing

In an Oct. 21 update, Intelsat declared the satellite a total loss. The company said it is working with government agencies to analyze data and observations, and has set up a Failure Review Board to investigate the anomaly's cause.

"Currently tracking around 20 associated pieces – analysis ongoing. S4S has observed no immediate threats and is continuing to conduct routine conjunction assessments to support the safety and sustainability of the space domain."

SPACEFLUX



A snapshot of Intelsat 33e's break-up taken Oct. 19 by U.K.-based Spaceflux. 44071 and 58698 are the WGS 10 (USA 291) and Ovzon-3 satellites, respectively, which Spaceflux said are unlikely in danger of being hit by the debris. "The problem is that there is a lot of uncertainty regarding the orbits of these fragments at the moment," Spaceflux spokesperson Viktoria Urban said Oct. 21. "They can be potentially dangerous for other satellites but we do not know that yet." Credit: Spaceflux.

Source: J. Rainbow, Intelsat 33e breaks up in geostationary orbit, Space News, Tempa, Florida, USA, 19 October 2024, Available: https://spacenews.com/intelsat-33e-loses-power-in-geostationary-orbit/

Impact on astronomy

Starlink strings of pearls in the night sky (dlr.de)

SKAO needs corrective measures from satellite ‘mega-constellation’ operators to minimise impact on its telescopes

nature astronomy

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nature › nature astronomy › letters › article

Letter | Open Access | Published: 02 March 2023

The impact of satellite trails on Hubble Space Telescope observations

Sandor Kruk ✉, Pablo García-Martín, Marcel Popescu, Ben Aussel, Steven Dillmann, Megan E. Perks, Tamina Lund, Bruno Merín, Ross Thomson, Samet Karadag & Mark J. McCaughrean

Credit: NASA

https://www.nature.com/articles/s41550-023-01903-3

Re-entry & impacts on humans

BBC

Home News Sport Business Innovation Culture Arts Travel Earth Audio Video Live

SpaceX rocket debris crashes into Poland

19 February 2025

https://www.bbc.com/news/articles/c62z3vxjplpo

GIF derived from video on X

Science brought to you by EPF Lausanne

NEWS | ENVIRONMENT

Burned-up satellites are polluting the atmosphere

As commercial fleets grow, concerns raised about ozone-destroying effects of metal particles

23 JUL 2024 · 3:50 PM ET · BY DANIEL CLERY

https://www.science.org/content/article/burned-satellites-are-polluting-atmosphere

"Almost no one is thinking about the environmental impact on the stratosphere," says atmospheric chemist Daniel Murphy of the National Oceanic and Atmospheric Administration's Chemical Sciences Laboratory. "It would be better to understand it now than when there's much more."

The very best Disney movie: "Dinosaur" (2000)

Sustainability for space

Image taken from the Disney film “Dinosaur” (2000)

What to consider?

- Environmental impacts throughout life cycle
  - Design phase
  - Manufacturing & Testing phase
  - Launch phase
  - Operation phase
  - End-of-life re-entry

See Lecture 8 & 9 on LCA and Ecodesign

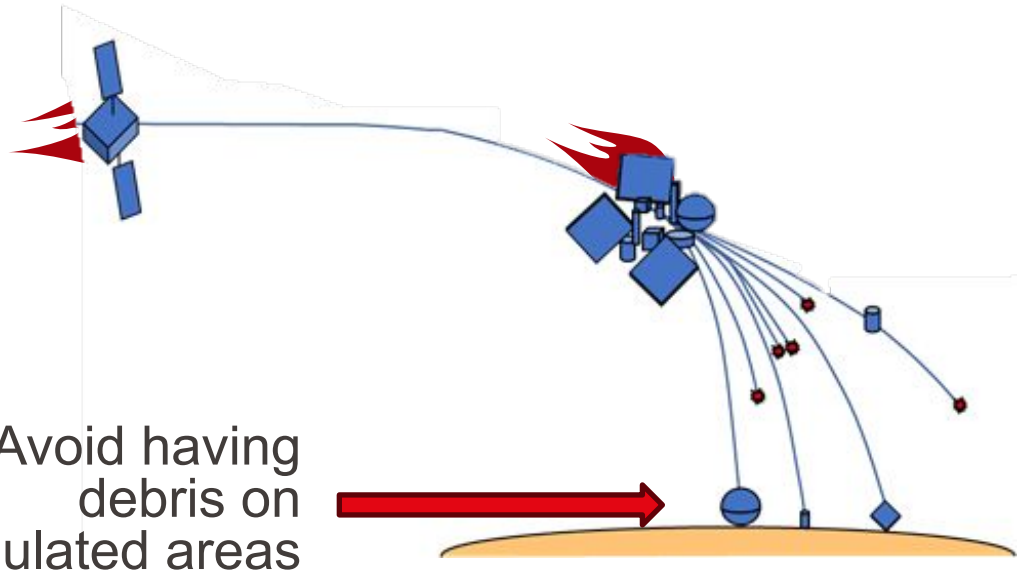
→ Discussed today

Question to you:

- What does “improving” environmental impacts during re-entry mean?
- What should designer take into consideration?

Re-entry considerations

- Kinetic energy converted in heat
- Heat melts the spacecraft Demise



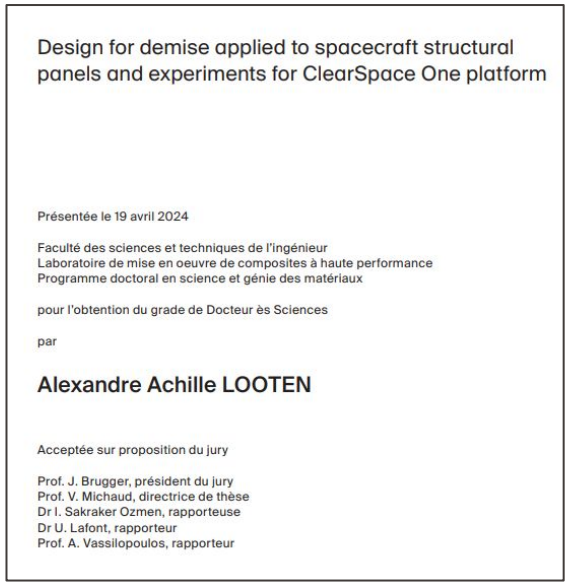
Avoid having debris on populated areas

Source: A game that every Aerospace engineer should play, namely “Kerbal Space Program”.
Enjoy ;-)

Re-entry considerations

- Kinetic energy converted in heat
- Heat melts the spacecraft Demise
  - Important to **design for demise**!
  - A lot of research is ongoing on novel materials and trajectory optimization.

