Space Sustainability

Overview of the topic and the approach taken by Aurora Propulsion Technologies

Whitepaper by

AURORA
PROPULSION TECHNOLOGIES

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White Paper Sustainable Space
What does it mean?

1. Sustainability in the space industry
    1. On-ground sustainability
    2. Launch and re-entry sustainability
    3. In-orbit sustainability
2. Aurora Approach to Sustainable Space
    1. Propulsion: a key tool for enabling extended missions
    2. Deorbiting: Sustainable end of mission for satellites
3. Implementing Sustainable Space for Space Operators
    1. Space conservation is a common responsibility
    2. Why space sustaiability is so important?
    3. Regulatory aspects
    4. In-orbit sustainability improves on-ground sustainability
    5. Future outlook

1. Introduction to sustainable space

Sustainability in the Space Industry

1. On-ground sustainability

- Impact of the space industry on our environment on the Earth

2. Launch and re-entry sustainability

- Impact of space launches
- Impact of the re-entry of objects into the Earth's atmosphere

3. In-orbit sustainability

- Impact of space debris
- Impact on other planetary bodies

1. On-ground sustainability

Impact of the space industry

This topic entails the impact of the industry on the conventional sustainability topics such as the environmental footprint of manufacturing or business travel.

These topics are well-researched, and analysis is fortunately widely available. Traditional methodologies are applicable to the space industry as a whole.

The main difference is that production volumes are extremely small in the space industry: this means that for the most part, raw resource utilization is not an issue. For example, compare the yearly resource demands of 500 000 tons of batteries on new Tesla vehicles, to the ~10 tons of batteries used by the whole space industry.

Space as an enabler of sustainability

The contribution of the space industry on sustainability as a whole cannot be understated. Our understanding of global warming and countless other environmental topics heavily rely on the data gathered by satellites. Every climate model uses satellite data.
Satellites are also crucial in finding and focusing the appropriate solutions to minimize many environmental problems and improve the impact of healing measures such as reforestation. This applies not only to climate change but also countless more localized issues.

2. Launch and re-entry sustainability

Impact of space launches

In terms of carbon footprint, the direct emissions of space launches are surprisingly small: in the process of delivering a typical CubeSat into orbit, the flights of the personnel responsible for integrating the satellite to the deployer create more emissions than the launch itself. The total emissions of launches are further reduced by the reusability of launchers.

Another concern that is sometimes brought up is the impact of dropping the launch vehicle first stages in the ocean or on land. This indeed does cause rare but major hazards. In the marine ecosystem the impact is still greatly smaller than for example that of sunken ships. However, this impact is already greatly reduced, and will continue to be reduced by the reusability of launcher first stages.

Impact of re-entry

The impact of hardware re-entering the Earth's atmosphere is an important topic as well: the potential hazards include

- Impact of debris dropping to Earth
  - This is prevented by Design For Demise, "D4D", which means that satellites are designed so that they fully burn up in the atmosphere, instead of surviving the trip all the way to the surface
- Impact of vaporizing man-made hardware into the upper atmosphere
  - The impact of man-made hardware makes no difference compared to the natural meteoroids that rain into the atmosphere at 40 000 tons/year

3. In-orbit sustainability

We must ensure that space remains usable not only in 10 years but in 100 and 1000 years. The enablers for this are

- Zero-debris approach: less debris generated than deorbited by natural or artificial means
  - Deorbiting of satellites after their mission is the essential first step
    - Very Low Earth Orbits are the best solution as any dead or broken satellites naturally deorbit quickly
  - End-to-end automated collision avoidance infrastructure to prevent generation of debris clouds by impacts
    - Collision avoidance thrusters on satellites
    - Space Situational Awareness and Space Traffic Management infrastructure for detection of and automated response to conjunctions
  - On higher orbits, Active Debris Removal must be done proportionally to the amount of deployed satellites
- Radio spectrum sustainability
  - Standards that allow different users to access communication frequencies according to their needs: both highly shared mobile network-like bands for mass utilization, as well as a few high-cost dedicated bands for those who require them
- Planetary protection
  - Ensuring that we do not infect other planetary bodies with Earth life in an uncontrolled manner
- In-space economy
  - In the long term, rather than the space industry consuming Earth resources, it should contribute to them instead. Not only should the resources needed in space be sourced from space, but for example the future of cloud computing could be space-based, allowing for much more efficient solar power generation instead of taxing Earth power generation

