Search for design solutions to prevent the Kessler effect

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Abstracts. The article deals with the problems of near-earth space associated with the formation of objects called "space debris". The main sources of the appearance of "space debris" in near-earth orbits are highlighted. Examples of the negative impact of "space debris" on functioning spacecraft and stations are given. The general statistics of observations of near-Earth space, obtained by specialized complexes for recognizing space objects, are presented. Conceptual design solutions are proposed to prevent the Kessler effect.

1 Introduction

Today, there are many different national projects devoted to the study and exploration of the outer space, but their implementation will become impossible because of the Kessler effect. This effect considers a possible hypothetical scenario at the near-Earth orbit, when space debris from numerous launches of artificial satellites will lead to the complete unsuitability of near space for practical use. For the first time, such a scenario was described in detail by NASA consultant Donald Kessler. In 1978 he wrote the article “Collision Frequency of Artificial Satellites: The Creation of a Debris Belt”, stating that the global impact of space activities on the environment, since the clogging of space of the Earth negatively affects all countries.

The various natural phenomena and human actions on Earth may be both the reasons for the «space debris» formation. By «space debris» the authors mean the costs of human activity in space, these can be fragments of faulty equipment rotating in near-Earth space, or failed satellites, etc. Space debris also includes objects of natural origin, such as cosmic dust, meteors.

The purpose of this study is to review existing design solutions and propose a concept for preventing the occurrence of the Kessler effect.

Nowdays, the intensity of space exploration is only increasing, due to the development of various national projects aimed at the study and exploration of outer space. The implementation of ambitious long-term space projects may become impossible due to the Kessler effect, which hypothetically describes the scenario in near-Earth orbit, when the accumulated «space debris» makes the near space completely unusable. Ensuring the freedom of outer space from «space debris» should be comprehensive, taking into account

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the specific features of various types of space objects, the conditions for their operation and subsequent disposal. The general principles of ensuring the freedom, security and ecology of outer space are the following:

- timely forecasting the appearance of «space debris» and identification of threats to outer space, space objects and the Earth;
- implementation of operational and long-term measures to prevent threats associated with «space debris» objects;
- implementation of measures aimed at preventing or minimizing material damage from «space debris»;
- carrying out specialized training of services to work out the coordination of actions on Earth and in space to protect against the influence of «space debris»;
- cataloguing of international requirements for ensuring space security related to «space debris»;
- development and implementation of a set of measures to increase the level of freedom, security, environmental friendliness of outer space;
- search for conceptual design solutions related to the disposal of «space debris» and the Kessler effect prevention.

The problem of the «space debris» appearance is only increasing from year to year. The statistics of recent years shows that 60% of «space debris» occurrence is associated with explosions of space rocket stages and collisions of space objects [1, 5, 15]:

- 1980 year. - the destruction of the Fengyun-1 satellite (China) - more than 100 fragments;
- 2003 year. - explosion of a stage of an Indian space rocket - about 300 fragments;
- 2009 year. - collision of two space devices Iridium 33 and Cosmos - over 2000 fragments;
- 2018 - the upper stage Transtage SSN (Space Surveillance Network) of the Titan IIIC rocket (NSSDC_ID 1969-013B) collapsed. - over 60 new fragments;
- 2018 year. - Upper stage Tsen-TavrSSN #40209 of the Atlas-5 rocket (NSSDC_ID 2014-055B) collapsed. - about 500 new "space debris" objects.

Objects traped into space don't stay there forever. They are affected by cosmic radiation, gravity. "Space debris" gradually loses altitude and burns up in the dense layers of the atmosphere. Studies show that every 10 years the number of dangerous debris decreases by 200-300 points, but, unfortunately, new ones appear faster.

It is practically impossible to accurately determine and track how many unwanted objects and especially small fragments are located at the orbit, since many space debris objects have a diameter of less than 1 cm. Spacecraft fail, fragments of space objects burn up in the atmosphere, are fragmented, increasing and modifying "space debris". But it is known that today thousands of potentially dangerous objects of large sizes and millions of small fragments fly in orbit, and their total mass is several thousand tons [10].

At the moment, there are systems for tracking space objects, such as ESA Space Debris Telescope, TIRA (System), EISCAT, NASA Orbital Debris Program Office, Krona, Arkhyz, Okno, which contain tools that can highlight “space debris” objects. Data visualizations from the NASA Orbital Debris Program Office show that the total number of “space debris” objects is approaching 20,000 by 2020 (see Fig. 1).

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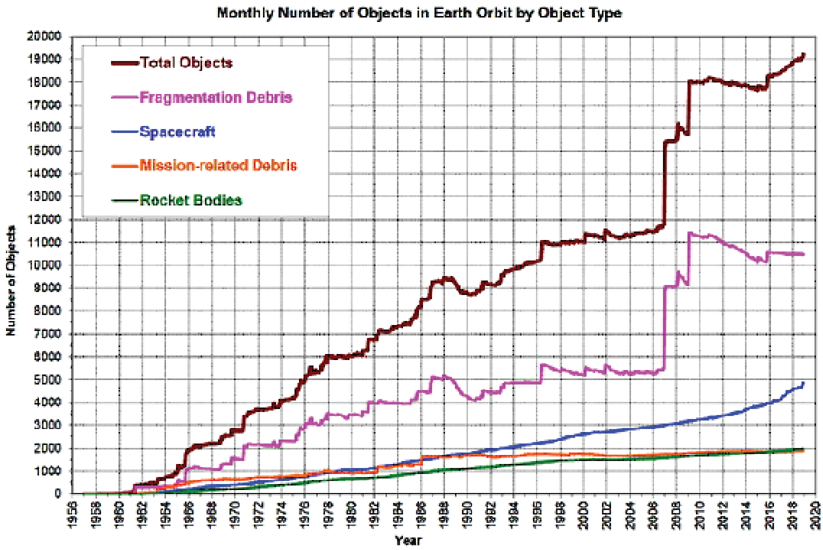

Fig. 1. Data visualization of the "space debris" tracking system [4].