Source: A game that every Aerospace engineer should play, namely “Kerbal Space Program”.
Enjoy ;-)



Design for demise applied to spacecraft structural panels and experiments for ClearSpace One platform

Présentée le 19 avril 2024

Faculté des sciences et techniques de l'ingénieur
Laboratoire de mise en oeuvre de composites à haute performance
Programme doctoral en science et génie des matériaux

pour l'obtention du grade de Docteur ès Sciences

par

Alexandre Achille LOOTEN

Acceptée sur proposition du jury

Prof. J. Brugger, président du jury
Prof. V. Michaud, directrice de thèse
Dr I. Sakraker Ozmen, rapporteuse
Dr U. Lafont, rapporteur
Prof. A. Vassilopoulos, rapporteur

https://infoscience.epfl.ch/entities/publication/064c9341-560d-438f-8f8e-1fe9d428e9a2

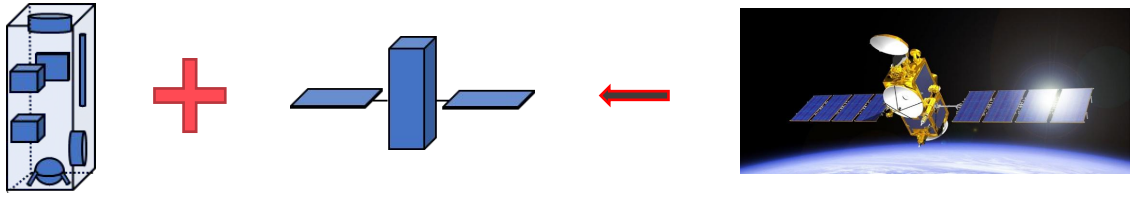
Atmospheric emissions of re-entry

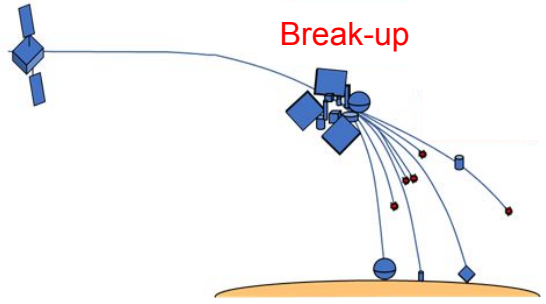
https://www.space.com/starlink-satellite-reentry-ozone-depletion-atmosphere

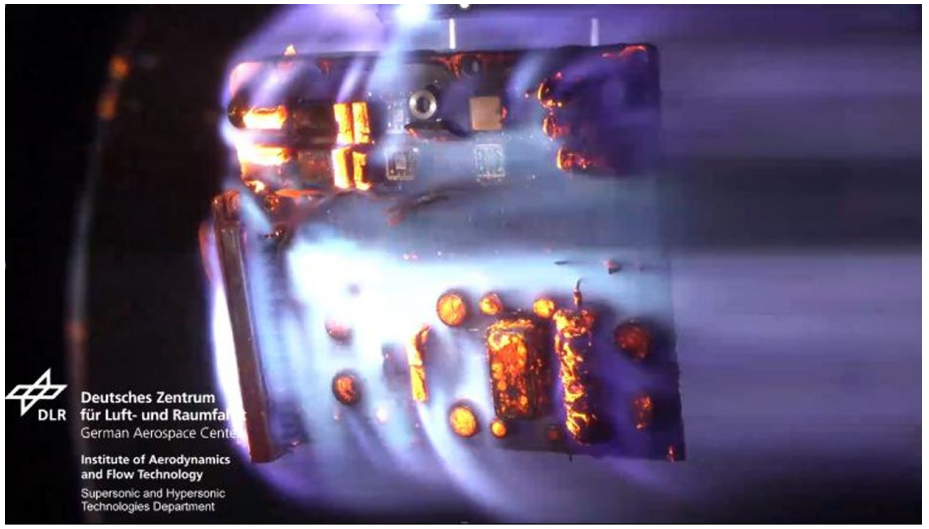
https://www.space.com/spacex-starlink-reentry-pollution-damage-earth-atmosphere

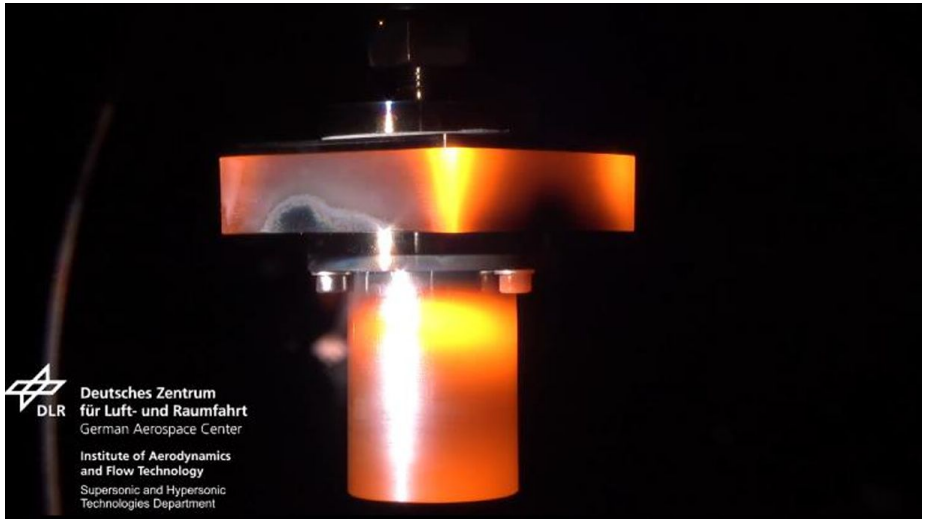
Demisability: an ongoing research

- How do certain components demise?
  - Electronics
  - Sun sensor (with glass)
- How to model breakups during re-entry?
  - DEBRISK tool









Source right images: B. Ganazer et. al., “Demise behaviour of platform optics and electronics”, ESA Clean Space Days, Noordwijk, 2024. https://indico.esa.int/event/516/contributions/9991/
Source left diagram: A. Bulleci et. al., Roadmap of DEBRISK V4: foreseen modeling and methodology improvements, Clean Space Days, Noordwijk, 2024: https://indico.esa.int/event/516/contributions/10025/

Environmental impacts

The demise of spacecraft cause environmental impacts

- Emissions
- Particle release

Not demising a spacecraft properly can cause harm

- Landing in populated areas,
- Littering natural reserves (sometimes with toxic materials)

So, should you favour Design for Demise, or re-entry in one piece?

What are the other technical implications of either choice?
 propulsion, risk management, etc

Sustainability in space

Image taken from the film “Gravity” (2014)