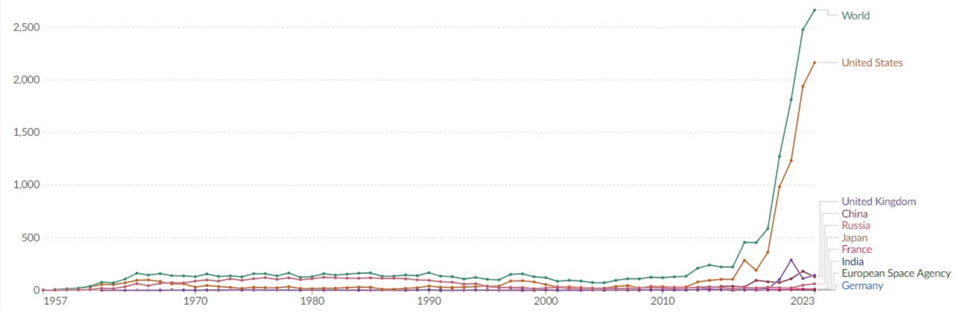
3. In-orbit sustainability

The core problem with the Low Earth Orbit is the generation of space debris which is currently somewhat proportional to the amount of satellites launched which grows quickly as seen in the figure on the right.

LEO capacity is not the problem

Provided that the topic of space sustainability is taken seriously, it is possible to have in the order of a million operational satellites in orbit at once. However, if we let the amount of debris increase, the limiting factor is the non-controllable debris instead of functional satellites.

More operational satellites fit into LEO than uncontrollable debris: currently there's 29 000 objects of 10 cm+ and 670 000 objects of 1 cm+ which are not able to react to potential impacts. With the ability to control all of the objects, one million can still be managed assuming proper Space Traffic Management practices



Annual number of objects launched into space
source: ourworldindata.org

2. Aurora Approach to Sustainable Space

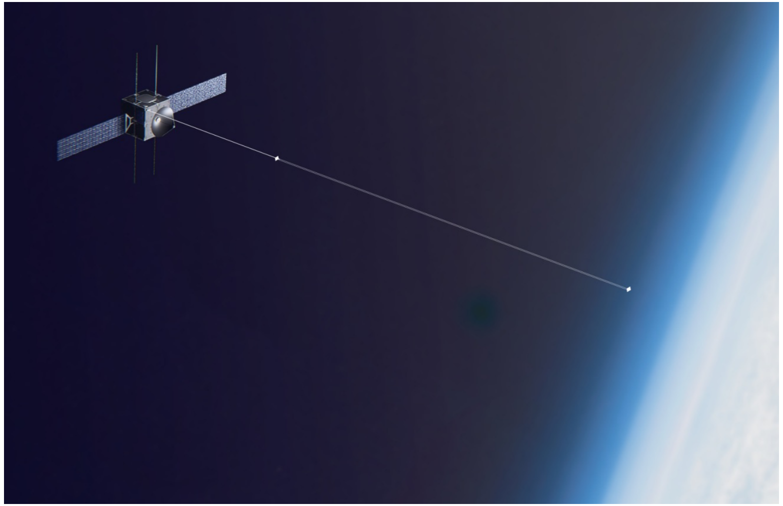
2. Aurora Approach to Sustainable Space

For each of the areas of space sustainability Aurora follows three key principles of action. These principles drive the development of our products and technologies for sustainability in space.

The first principle is to **maintain space debris free** by reducing the amount of debris in orbit. In Aurora this is done by miniaturizing the size and weight of our orbital products. Less material in orbit will reduce the amount of material sent in to space, reducing the environmental impact of both the spacecraft and its launch. Design for demise is also easier with smaller systems.

The second principle is to enable the **reuse or recycling** of spacecraft. We strive to develop systems that allow for extended missions and the repurposing of spacecraft after their original missions. This is an enabler for the creation of a second hand satellite market.

The final principle is the enabling the removal of spacecraft from orbit to minimize the generation of debris. This is done by our proprietary product line of Plasma Brakes designed to **deorbit** satellites after at the end of their extended missions.

