PLANET CHANGE

Space Hazards:
Space debris

Teacher manual

ECF level 3 and 4

Co-funded by the
Erasmus+ Programme
of the European Union

Planet change is the short name of an EU Erasmus+ project aimed at VET teachers and their students. With small activities, the idea is to create awareness about sustainability and acquire 21st century skills. All this is done in a technical context, mostly from space technology.

www.planetchange.eu

Contents:

1. General information

Target group, age: 16-18 y.o.

European Qualifications Framework level: 3 and 4

Duration: 60 minutes

Materials: Computers with internet connection, worksheets, blackboard/whiteboard

Software: Any browser and the website https://sky.rogue.space

Teacher preparation: Basic understanding of the software https://sky.rogue.space; Teachers are encouraged to complete the attached worksheet 'Space pollution exploration' as part of their lesson preparation.

Topic

Theme: Space Hazard

Keywords: Space debris, Kessler effect, satellite, cleaning space, 21st-century skills

Activity

Goals:

The student will get better knowledge and training about:

1. The problem of space debris
   a. What does this problem entail
   b. Why is space debris a problem
2. What happens when space debris collides?
   a. The 2009 Collision between Iridium 33 and COSMOS 2251
   b. The Kessler effect
3. Training of 21st-century skills including:
   a. Media literacy
   b. Information literacy
   c. Critical thinking
   d. Collaboration
   e. Communication

Summary

During this lesson, the students will discuss the kinds of space debris and get to know the extent of the pollution through a tool that shows the mapping of current space objects. By looking at the debris and noting down data, a basic understanding of the dangers will be formed. This understanding is used to investigate what happens when two pieces of debris collide with each other. The students will look into the dangers of space debris and what could happen if nothing is done to prevent the resulting pollution. After, the students discuss current guidelines to prevent space debris and think of solutions to clean up and prevent more debris in protected orbits.

2. Introduction

During their missions, satellites help us understand what is happening on Earth. We can determine our location with the help of GPS satellites, make bank transfers thanks to the precise timing of satellites, and monitor wind patterns from above with the data they provide.

The mission of the satellite partially determines how far from the Earth the satellite will be in orbit (see table 1). If the satellite is placed in the Low Earth Orbit (LEO), it can monitor a small section of the Earth. Most satellites in this orbit are part of a larger network, such as the Iridium network with 66 active satellites. If the satellite has to monitor one specific side of the Earth, it is placed in the Geostationary Earth Orbit (GEO). The satellite will be positioned 35,786 km above the equator. By following the rotation of the Earth, the satellite will view the same part of our planet for the duration of its mission. Every satellite between the LEO and GEO is in the area called the Middle Earth Orbit (MEO). The GPS, Galileo and GLONASS satellites used for navigation are all placed in the MEO.

Table 1: Earth Orbits and their altitudes

Name	Altitude (from the surface of the Earth)
LEO	Less than 2000 km
MEO	2000 – 35,786 km
GEO	35,786 km

If a satellite in the LEO has completed its mission, it can fall back to Earth within 5 to 10 years after its last moments. If the satellite is farther away, in the GEO, it will stay in orbit, and reaching the Earth's atmosphere could take centuries. Most satellites in the GEO are moved to a graveyard orbit, 300 km above the GEO.

Currently in space

Since the first satellite, Sputnik, was launched in 1957, more than 56,000 tracked objects have been launched into orbit. As of November 2022, around 36,500 objects larger than 10 cm remain in space, including around 10,500 satellites. Around 8400 of these satellites remain operational. The objects are monitored by sensors on Earth and in space. However, not all objects can be tracked and cataloged, in some cases because they are too small to detect. By the European Space Agency's (ESA) estimation of space debris objects, there are:

- 36,500 objects larger than 10 cm.
- 1,000,000 objects larger than 1 cm.
- More than 130 million objects larger than 1 mm.

The origin of the objects differs. A significant part of the debris originates from satellites and discarded parts of rockets. In December 2020, the United Nations showed that around 14% of all space debris is from an unknown origin.

Dangers of space debris

The debris poses a risk to the operational technology in orbit around Earth. In the LEO, fragments of debris travel at speeds of around 7 km/s, meaning they could pass 70 football fields within one second. These objects travel at hypervelocity, meaning they travel at speeds between 1 km/s and 20 km/s. The satellites in the LEO region can complete an orbit around the earth within two hours.