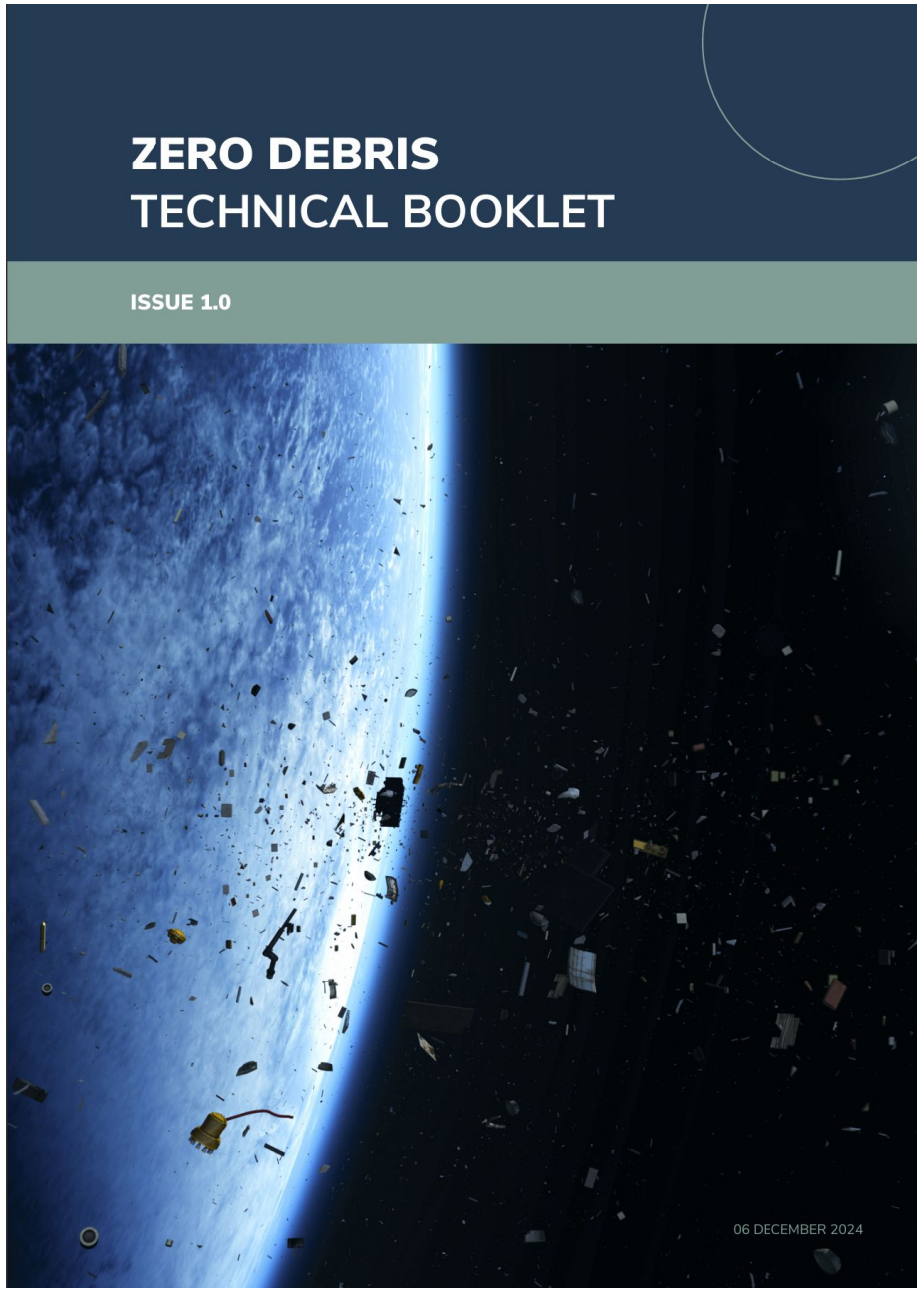
Zero Debris Technical Booklet

Complementing the Zero Debris Charter

Document written by the space community, to outline the Zero Debris **needs**, **solutions** and **enablers** roadmap until 2030

Needs:

1. Prevent Release of Debris
2. Guarantee Timely and Successful Clearance
3. Prevent Debris Generation through Break-ups or Collisions
4. Improve Space Traffic Surveillance and coordination
5. Prevent Casualties on Ground
6. Understand and mitigate adverse consequences of space objects and debris.



Openly available on ESA's website.
See their announcement of the first version's publishing here.

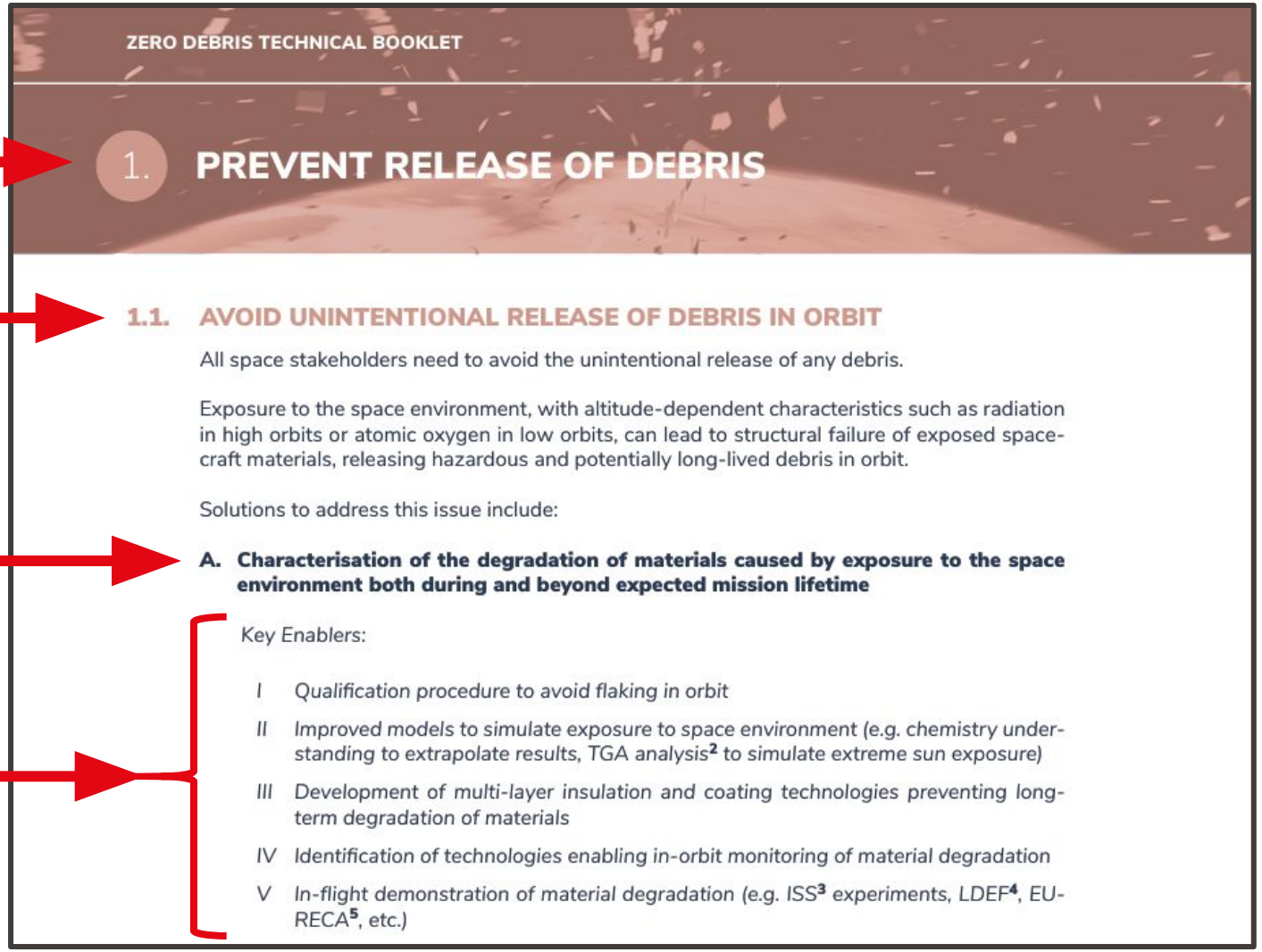
Example of Need, Solution and Enabler in the Booklet

Need

Subdivision of Need

Solution

Key enablers



ZERO DEBRIS TECHNICAL BOOKLET

1. PREVENT RELEASE OF DEBRIS

1.1. AVOID UNINTENTIONAL RELEASE OF DEBRIS IN ORBIT

All space stakeholders need to avoid the unintentional release of any debris.

Exposure to the space environment, with altitude-dependent characteristics such as radiation in high orbits or atomic oxygen in low orbits, can lead to structural failure of exposed space-craft materials, releasing hazardous and potentially long-lived debris in orbit.