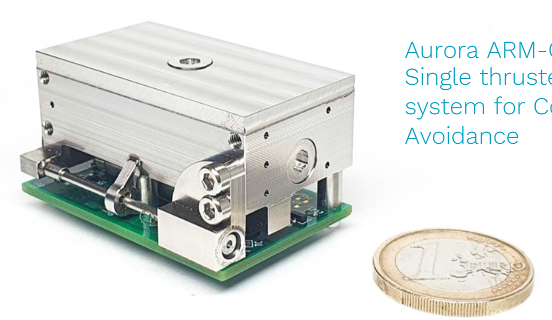


Propulsion: a key tool for enabling extended missions

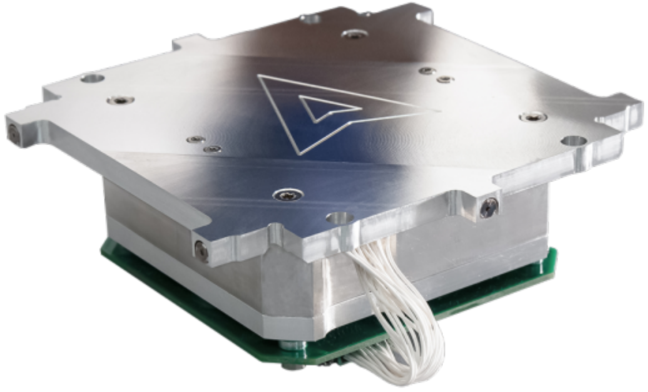
Propulsion is a key tool for management of a satellites precise position and speed in orbit, together with other systems it is also used for attitude or angle of flight control. Key target of propulsion use is to extend satellite lifetime by avoiding hazards such as collisions and by prolonging in orbit lifetime.

Aurora Propulsion offering targets **Collision Avoidance** for very small and small Satellites. In addition our special products using the same thrusters can be configured for proximity operations, constellation formation management and other typical propulsion use cases.

The collision avoidance is done by single matchbox sized all-in-one thruster module. Featuring a single thruster, propellant tank with propellant to enable 5 collision avoidance maneuvers for a 25kg satellite. Collision risk monitoring service and crash warning with a collision avoidance procedure is provided through partner services. Other use cases for propulsion are tailored to satellite specifications.



Aurora ARM-C Single thruster system for Collision Avoidance



AuroraSat-1 ARM thruster system with 6 attitude control thrusters

Deorbiting: Sustainable end of mission for satellites

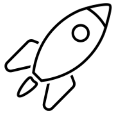
Deorbiting is the final stage of a satellites mission. The target of deorbiting is to clear the satellite from orbit according to regulations and ensure that low earth orbits are as clear of debris from unused satellites as possible.

Aurora has designed and manufactures deorbiting devices for Small Satellites from less than 1 kg cube sats to larger 250- 300 kg spacecraft. The technology named **Plasma Brake**, utilizes an electrically charged microtether and control system to generate drag that causes the satellite to slow down. Earths gravitation then pulls the spacecraft over time to burn in the atmosphere as a shooting star.

3. Implementing Sustainable Space for Space Operators

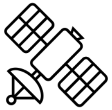
Space conservation is a common responsibility

As the orbital space is used by all parties, it is crucial that everyone is active and collaborates in the space debris mitigation



