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REDUCTION METHOD OF SPACE DEBRIS USING A REUSABLE SPACE PAYLOAD UNIT

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Abstract. *The problems of space debris were first identified in the 2000s, and as a solution to these problems, various solutions were adopted, from changing the operating height of the orbit for commercial satellites to creating standards and restrictions of launch companies and spacecraft developers. The first dated damage was caused by a 1 mm particle on a space shuttle porthole back in 1983. Since that time, the number of objects of space debris has grown exponentially, forming new elements as a result of the collision of parts of launch vehicles or spent or existing satellites.*

This article examines the existing methods and means of cleaning the near-Earth space and their advantages and disadvantages. Based on the analysis of space debris problems, it is proposed to improve the space main parts for the simultaneous removal of space debris from orbit after the completion of the mission to remove the spacecraft.

Key words: *Space Main Part, Space Debris, Satellite.*

Introduction.

According to the European Space Agency (ESA), there are currently about 26000 objects of space debris with a diameter of more than 10 cm and over a million pieces of debris with a diameter of 1 to 10 centimeters in orbit in near-Earth space now (Figure. 1) [1].

Figure 1 - Space debris in the near-Earth orbit

The definition of space debris includes:

- structural elements of spent booster units;
- systems for securing and separating satellites on booster platforms;
- failed spacecraft or those that have been damaged by existing space debris.

Most space debris objects can cause unwanted collisions with operational objects, leading to an increase in non-operational space objects and increasing the demand for launches of new satellites, the duration of which will be reduced due to the probability of collision, or the need to complicate the design.

Analysis of recent research and publications.

Space debris problems are experienced when launching new spacecraft, with more and more maneuvering cycles being built into the launch program. The International Space Station (ISS) has also had problems with space debris, and just for the last week alone it maneuvered twice to avoid a collision with space debris.

To combate space debris, scientists from different countries have been involved, many startups have been created, many ideas have been presented, highlighted in articles and conferences, whereas standards and recommendations have been written under the leadership of NASA.

Existing methods of combating space debris:

- placing spent booster stages and satellites in disposal orbits. These orbits have a reduced influence of Earth's gravity and space debris objects can remain there forever, but the number of objects there is grows every year and will be a new task in the future to clean up the disposal orbit;
- de-orbiting of spent objects and burning up in dense layers of the atmosphere, which also does not solve the problem here and now, because these objects can de-orbit for decades (Table 1) [2, 3], and until they fully de-orbit, these objects will endanger other working satellites.

Let's consider promising ideas, their advantages and disadvantages, which are currently being implemented.

Huge Laser to Shoot Down Space Junk From the Ground. A team from Japan has launched a startup called EX-Fusion, which uses a solid-state laser to push space debris out of orbit and into the safe zone of the Earth's atmosphere [4]. The advantages of this method include:

- cheapness, because there is no need to put anything into orbit, thereby not creating new objects of space debris;
- speed of response to threats to the ISS and other important objects;
- high mobility of these devices.

Table 1. Approximate de-orbit rate without orbit correction

Initial orbit, km	Approximate orbital altitude, km					
	1 year	2 year	3 year	4 year	5 year	6 year
800	799	798	797	796	795	793
600	592	585	575	565	550	530
500	450	395	320	220	De-orbiting	-

However, these advantages give rise to even more disadvantages:

- can knock down large and medium-sized objects, thereby creating smaller objects that these lasers can no longer handle;
- work at limited heights, because the further the laser is directed, the more energy is needed, which also has limitations today;
- has a certain cleaning sequence, because the closer orbits will be cleaned first, and then move on to the next ones.

Satellite "guard". In January 2024, the Japanese company Astroscale Holdings Inc. ("Astroscale") announced the completion of the ELSA-D mission (Figure. 2). The mission consisted of two satellites - a service satellite and a client (demonstrator). The mission's goal was removal space debris around the client satellite. This goal was achieved and this object became additional space debris for the next 3.5 years until it de-orbited into the dense layers of the atmosphere where it would be disposed of [5].