Solutions to address this issue include:

A. Characterisation of the degradation of materials caused by exposure to the space environment both during and beyond expected mission lifetime

Key Enablers:

I *Qualification procedure to avoid flaking in orbit*

II *Improved models to simulate exposure to space environment (e.g. chemistry under-standing to extrapolate results, TGA analysis[2] to simulate extreme sun exposure)*

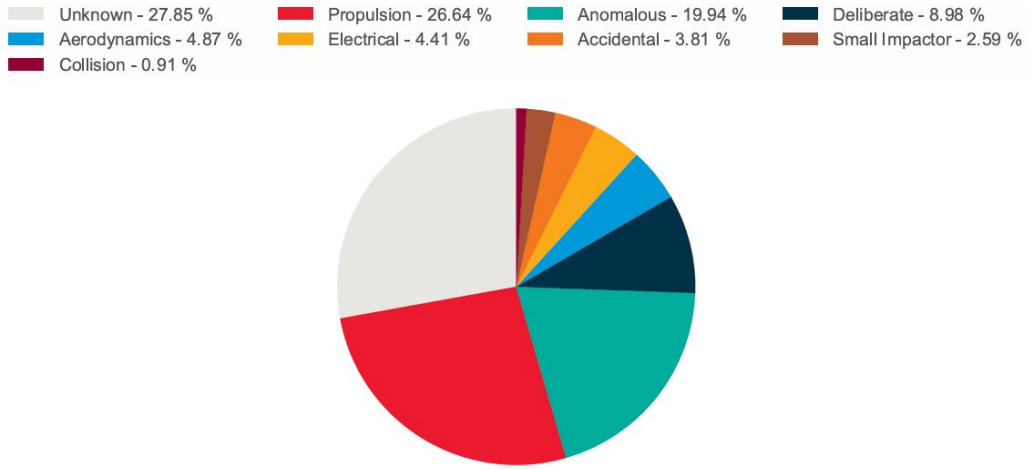
III *Development of multi-layer insulation and coating technologies preventing long-term degradation of materials*

IV *Identification of technologies enabling in-orbit monitoring of material degradation*

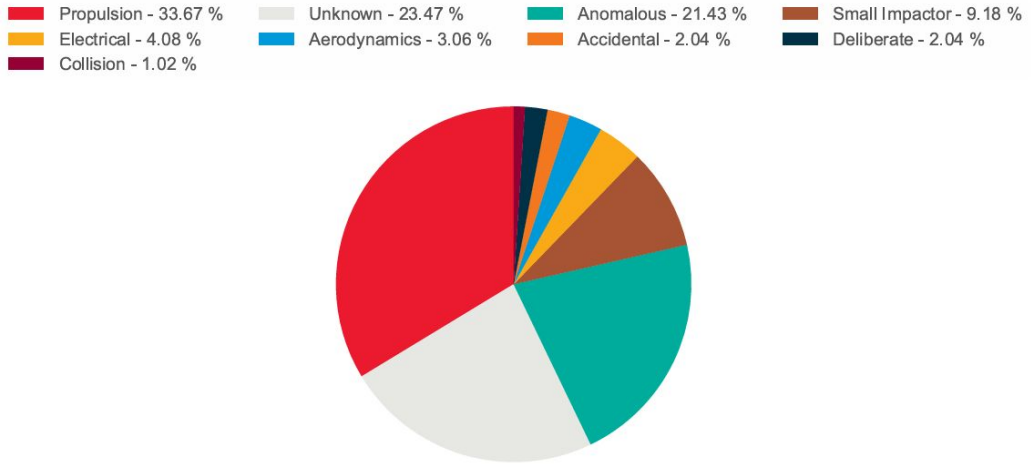
V *In-flight demonstration of material degradation (e.g. ISS[3] experiments, LDEF[4], EU-RECA[5], etc.)*

What are some other causes of breakup?

- ESA's fragmentation database
- DISCOSweb



(a) Whole history.



(b) Last 10 years.

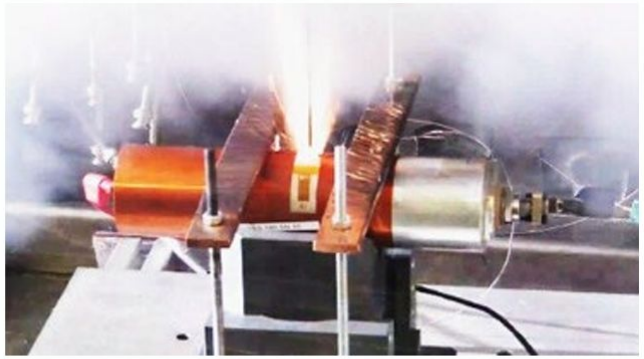
Passivation considerations

- Propellant Tank passivation
  - Propellant tends to heat up increase tank pressure Explode the tank
  - You must eject all propellant

- Battery passivation
  - ESA is developing battery containments for satellites up to 100kg (small satellites)
  - Passivation includes depletion of battery and disconnecting electrical systems

Batt. Module explosion

Micrometeorid impact test

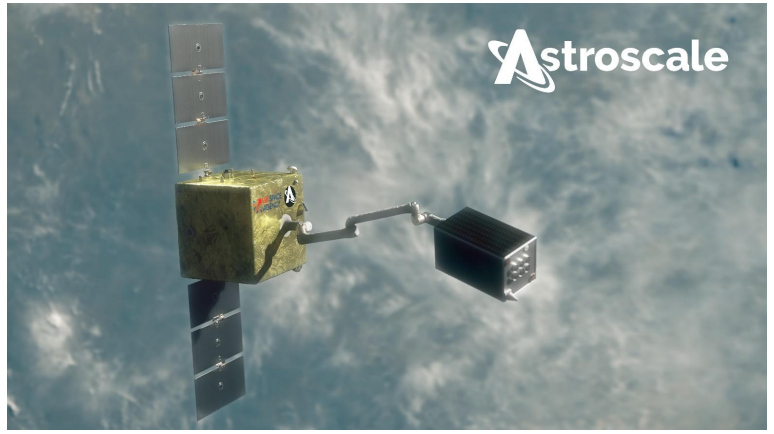


Internal short-circuit test

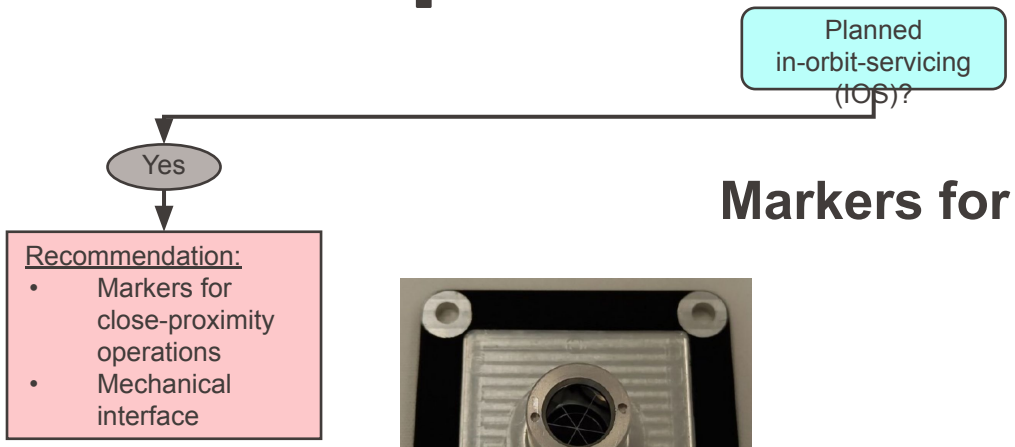
Active Debris Removal

- Many missions are being designed
- Some require dedicated hardware
  - Astroscale
- Others can grab any debris
  - Clearspace (ClearSpace 1 & UK's CLEAR mission)
  - Other research

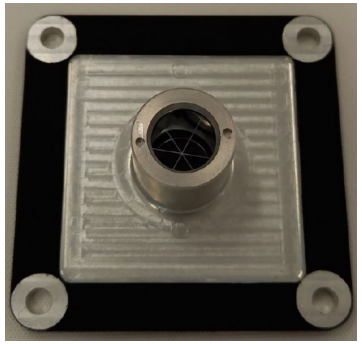
- Question is: should you rely on these services for your mission's sustainability in space?