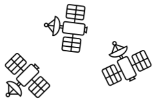
1. Launchers

- Terminal / 3rd stage deorbiting



2. Large satellites

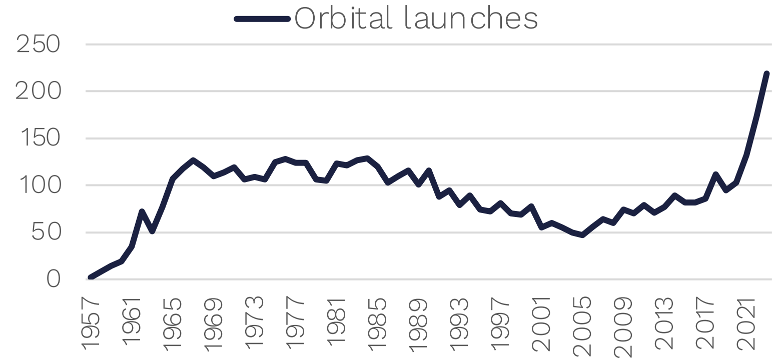
- Deorbit
- Dead man's switch



3. Small satellites

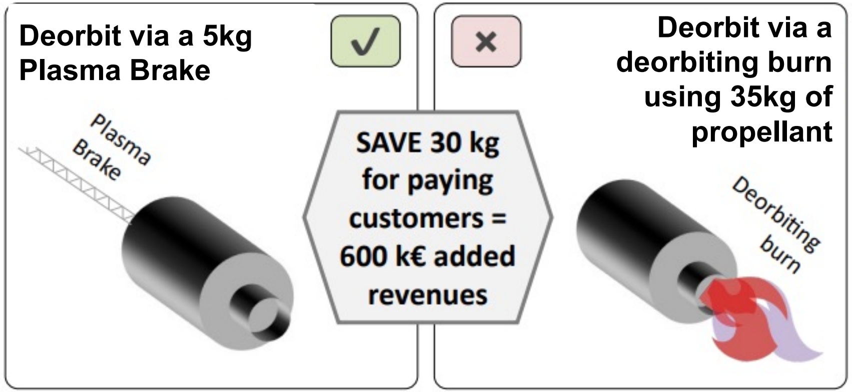
- Deorbit
- Collision avoidance
- Learning to use propulsion

Launchers: Record number of launches achieved in 2023



- The quantity of orbital launches reached a new record in 2023
- Minimizing the necessary mass to deorbit a terminal rocket stage especially in a small rocket, impacts its business case directly. Sustainability is also improved by being able to carry more payloads to orbit with a single launch

USE CASE: HOW TO DEORBIT WITHIN 5 YEARS
(rough example)
Used rocket stage with the mass of 750 kg orbiting at 750 km



Sources: Statista, Gunter's Space Page

Satellites: Satellites without propulsion and deorbiting capabilities are a potential hazards from the start

Large satellites

Deorbiting

- Use all propulsion for station keeping and prolonging the lifespan of the spacecraft, deorbit with a standalone deorbiting device
- Free up the orbit from the decommissioned satellite more quickly, to replace it with a new one more quickly
- Mitigate the creation of space debris, and keep the orbits clean for future use

Dead-man's switch

- Utilize the satellite to its fullest extent and decommission it only after it breaks down
- Deploy the deorbiting mechanism with a dead-man's switch to free up the orbit
- Improve sustainability aspects by unlocking the fullest potential of the satellites and limiting "unnecessary " launches

Small satellites

Deorbiting

- Mitigate the creation of space debris, and keep the orbits clean for future use

Collision avoidance

- Majority of CubeSats (i.e., 92%) lack on-board propulsion, making them effectively space debris from the start from the viewpoint of other spacecraft

Learning to use propulsion

- In-orbit maneuvering is still a niche expertise, and thus, teaching the next generation of space industry workers is important to build the necessary expertise to mitigate future collisions

Why propulsion & deorbiting is so important?

- In 2017, the US government logged 308,984 close call collision risks, and issued 655 ”emergency-reportable” alerts to satellite operators
- With ever increasing quantity of satellites in orbit, the figures are only going to rise

- Satellites without on-board propulsion are going to be “bombs”, indistinguishable from dead spacecraft, i.e., actual space debris
- Mitigating the amount of space debris with deorbiting devices is going to be crucial for the longevity of the space industry

Image courtesy of European Space Agency

Sources: Business Insider

Steps in regulation in the correct direction

- FCC 5-year deorbiting regulation
  - US-based Federal Communications Commission lowered the deorbiting rule from 25-years to 5-years. Any spacecraft in <2000km orbit, must deorbit within 5 years after the mission ends
  - Decision made, coming into effect in September 2024
- EU Space Law (EUSL) / New Space Law
  - EUSL safety pillar: Eensure a safe satellite traffic that tackles the increasing risk of collisions and damages by space debris
  - EUSL resilience pillar: Coherently protect the EU and national space infrastructure and assets against harmful threats (notably cyberattacks)
  - EUSL sustainability pillar: Guarantee the long-term sustainability of space operations, ensuring the ability of the EU to rely on space as an important enabler of services and economic growth
  - Currently in the making, could be adopted as soon as the first trimester of 2024
- EU Space Traffic Management (STM)
  - STM encompasses the means and the rules to access, conduct activities in, and return from outer space safely, sustainably, and securely
  - Currently in the making