A fuelless spacecraft. The ElectroDynamic Debris Eliminator (EDDE) can perform the near-Earth space cleanup functions by leveling the altitude and inclination of the orbit, removing objects weighing more than 2 kg [6]. However, the cost of its removal is prohibitively high.

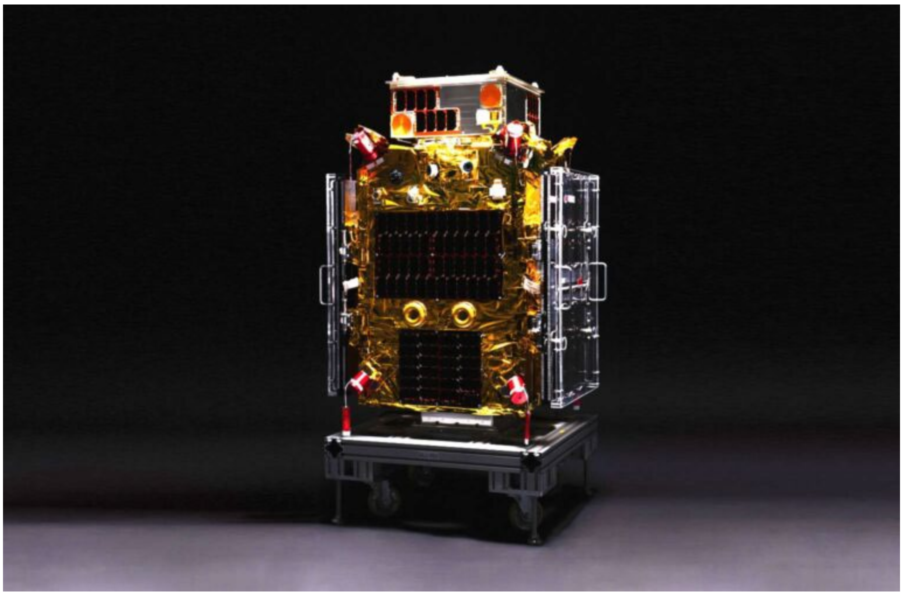

Figure 2 - One of the spacecraft of the "ELSA-D" mission

Research results.

The purpose of the research is to create methods and means for cleaning the near-Earth space by improving space main parts (SMPs) (figure 3).

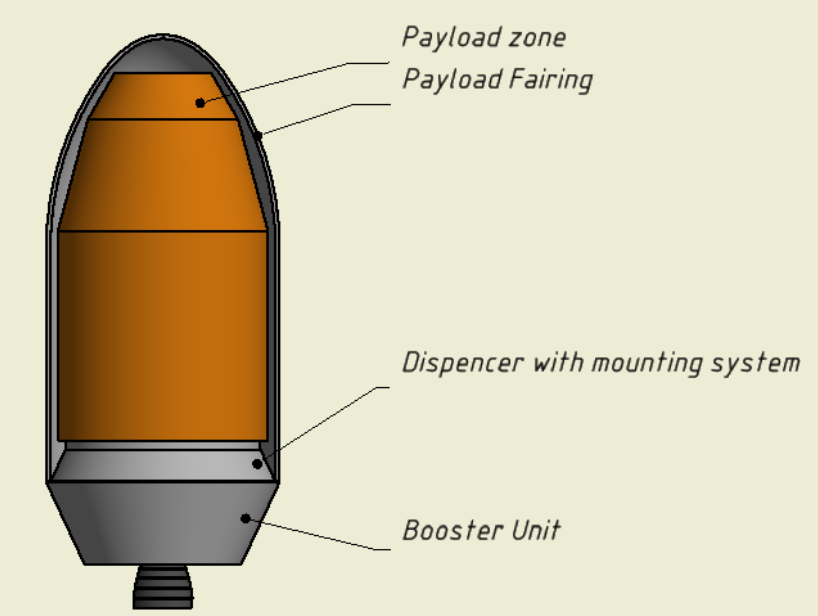

Figure 3 - Typical composition SMP

Based on the analysis, we can see many promising ideas that are already being implemented. Also, space debris increases with each new launch. According to existing NASA standards [7], launches occur according to the following scheme:

- launching a satellite or a group of satellites into orbit;
- relocating the booster to a “burial” orbit;
- further launching a group of satellites into orbit using their own systems.