If two objects that travel at hypervelocity collide, it causes significant damage to both objects. From observations of collisions in space and experiments on Earth we know that a small projectile could melt and break up completely upon impact with a larger target. Fraunhofer Institute in Germany conducted an experiment where a 2.7 mm aluminum ball collided with a protective shield vaporizes upon impact. In this example, the average speed of the object is 7 km/s, the same speed as most objects that are in the LEO.

Figure 1: Collision of a 2,8 mm aluminium sphere at hypervelocity (Source: Fraunhofer Institute for High-Speed Dynamics)

If the experiment is viewed in real time, it may look like the ball vanishes, leaving a hole in the shield. On a larger scale, with objects colliding in space, it seems as if the objects seem to pass through each other and transform into a cloud of dust. The extent of damage to the target is partially dependent on the projectile. The picture below shows the impact of a millimeter-sized piece of debris that collided with the Sentinel 1A satellite and created a damaged area of around 40 cm in size (see below). If the piece of debris gets bigger, the damage also increases. A collision with a 10 cm object could shatter a satellite and a 1 cm piece may penetrate the shields of the ISS.

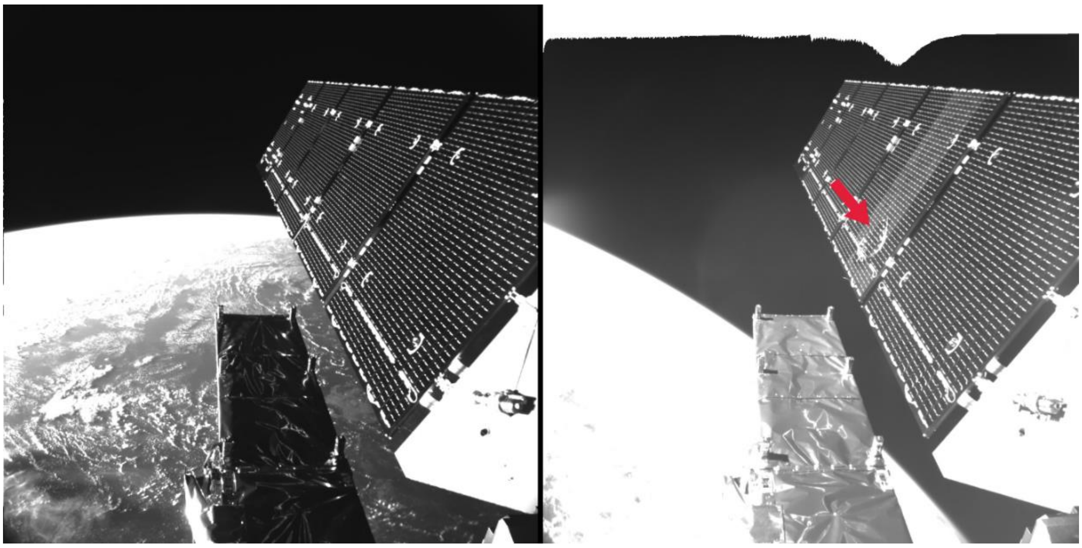


Figure 2: Before and after impact of a 1 mm sized object on Sentinel-1 (Source: ESA)

Dealing with the fragments of a satellite can be difficult. The environment in space does not allow for the natural decomposition that we know here on Earth. The objects that remain in space, defunct satellites, discarded rocket bodies, and so on; will not grind to dust and decompose.

The Kessler effect

If a piece of debris is big or fast enough, it could shatter other pieces of debris. When the pieces collide, they fragment into smaller chunks. These smaller pieces can also collide with other space objects and damage them too.

After a few collisions, there will be more fragments than there were before the first collision. More pieces of debris will then occupy the same space.

When the number of objects increases in the same amount of space, there is a higher chance of the pieces colliding with each other.

To illustrate this point, imagine a section of a highway. On a calm morning, two cars collide on the highway. Since there are no other cars on the highway than the two colliding cars, there is only one collision.

This situation is different when two cars collide in a traffic jam. During the traffic jam, there are more cars occupying the same space. After the two cars collide, they can collide again with nearby cars. They cause a chain reaction.

This chain reaction of collisions is also possible with space debris. When the number of collisions increases and more space debris is formed, we call it the Kessler effect.

Eventually, if the collisions continue, the Kessler effect will become so severe that space debris will fill all orbits around Earth and it can be nearly impossible to leave Earth.