Next needed steps in regulation

- Space Sustainability Rating (SSR)
  - SSR is a tiered scoring system that serves to quantify and measure sustainability decisions taken by operators
  - The Space Sustainability Rating is initiated by the World Economic Forum in 2016 and developed by a consortium involving the European Space Agency, the Massachusetts Institute of Technology, BryceTech and the University of Texas at Austin
  - As of 2023, managed by an independent association

Aurora’s commentary

Consistency in regulation is crucial. The current coverage of the regulation is localized, and for the rules to have a consistent and long-lasting global impact, they need to be global. We see a potential future where the EU & US regulatory requirements could be rolled out globally via United Nation’s Office for Outer Space Affairs if, and only if, the requirements are similar enough across different governing bodies. Special focus should be placed in

- space manoeuvrability i.e., collision avoidance
- deorbiting

We also believe that ultra-low orbits (i.e. <300km), should be less scrutinized due quick naturally occurring decommissioning

In-orbit sustainability improves on-ground sustainability

By utilizing the satellite for its entire lifespan and deorbiting it only after it no longer works. Over a long timeframe the satellite operator can achieve the same service outcome with

- Less satellite replacements required
  - Less launches required
  - Less satellites required

If a satellite lacks propulsion, adding a small collision avoidance propulsion system lowers the risks of a in-orbit collision by a significant amount

- If a satellite crashes into another one, the operator needs to replace the broken satellite by launching a new satellite onboard another rocket

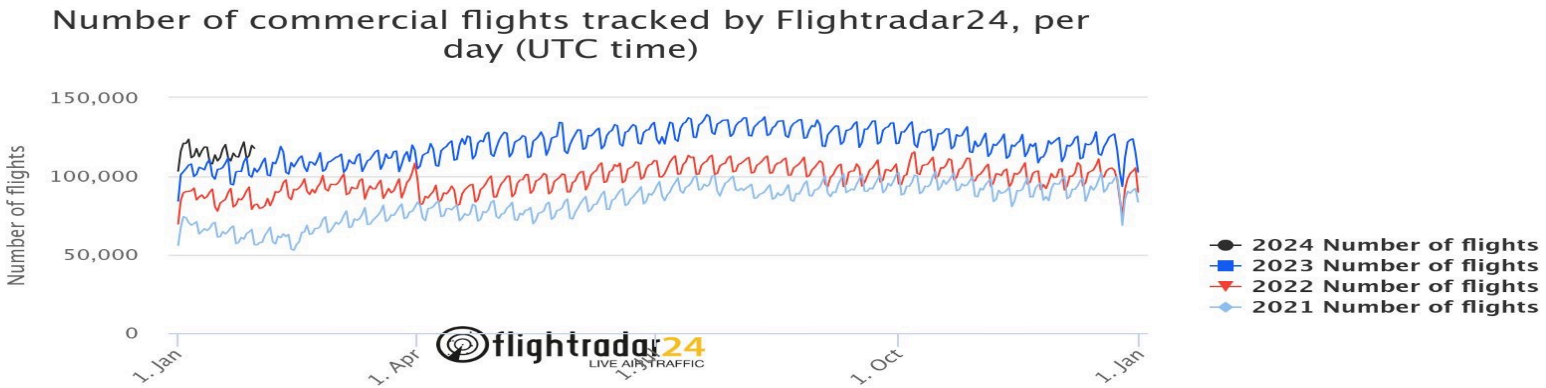
In addition to deorbiting after the mission, satellites can significantly expand their lifespan by adding in-built orbital propulsive capabilities onboard

- Longer mission lifespan lowers the necessary replacement rate of the satellites

Bright future ahead for the space sector

- The orbital planes can manage 100,000+ satellites with relative ease, however, it will require:
    - Collision avoidance capabilities for all the satellites
    - Increased radar (i.e., tracking) capacity
    - Improved common rules (i.e., common regulation) regarding orbital control, and

- As a comparison, Flightradar24 tracks over 100,000 commercial daily flights (passenger, cargo, charter & business jet flights)



Sources: Flightradar24

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