However, space debris continues to grow, as ejection results in objects formed after the operation of the separation systems of payload fairing flap and spacecraft separation systems directly in orbit. And while some companies are looking for ways to solve them, other companies continue to leave debris in orbit.

But, if there is no littering, then there will be no need for cleaning, and the existing litter will be removed by means of a side discharge after each launch mission. This idea was proposed in [8] Danylchenko D.A. and Dron M.M. projects.

To reduce pollution, it is proposed to improve the space main components and simultaneously use the SMP or booster units to capture and introduce space debris after the launch mission is completed.

Complicating the design of the SMP accordingly can increase the cost of launching the spacecraft by reducing the weight of the payload and at the same time allow for clearing the near-Earth space.

The improved space main part will have:

- ✓ an acceleration block for further launching the spacecraft into orbit;
- ✓ payload fairing flaps to protect the spacecraft during passage through dense layers of the atmosphere;
- ✓ separation systems of payload fairing flap;
- ✓ speed compensation system;
- ✓ near-Earth space cleaning systems.

According to existing programs for launching satellites, the booster unit launches satellites to altitudes of up to 500 km, then each spacecraft deploys solar panels and is launched to the required altitude using its own low-impulse engines. Small satellites that do not require constant orbit correction and a long operating time almost do not use such engines, and accordingly, such objects will be deorbited by Earth's gravity.

The aim of the research is to create an improved SMP for small satellite groups and launch them into orbits of 500-700 km, as well as capture and remove space debris before the completion of the launch mission. If the tasks of launching spacecraft into orbit are more than 60 years old, then the tasks of removing space debris have not yet been set and have only theoretical calculations.

SMP modernization will consist not only in changing the design, but also in trajectory calculations for each accompanying mission, calculations and testing of additional debris capture systems, calculations of the mass of systems and fuel for additional missions, and calculation of safe trajectories for space debris removal.

Let us consider some changes in the calculations of improved SMPs (Figure. 4).

Given that the speed of the spacecraft in orbit is 11.7 km/s, fuel will be used only to equalize the speed of movement and to perform the capture of space debris objects. The upper stage calculates the fuel for each launch mission, but additional fuel will be added to perform auxiliary missions and the fuel mass formula will be as follows:

$$G_F = G_M + G_B + G_A, \tag{1}$$

where G_M is the mass of fuel for the launch mission,

G_W is the mass of fuel to be removed from launch orbit for combustion in dense layers of the atmosphere;

G_A is the mass of additional fuel to carry out the mission to clean up the near-Earth space.

The total mass of the structure will be as follows:

$$G_S = G_C + G_B + G_F + G_{AS}, \tag{2}$$

where G_C is the mass of the structure of SMP , which will include the mass of the PF, separation systems of payload fairing, spacecraft attachment systems, sensor equipment, and the mass of the spacecraft itself;

G_B is the mass of booster unit, which will include the mass of the engine installation with tanks;

G_F is the mass of fuel for the mission (1);

G_{AS} is the mass of the near-Earth space cleaning systems.

Each launch mission will be aimed at orbits where the risk of collision with important spacecraft will be the greatest, and step by step with each launch mission, the near-Earth space will be cleared.