Mitigate collisions

To prevent the Kessler effect from happening and safeguard their operational satellites, space organizations communicate with their satellites to avoid their collisions with debris. First, they map the trajectory of the satellite with radars on Earth and in space. When there seems to be a risk of colliding with debris, the organization formulates a plan that causes the least damage to the spacecraft and its resources. As the last step, they send the command to move to the calculated position and evade the debris.

There are also instances of two operational satellites nearly colliding with each other. In 2019, ESA predicted that their satellite Aeolus would hit Starlink 44. ESA contacted SpaceX to collaborate and prevent the crash. However, due to a bug in SpaceX's communication system, ESA's messages were not received by the Starlink operators. To rescue Aeolus, ESA increased its altitude by 350 meters and successfully avoided Starlink 44.

Today, communication between space organizations about potential crashes is through email. With the ever-increasing numbers of space traffic and the resulting need for more mitigation actions, this process will not be feasible in the future.

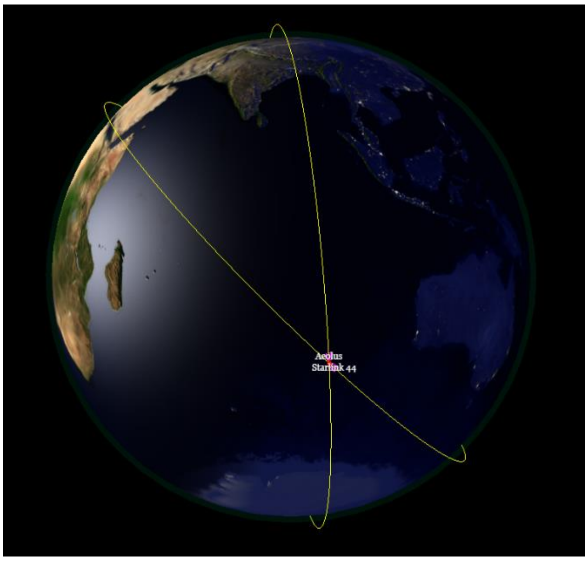


Figure 3: Orbits of satellites Aeolus and Starlink 44 and their calculated place of collision (Source: ESA)

Cleaning space

A collision between satellites is not the only event that produces debris, although these collisions do produce a lot of fragments. There are many ways a satellite can become a piece of debris. It is possible the satellite breaks during its mission because of its mechanical parts malfunctioning. A rocket's or satellite's fuel is a risk as well. The energy source can explode, or, when used, it can release small particles of less than a millimeter in the exhaust.

Debris can also be deliberately released or created in orbit. Rocket stages that are no longer needed are discarded or an anti-satellite rocket hits a satellite, as was the case in 2007 when a Chinese anti-satellite rocket hit an old weather satellite, creating over 600 pieces of debris larger than 10 cm.

To prevent more debris from forming, international agencies have published standards for space organizations. Space organizations have translated international standards into guidelines. ESA's guidelines have the goal to:

- Prevent uncontrolled growth of abandoned spacecraft and spent launch vehicle orbital stages with particular regard to preserve the LEO and GEO Protected Regions.
- Prevent debris generation as a result of intentional release of mission-related objects or break-up of space systems.
- Prevent accidental break-ups as a result of explosions of components storing energy on-board space systems and collision with space debris and meteoroids.
- Prevent orbital collisions by performing collision avoidance maneuvers and disposal maneuvers to limit long-term presence of non-operational space systems in the Protected Regions.
- Limit casualty risk due to controlled or uncontrolled re-entry of space systems

These guidelines take the satellite's design, production, launch, mission and end-of-life stage into account.

2. Description of the activity

Part 1: Satellites eyes help from Space (15 minutes)

The teacher begins the lesson by posing the question to the students: “what do we use space for?” The class makes a word web with actions relating to space services, followed by: “Is there waste in space? If so, what kind of waste?” The class makes word web of objects that could count as space debris (e.g. inactive satellites, discarded parts of rockets, mission-related debris like cameras or cables).

The class discusses the kinds of space debris.

During the next task, the students need a laptop. They look at the objects around the Earth on https://sky.rogue.space and answer the questions on the worksheet.