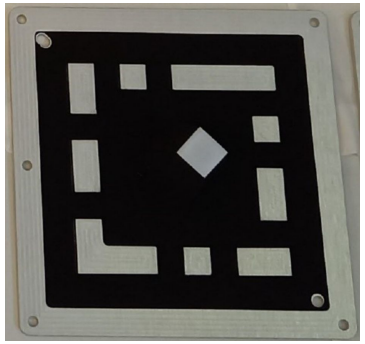


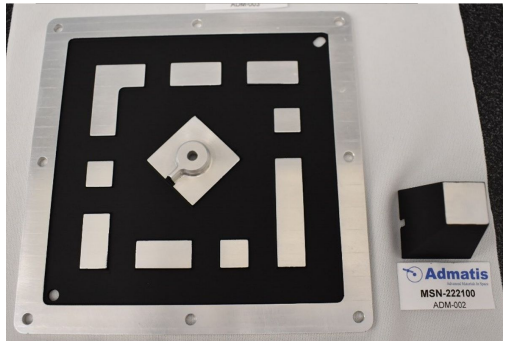
Good hardware practices for sustainability in space



Markers for close-proximity







2D markers

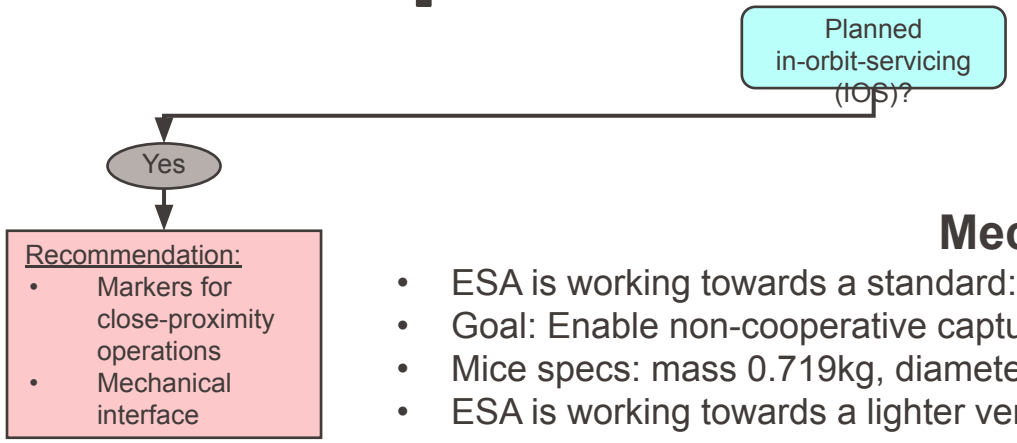
- For far to close rendezvous (50.5m)
- Planar distribution needed
- Can be 2D patterns and/or Laser Ranging Retroreflector (LRR)
- Size of LRR above: 60x60mm
- Mass of LRR above: approx. 0.036kg

3D markers

- For capture (less than 5m)
- Only a single 3D marker is needed for pose estimation
- Size of unit above: 150x150mm
- Mass of unit above: approx. 0.25kg

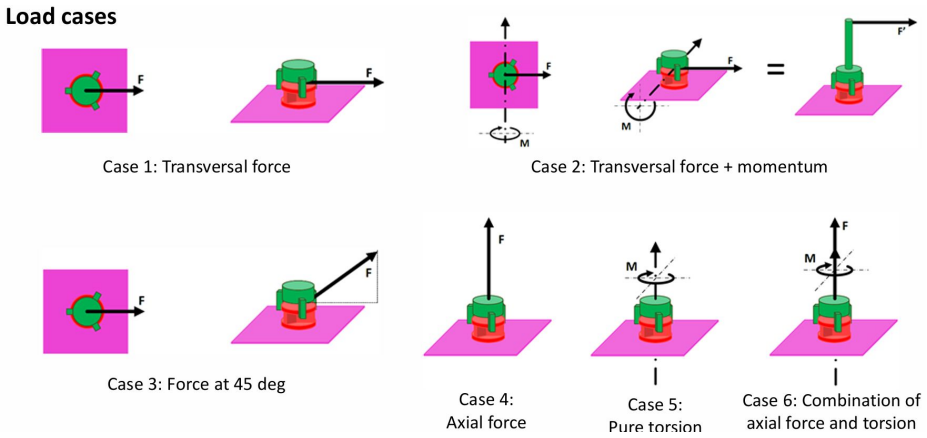
Source: L. Szegedi et.al., Markers Supporting Navigation Development and Qualification, Clean Space Industry Days 2023, ESTEC, Noordwijk, the Netherlands, 19 October 2023. Available: https://indico.esa.int/event/450/contributions/8886/

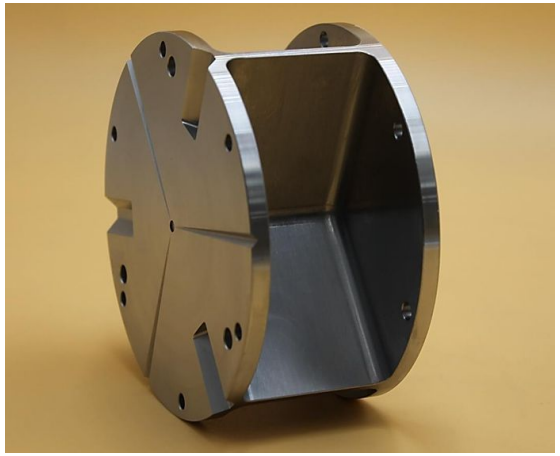
Good hardware practices for sustainability in space

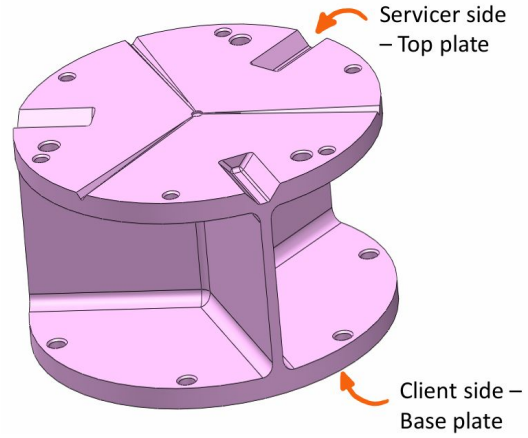


Mechanical Interface

- ESA is working towards a standard: MICE (Mechanical Interface for Capture at End-of-Life)
- Goal: Enable non-cooperative capture of satellite after EOL (End-Of-Life)
- Mice specs: mass 0.719kg, diameter 98mm, height 50mm
- ESA is working towards a lighter version of MICE: MICE-LITE