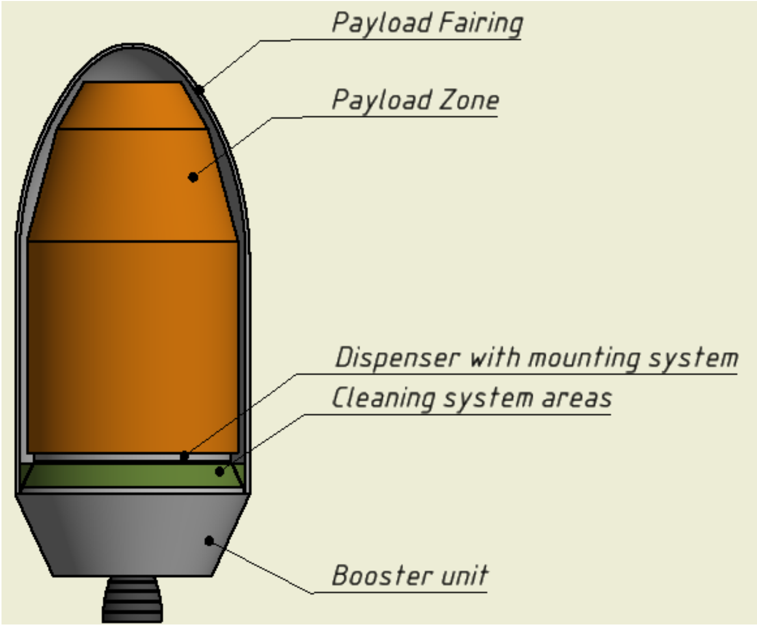

Figure 4 - Improved SMP

Let's consider the purpose of SMP elements.

Payload fairing flaps are dropped after passing through dense layers of the atmosphere. Further, friction and heating are reduced, so there is no need for a main fairing. Most companies, to reduce weight, drop the fairing, which either burns up in dense layers of the atmosphere or is waterlogged. This is also done to reduce the weight of the upper stage with the spacecraft group and to reduce the mass of fuel required for the mission.

But with each launch mission, tasks can be set to rescue unsuccessfully launched expensive spacecraft [8]. Accordingly, this idea can be used as a multi-purpose one aimed at cleaning the near-Earth space and rescuing valuable equipment.

Separation system of payload fairing flap. Typically, pyrotechnic devices such as pyrobolts, pyrolocks, pyrocords, and others are used. However, these elements, when separated, can create additional space debris objects up to 10 cm in size. Each company has its own solutions for this, and these solutions are aimed at:

- reduction of debris after separation through the use of special catchers;
- reduction of manufacturing costs;
- ensuring separation without collision with the SMP.

But all these systems are one-time in nature and are not suitable for performing missions to rescue the spacecraft if necessary.

Speed compensation systems. Space debris moves at a speed of about 11.7 km/s. After the spacecraft is launched into orbit, the SMP will have an estimated speed of 11.7 km/s, however, to avoid new space debris with its own systems, it is necessary to have enough fuel not only to launch the spacecraft, equalize speeds and change orbit to dispose of space debris, but also to be able to reduce the speed gained in time to avoid a collision with space debris. As such elements, additional nozzles installed in the directions opposite to the movement and perpendicular to the movement will be used to reduce speeds and the necessary course correlation. For the correlation of movement, compressed air from the engine installation's fuel tanks will be used due to the enlarged compressed air cylinder.

The cleaning systems in the SMP will be installed on the SMP frame and will be activated after the mission from the spacecraft compartment. The areas and locations of their installation may vary.

It is proposed to use harpoons, nets, magnetic traps [2], manipulator arms or the implementation of new ideas. These systems will be modified with each launch mission. The analysis of the use of capture systems is summarized in Table 2.

Let's consider one of the possible space debris disposal missions as an example.

The initial data for the spacecraft launch will be:

- the target orbit, its altitude and inclination angle;
- the orbit and inclination angle of the space debris;
- analytical data on the threat of the necessary debris;
- calculations of speeds, orbits and the necessary fuel for the disposal mission;
- calculations and data for a safe descent from orbit into the dense layers of the atmosphere.