Part 2: Central core of the task itself (25 minutes)

The teacher asks the students about their answers to the last question “*Do you think the number of space debris pieces will increase over the years? Why or why not?”*

After a discussion, the students make **groups of two** and investigate the 2009 collision between Iridium 33 and Cosmos 2251. They search the internet for information about the collision and discuss the following questions:

- *How many pieces of debris were reported?*
- *What factors are involved in a collision between two satellites?*
- *Draw a situation where two satellites collide and cause the most damage to each other. Indicate the point of impact on both satellites and in which direction they move.*
- *Why is this point of impact the place that results in the most damage?*
- *What do you think happens if one of the pieces of debris hits another satellite? Hint: look at the speed of one of the pieces on https://sky.rogue.space*

The class discusses the questions with more focus on the last question: “*What do you think happens if one of the pieces of debris hits another satellite? Hint: look at the speed of one of the pieces in https://sky.rogue.space”.* Afterward, the class discusses the dangers of space debris, the scenario of the Kessler effect, and current guidelines to reduce debris.

Part 3: Reflection and next steps (20 minutes)

The students stay in their duos. They discuss what goal their action would have, which problem they want to address and in which part of a satellite's life cycle they want to implement the change. They then discuss what solution they would implement and what specific problem their solution would solve. It is optional for the students to use the internet. At the end of the lesson each group presents their solution and what problem their solution would solve.

Part 4 (optional): A possible future in the space sector

Space agencies from all around the world use telescopes, radars, and lasers to track objects in space. In Europe alone, there are more than 50 systems that are able to track space debris. One of these systems is the radar TIRA near Bonn in Germany. This radar can detect objects the size of a 1-Euro coin from 1000 kilometers away in the LEO. Its ability to detect these objects is due to its precise radar sensors. The radar sensors can detect an object's speed and the distance between said object and the radar's own position. Radar technology has a lot of applications. Pilots use it to detect obstacles; ships to detect other ships; police officers to detect the speed of passing drivers; and it is even used to predict the weather.

Other technology can also be used to detect objects from a long distance. The Optical Ground Station at the Teide Observatory in Izaña, Tenerife uses an optical camera to detect objects in the GEO. With a diameter of 1 meter, the lens can detect objects with a 10 cm diameter from a 36,000 km distance.

Part 5 (optional): Excursion

It is possible to visit both the TIRA radar telescope and the Optical Ground Station. These two telescopes are the two that focus most on space debris, but it is also possible to visit other telescopes. Other than Germany and the Canary Islands, there are also various telescopes that can be found in mainland Spain, Belgium, Germany, France, Italy, Switzerland, and the UK. While these telescopes have other missions than tracking space debris, a visit provides an insight in what is needed to make these telescopes function and how they function.

3. Annexes

Background information

ESA's mitigation guidelines

ESA’s Space Debris Mitigation Compliance Verification Guidelines are a set of guidelines that describe what could be done to reduce the amount of space debris in the orbits around Earth. This handbook states the objectives as mentioned above and their application as guidelines through requirements. These guidelines explain the aim behind them, methods that could be used to adhere to the requirement and measures that can be taken to minimize risks related to the subject of the requirement. An example is the intentionally caused break-up of debris. The aim behind the requirement is to reduce the amount of debris intentionally released in space. The proposed method is a review-of-design that does not include releasing debris in space and the mitigation measure is to not plan the release of debris.

It should be noted that a review-of-design means the review of the plan for the satellites life cycle. In this review the requirement is checked in every phase of the satellite’s life, from its design, through its production, launch and mission to the end-of-life plan.

The 2023 document of ESA’s Space Debris Mitigation Compliance Verification Guidelines can be found here: https://esamultimedia.esa.int/docs/spacesafety/ESSB-HB-U-002-Issue2(14February2023).pdf

Clean Space project

A project that aims to clean up space debris is the Clean Space project. This project aims to reduce the debris in three ways.

The first method is to design space missions that are environmentally sustainable. The satellite is monitored from its design to its disposal and analyzed based on its emissions, resources used, and its impact on health and environment. The negative impact will be assessed and reduced for each stage between a satellite's design and disposal without increasing the impact of other stages. More information can be found at: https://www.esa.int/Space_Safety/Clean_Space/ecodesign

The second method is to reduce the creation of more space debris by preventing the satellite from breaking apart. One solution could be that one satellite can fuel, repair and push another satellite. In 2018, the repairing satellite mission was proposed for the Clean Space project. The proposed satellite could capture the other satellite and provide reparations or even push the defunct satellite out of orbit for reentry into the atmosphere if it is not fixable. This satellite could also take the fuel from the broken satellite to prevent the container from bursting and creating more debris. More information can be found at: https://www.esa.int/Space_Safety/Clean_Space/cleansat_