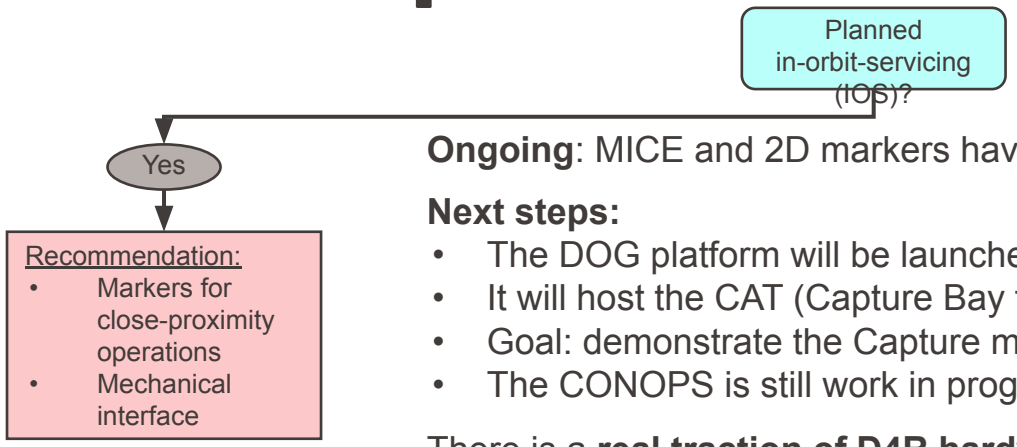






Sources:
- C. Carnañes et.al., CAT-IOD: MICE (Mechanical Interface for Capture at End-of-Life): Qualification results and future use, 2023 Clean Space Industry Days, ESTEC, Noordwijk, the Netherlands, 19 October 2023. Available: https://indico.esa.int/event/450/contributions/8878/
- L. Valencia Restrepo et.al, MICE-LITE: Reducing mass of the Mechanical Interface for Capturing at End-of-Life to facilitate its integration with small satellites, Clean Space Days 2024, ESTEC, Noordwijk, the Netherlands, 10 October 2024. Available: https://indico.esa.int/event/516/contributions/10011/

Good hardware practices for sustainability in space

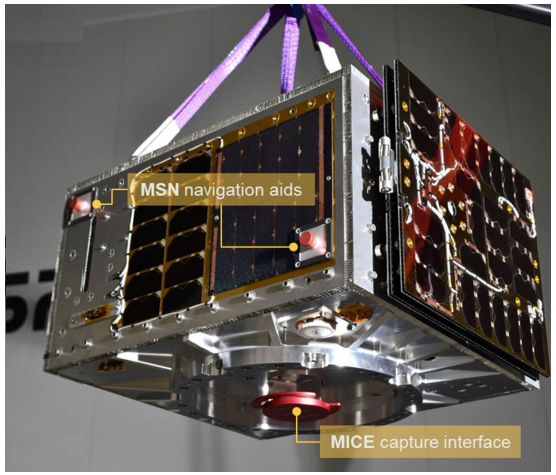


Ongoing: MICE and 2D markers have been launch on the LUR-1 satellite in 2023.

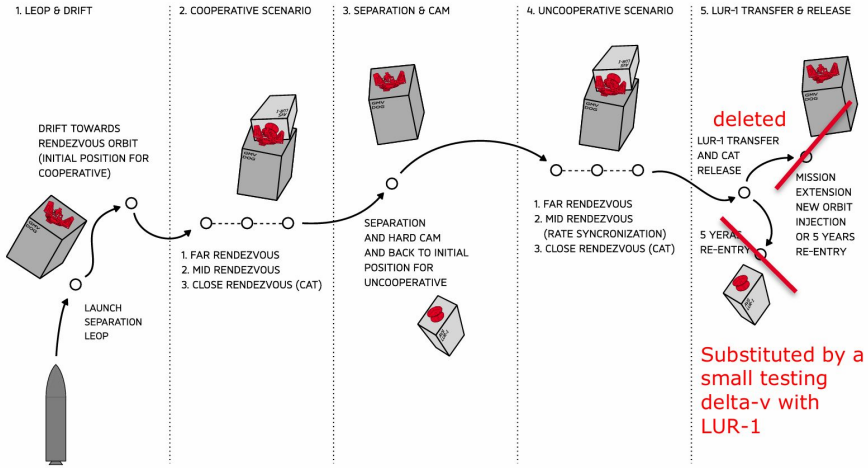
Next steps:

- The DOG platform will be launched around 2027-28, towards the EOL (End-Of-Life) of LUR-1
- It will host the CAT (Capture Bay for Active Debris Removal, ADR) payload
- Goal: demonstrate the Capture mechanism
- The CONOPS is still work in progress (see figure below)

There is a **real traction of D4R hardware**: The Copernicus Sentinel Expansion missions (more info here) will adopted D4R (Design for Removal) interfaces



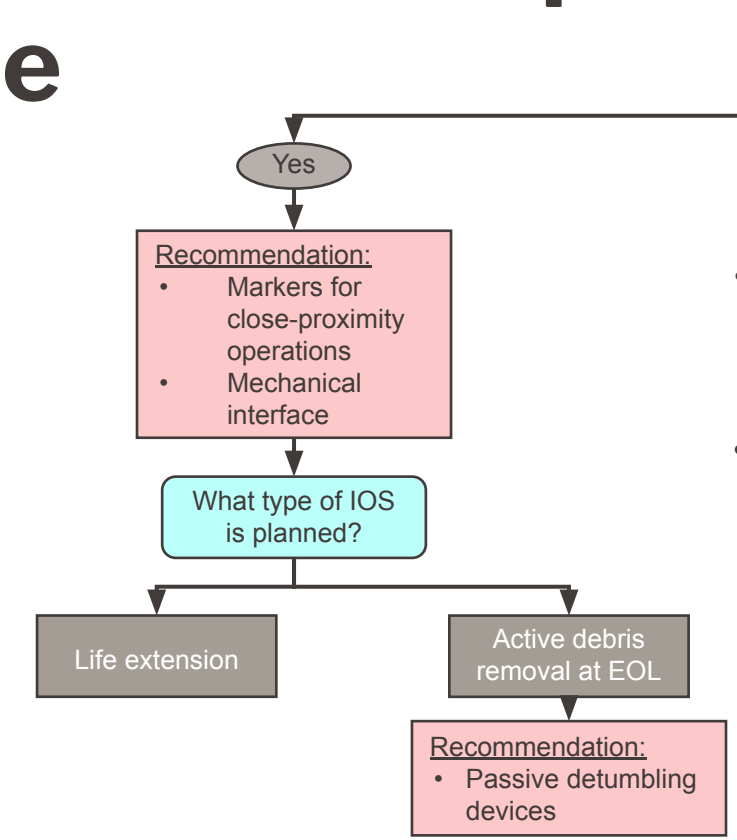
LUR-1, assembled with MICE and the navigation aids



Source: A. Cortese et.al., CAT-IOD: CAT in-orbit demonstration mission for a prepared active debris removal scenario, Clean Space Days, ESTEC, Noordwijk, the Netherlands, 8 October 2024. Available: https://indico.esa.int/event/516/contributions/9965/