The execution algorithm is as follows:

- launching the spacecraft into orbit;
- determining the trajectory of movement towards space debris;
- giving the engine a boost in the direction of space debris;

- speed compensation, correlating the course using compressed air from the speed compensation systems;
- using harpoons, nets, manipulator arms or magnetic traps of the cleaning system;
- capturing and holding space debris;
- determining the descent trajectory;
- giving the engine a boost in the direction of de-orbiting;
- slow descent from orbit and, if necessary, correcting the trajectory to avoid collision with other objects;
- taking it to the disposal zone;
- completing the mission.

Table 2. Space debris capture systems

	Elements of the capture and retention system			
	Harpoons	Nets	Magnetic catchers	Manipulator hands
Weight	Medium. Comes with compressed air cylinder and cable	Minimal. Comes with compressed air cylinder and cable	Medium. Comes with compressed air cylinder and cable	Big. Requires a bunch of extra mechanisms and power sources
Overall dimensions of the system	Minimal. Does not require extra seating space	Medium. There is a need to replace 1 seat of the spacecraft	Minimal. Does not require extra seating space	Medium. It is necessary to ensure the functionality and safety of the spacecraft during the withdrawal phase
Dimensions of objects to be captured	Medium and large	Small and medium	Medium and large	Medium and large
Debris formation	Yes Space debris penetrating the surface will create small fragments	No Except for protruding elements	No If the hook surface is selected reliably	No If the hook surface is selected reliably
Containing space debris until the mission is complete	Yes If the force surface is penetrated	Yes	Yes	No It is necessary to additionally record space debris on the platform before the mission is completed
Efficiency	Medium. Causes debris	High For small objects Low for large ones	High for small objects. Medium for large objects, additional fixation is required	Medium For large and medium Ineffective for small

The completion of the mission will be considered the launch of the spacecraft into orbit. As well as the removal of space debris from orbit, including the avoidance of new space debris by its own systems or during the mission.

Conclusions.

By implementing the near-Earth space cleaning systems into the design of the SMP, the following will be achieved:

1. Reducing the cost of launching spacecraft into orbit. This will be achieved by implementing additional missions to clean up the near-Earth space.

2. Gradual cleaning of the near-Earth space from existing debris. With each launch mission, a reduction in space debris by its own systems and the associated removal of space debris will be achieved. Cleaning of the near-Earth space will lead to an increase in the operating time of the spacecraft due to a decrease in the probability of collision with space debris. One launch mission will not give effect, but if this method is implemented as the main requirement for launch companies, the amount of debris will decrease. Only in the last year, 215 launch missions were carried out around the world, out of 5 launches there was a complete or partial failure. The implementation of this method would provide 215 missions to clean up the near-Earth space. Accordingly, just for 1 year, more than 200 objects of space debris can be disposed of.

3. Possible rescue of disabled spacecraft. The improvement of the SMP will allow to carry out missions of incidental rescue of spacecraft for their reuse, which will significantly reduce the cost of the spacecraft itself, because there will be no need to create another spacecraft, but only to refine the rescued one. Accordingly, the rescue of the spacecraft will also entail the cleaning of the near-Earth space.

4. Non-pollution by own systems. Removing the upper stage from orbit reduces contamination of the near-Earth space by own systems, and improving or replacing pyrotechnic and pyromechanical separation means used to attach the payload fairing flaps and the spacecraft's mounts will reduce the formation of small space debris.

5. Reducing the likelihood of destruction of working spacecraft and stations. Spacecraft suffer from collisions with defunct spacecraft, their debris, and spacecraft

ejection systems. The less space debris, the less likely it is to collide with it.

6. Increase the operating time of spacecraft due to the reduction of debris. Reducing space debris will increase the safe operating time of spacecraft.

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