The third method is focused on actively removing space debris, which has a lot in common with the second method. However, this third method does not focus on keeping the affected debris in orbit but focuses on actively removing the debris. One of the proposed ways is to push the debris out of orbit, either toward Earth's atmosphere or a so-called graveyard orbit, where the space debris would be gathered safely away from functioning systems. In 2025, a system will be launched that can capture various objects and de-orbit them safely. This satellite can capture objects with a giant claw, but other methods to capture debris are also possible. Other proposed methods are using a large net, a harpoon, and a robot arm. More information can be found at: https://www.esa.int/Space_Safety/Clean_Space/in-orbit_servicing_active_debris_removal and https://www.esa.int/Space_Safety/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

Recommendations on minimizing space debris:

In 2010, an advisory committee of the United Nations published seven guidelines to minimize space debris and disturbances caused by space debris. These recommendations are:

1. Limit debris released during normal operations
2. Minimize the potential for break-us during operational phases
3. Limit the probability of accidental collision in orbit
4. Avoid intentional destruction and other harmful activities
5. Minimize potential for post-mission break-ups resulting from stored energy
6. Limit the long-term presence of spacecraft and launch vehicle orbital stages in the low earth orbit region after the end of their mission
7. Limit the long-term interference of spacecraft and launch vehicle orbital stages with the geosynchronous Earth orbit region after the end of their mission

Useful links:

Current numbers of space debris: https://www.esa.int/Space_Safety/Space_Debris/Space_debris_by_the_numbers

Information to the teachers

To facilitate discussion, it is recommended that the tables in the class are placed in a U-formation. In this formation, the students will be able to look at each other during the discussions that take place during the activity and react more easily to the comments made.

The presentations of their ideas at the end could be done in the format of an elevator pitch. Ask the students to introduce their solution and substantiate why they chose this solution within 1 or 2 minutes. Remind them to briefly mention their chosen objectives, problem and the design phase in their substantiation. Keep a timer ready during the pitches and cut the presentation short if the time limit is not honored.

VET Schools

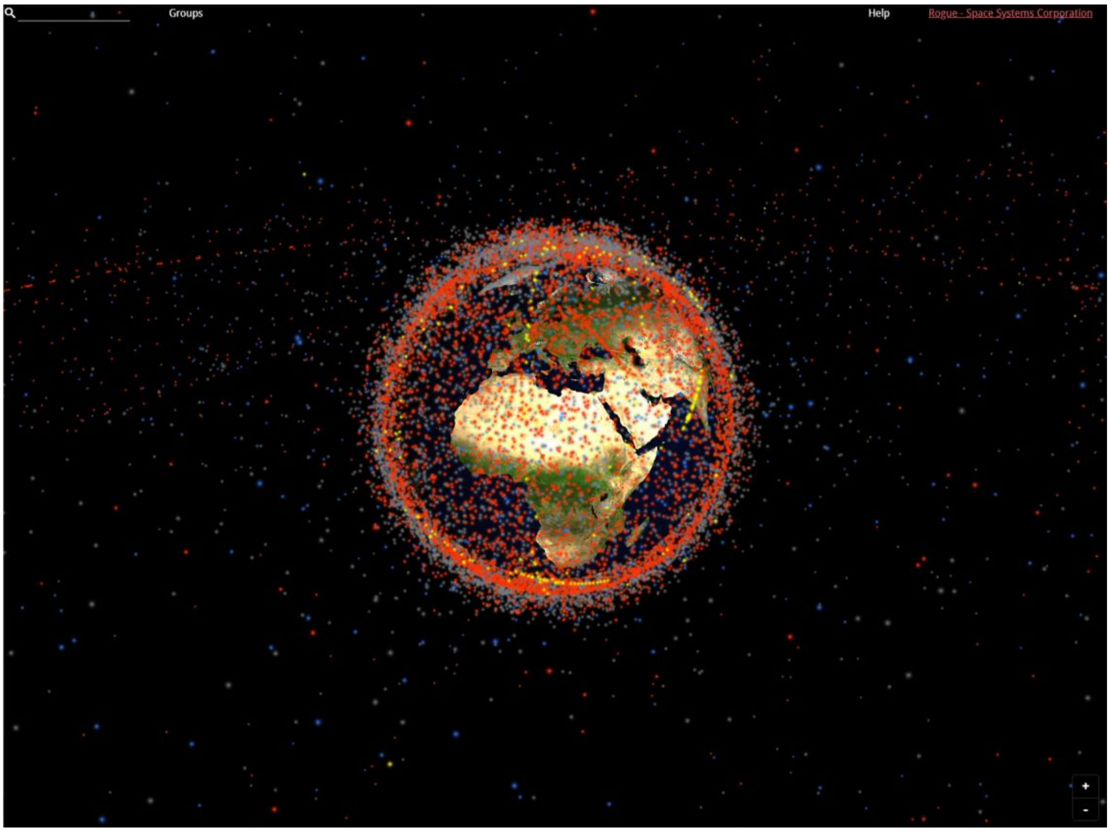
This lesson could be applicable to all VET schools.