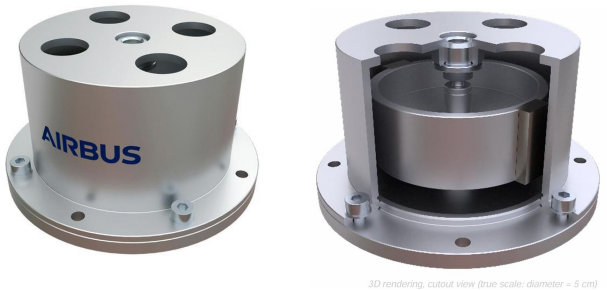
Interesting Linkedin post by ESA Space Safety: Post | LinkedIn

Good hardware practices for sustainability in space



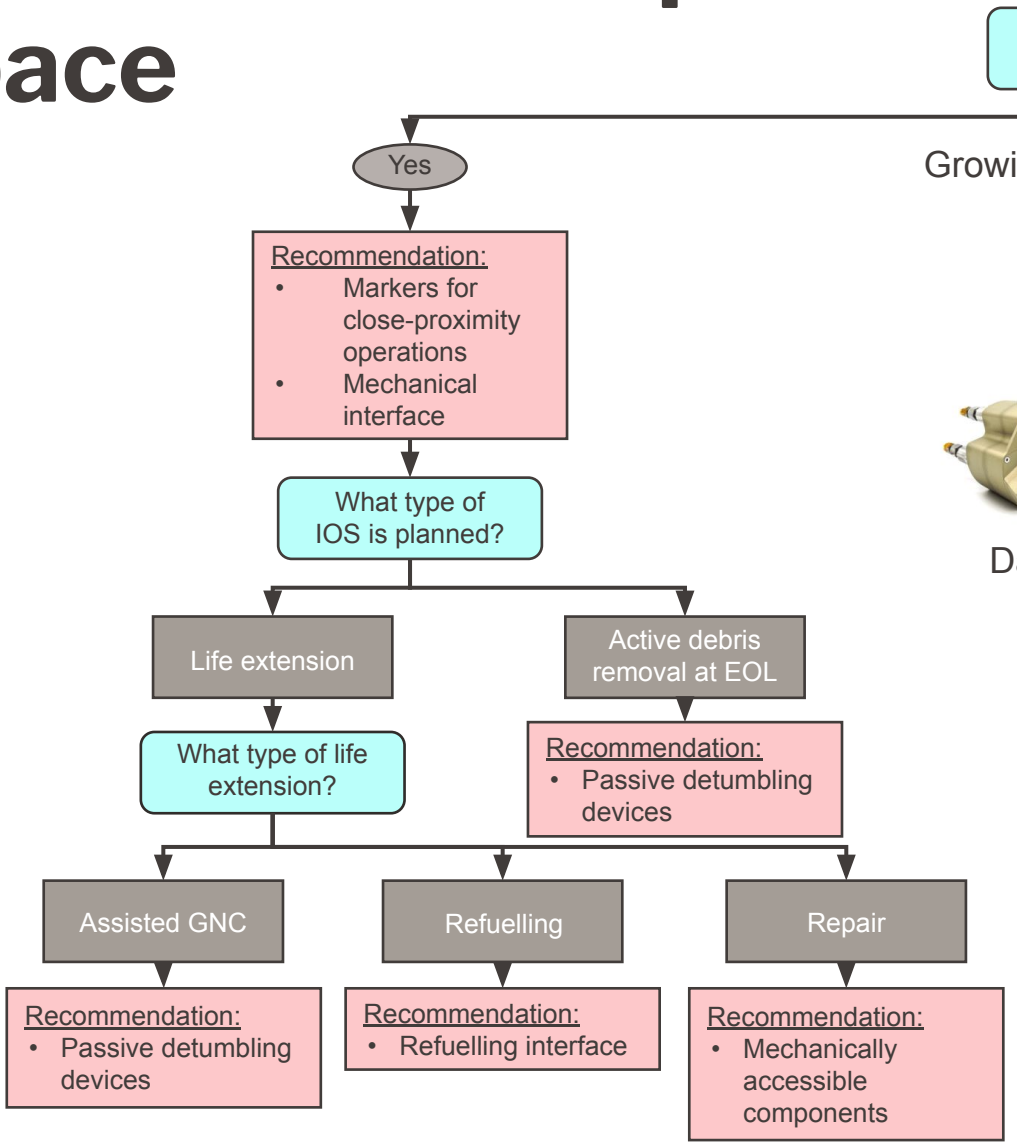
Passive detumblers

- Passive **Magnetic Detumblers**
  - Use the interaction between Earth magnetic field and the spacecraft
  - Effective if the magnetic torquers are shortcircuited
  - But, solar radiation pressure may diminish the efficiency (or counteract it).
- **Internal kinetic and electromagnetic device** (such as Airbus's DETUMBLER, shown in pictures)
  - Works by having a freely rotating rotor with magnets
  - Differential rotation rates between the satellite and the rotor causes electromagnetic forces
  - Effect: satellite reaches a constant spin rate, instead of spinning up.

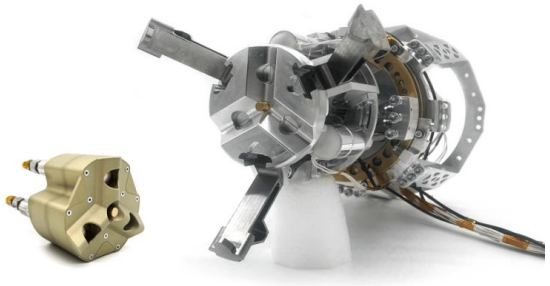


Sources:
- A. Benoit et.al., The puzzling dynamic evolution of defunct satellites: a challenge for Active Debris Removal missions, 2023 Clean Space Industry Days, ESTEC, Noordwijk, the Netherlands, 19 October 2023. Available: https://indico.esa.int/event/450/contributions/8894/
- M. Senes et.al, A passive device for postmortem detumbling/antitumbling of LEO satellites, to facilitate active removal, 2023 Clean Space Industry Days ESTEC, Noordwijk, the Netherlands, 10 October 2024. Available: https://indico.esa.int/event/450/contributions/8879/

Good hardware practices for sustainability in space



Growing number of refuelling interfaces and services. See examples below:

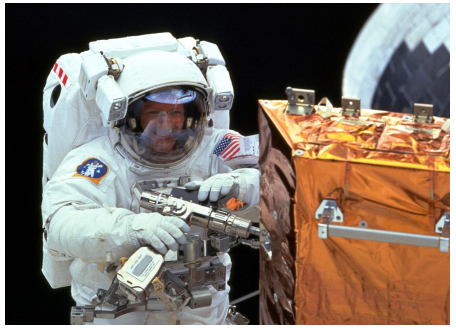


Dawn Aerospace's Docking and Fluid Transfer Port

Orbit Fab's refuelling interface

etc

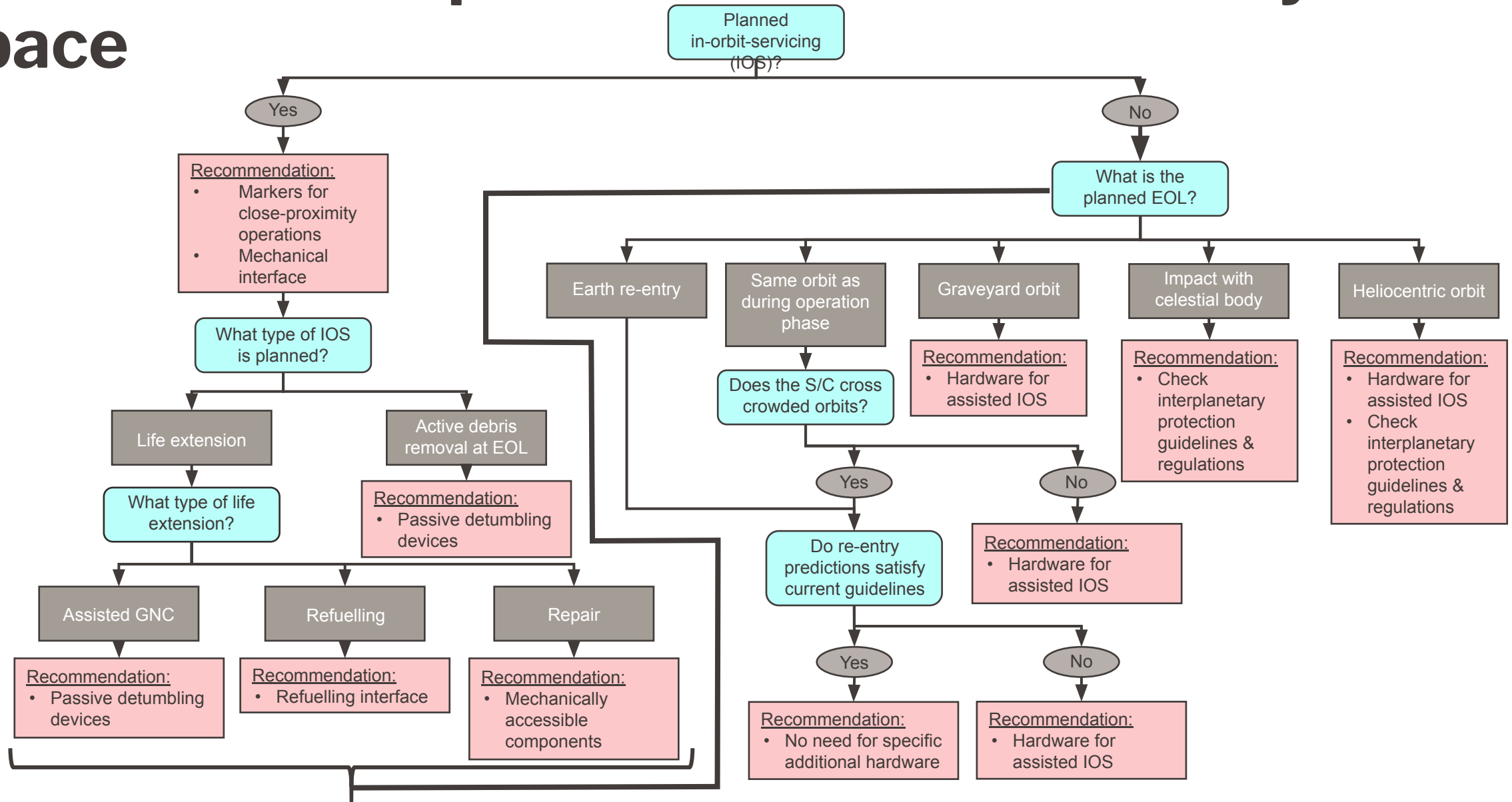
An example of a spacecraft with "mechanically accessible components" is the Hubble Space telescope. It was designed to be serviced in orbit.



Sources:

- S. Hill, Orbit Fab Refuelling Interface and Service Mission Development Progress in Europe, Clean Space Days 2024, ESTEC, Noordwijk, the Netherlands, 9 October 2024. Available: https://indico.esa.int/event/516/contributions/9986/
- D. Werner, Dawn unveils docking and refuelling port, Space News, Las Vegas, USA, 1 August 2024, Available: https://spacenews.com/dawn-unveils-docking-and-refueling-port/
- NASA, Missions to Hubble. Available: Missions to Hubble - NASA Science

Good hardware practices for sustainability in space



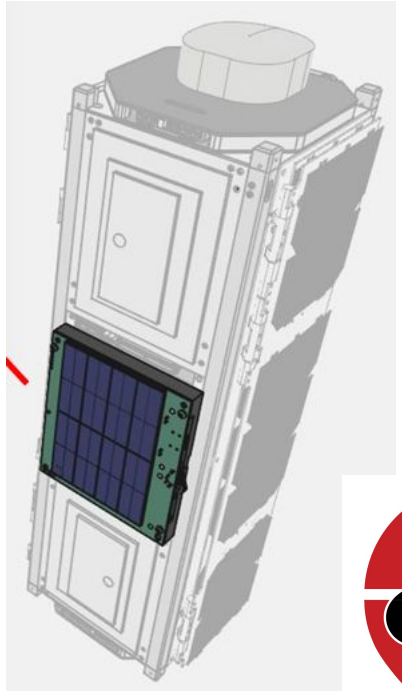
Dark & Quiet Skies

- Dark Skies good practices:
  - Simulate your reflectivity
  - Limit the use of reflective surfaces
  - Consider darkening you satellite (perhaps in addition to using retroreflectors)
  - Re-consider your mission architecture
    - Can you limit the number of satellites?

- Quiet Skies good practices:
  - Test and simulate the radio-emissions of your satellite
  - Adhere to ITU regulations and given frequency band
  - Inform others (satellite operators, ground centres, radio astronomers) about your mission and used frequency

Improve tracking: Retroreflectors and/or transponders

Interoperability for satellite tracking aids: the Satellite Retroreflector Standards



BEECON - TU Berlin

Clean Space Days (8-11 October 2024): Spacecraft Beacons: radiocommunication approaches towards interoperable autonomous self-identification and tracking · Indico at ESA / ESTEC

Key takeaways for your missions

Now it is up to you!

- L01- Which guidelines and legal framework are applicable to your mission? What will be the impacts? Which type of orbits and what is their impact
- L02- What is your approach for SSA, impact of space weather and impact on radio astronomy? Is there a risk (qualitative analysis)? Which part could be improved?
- L03- Is your mission eligible for a rating and what are the main inputs you have for each module? Perform a qualitative analysis of the rating
- L04- Which hardware for space sustainability (in space and for space) is already included and what are your recommendations?
- L05- Perform analysis using DRAMA (define the needs of analysis to be performed, see the frame of the analysis and parameter to modify, analysis and outcomes)

Mid-Term presentations

- 10-12 min presentation + 8 minutes Q&A (mission from teachers and also by the students)

#4	14:20	PhotSat
#3	14:40	PlantB
#2	15:15	Starlink/IRIS^2 or own mission
#1	15:35	ADS EO mission

Interesting event

Interesting event

On Thursday March 27th, Matthieu Derrey, a programme manager at Airbus Defense and Space, and creator of a **"space sustainability fresco"** with its association Azurite, will be at EPFL for the Bridging Initiatives and Perspectives event !

He's also coming to perform the teamwork exercise of the space sustainability fresco and we are looking for interested people to join for 2.5 hours (ideally we would be around 12 people). The fresco is built in a similar way as the ones for climate, adapted for the problematics of space sustainability, to have participants understand the concepts and challenges, and also discover solutions!