The worksheet can be found on the next page

Space pollution exploration:

Go to the website https://sky.rogue.space

This website visualizes every detectable object that is currently in space. Every object is represented by its own dot with a color that signifies its category.



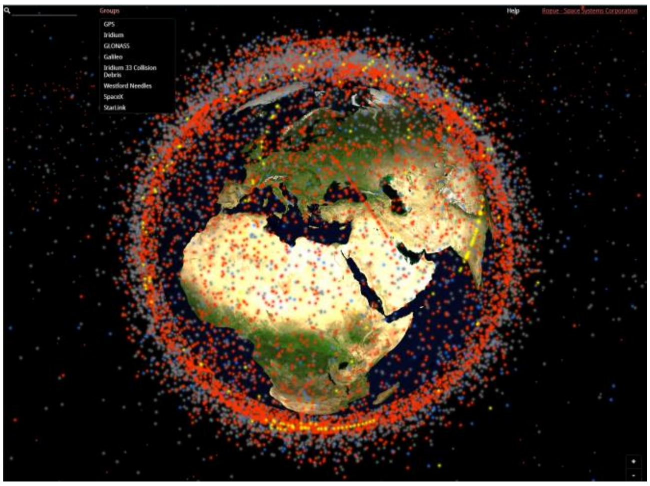
1. *What colors do the objects have? Name the four colors in the table below.*
2. *What category does each color correspond to? Add the categories in the table below.*

Color	***Category***

3. *Do you think the objects in the category 'rocket body' are also space debris? Why?*

____

____



Hover over 'Groups' in the upper-left corner of the screen and click on 'GPS'.

4. *What do you think the blue lines represent?*

____

____

Click on the black background to see all objects again. Zoom in on the country you live in.

5. *Over the next 30 seconds, count the objects that fly through the airspace directly above the country. How many objects have been there?*

____

6. *Click on one of the objects. Fill in the table below.*

Name of object	
Type of object	
Speed	
Altitude	
Orbit	*LEO / MEO / GEO*

Right now, there are around 36,500 pieces of space debris larger than 10 cm in orbit around the Earth. This number will increase over the years.

7. *Why will this number increase? Give two possible reasons.*

1. ____

____

2. ____

____

Collisions in space

Investigate the 2009 collision between two satellites, Iridium 33 and Kosmos 2251.

You can search the internet to find answers to the questions below.

1. How many pieces of debris were reported?

____

____

2. What factors are involved in a collision between two satellites? Give three possible factors.

1. ____

____

2. ____

____

3. ____

____

3. Mark the spot where a collision would cause the most damage to a satellite on the image below.

Figure 4: ESA-satellite Galileo, a part of the Galileo navigational system (Source: ESA)

4. Why is this point of impact the place that results in the most damage?

____

____

5. What do you think happens if one of the pieces of debris from this collision hits another satellite?

   Hint: Look at the speed of one of the pieces on https://sky.rogue.space

____

____

Clean the orbits

Circle one of the five objectives to focus on:

- Prevent uncontrolled growth of abandoned spacecraft and spent launch vehicle orbital stages with particular regard to preserve the LEO and GEO Protected Regions.
- Prevent debris generation as a result of intentional release of mission-related objects or breakup of space systems.
- Prevent accidental break-ups as a result of explosions of components storing energy on-board space systems and collision with space debris and meteoroids.
- Prevent orbital collisions by performing collision avoidance maneuvers and disposal maneuvers to limit long-term presence of non-operational space systems in the Protected Regions.
- Limit casualty risk due to controlled or uncontrolled re-entry of space systems

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Circle the problem you want to address

Debris release   Particle release in Earth's atmosphere   Internal or external break-up

Clearance in LEO or in GEO   Re-entry of debris

Circle the part of the satellite's life cycle you want to implement your solution in.

Design   Production   Launch   Mission   End-of-life disposal

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What is your solution?

What does your solution solve?