The graph shows the main elements that make up "space debris":

- the total number of elements of space debris (Total objects);
- space debris resulting from equipment failure (Fragmentation Debris);
- space debris of natural origin (Spacecraft);
- remnants of space debris from various missions (Mission-related Debris);
- space debris resulting from rocket launches (Rocket Bodies).

Based on these visualized data, it can be concluded that the amount of "space debris" appears most of all as a result of equipment failure, and every year the probability of the Kessler effect increases many times. Effective methods of "space debris" disposal in order to prevent the Kessler effect have not yet been found, but there are conceptual solutions that can be the beginning of solving this complex system problem.

Roskosmos has developed a conceptual solution for "catching space debris" using special satellites and a web-like network (Fig. 2). The device is a cone-shaped netting with large cells, the base of which is fixed by a sliding frame and has engines for maneuvering. The top of the cone is attached to the spacecraft by a cable. When the net covers "space debris" from all sides, the frame shrinks and the objects become trapped. Further, the towing of "space debris" objects is carried out, either for the purpose of breaking and entering the dense layers of the atmosphere, or dispersing the "space debris" objects in order to transfer it to the "burial" orbit. At the moment, this option is not suitable for collecting small elements, the size of which is about 1 cm in diameter due to the larger size of the netting cells.

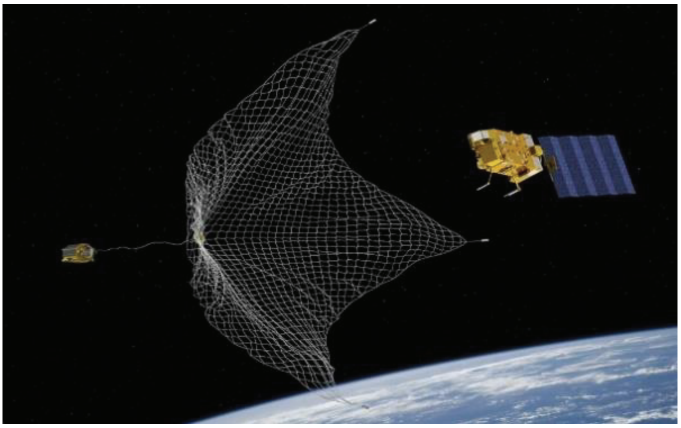

Fig. 2. The concept of a net for "space debris catching".

There are a number of rational ideas for the "space debris" disposal. For example, the installation of a powerful laser with a continuous action, which allows to adjust the debris speed and the trajectory. But such a system allows to work only with large debris, such as rocket stages and spent vehicles [5,17,18].

It is also possible to use satellites with magnetic installations for catching and fixing “space debris” [4]. Earnshaw's theorem states that a set of point charges cannot be maintained in a stable stationary equilibrium configuration only due to the electrostatic interaction of charges. It is possible to counteract the gravity force with the help of magnetism, but it is not easy to create a stable equilibrium. The Earnshaw’s theorem "prohibits" static paramagnets and ferromagnets from generating stable levitation. Without additional conditions, the rotation of two permanent magnets, even at a small angle, will cause them to turn to each other with opposite poles, repulsion will turn into attraction, which will lead to the “loss of fragments”. There are several ways to get around this restriction. One of them is to place a diamagnetic in a magnetic field. A diamagnetic is a substance that is magnetized against the direction of an external magnetic field. It, unlike a paramagnet, is not magnetized along the external field, but opposite to it, and Earnshaw's theorem “does not forbid” it to hang steadily in the air, and with small deviations from the equilibrium position, the diamagnetic's own field can be rearranged in such a way as to return it to equilibrium, thus fixing the particles. It is possible to stabilize the particles using feedback - to keep track of where the object is and adjust the magnetic field magnitude. Maglev trains operate in a similar way on Earth.

Also the satellites with equipment which operation principle is based on the pressure of light, consisting not from the only wave, but also corpuscular properties, may be used to de-orbit “space debris”. A light beam can be imagined as a beam of elementary particles - photons, each carries a portion of energy and has an impulse, and therefore, by analogy with mechanical particles (for example, small pellets), can transfer this impulse to other bodies during interaction. If a device that allows to correctly dispose this impulse will be created, then an object will be pushed with a stream of radiation in the right direction.

With the help of tracking systems, it is possible to mark the places of accumulation of space "waste" and observe their movement, which is also a difficult task, since the dimensions of the tracked “space debris” can be less than 1 cm. This problem also applies to a complex system task.

The creation of a conceptual design system for the “space debris” disposal is based on the above methods and solutions with the possibility of trapping larger debris.

The system under development consists of a satellite, a facility for magnetic field forming, and laser systems. The particular attention in the design solution is given to the satellite body strengthening, since there is a high probability of direct interaction with “space debris”.

That's why it is planned to use new materials, for example, foam metals. This is a new class of materials with low density and new physical, mechanical, thermal, electrical and acoustic properties. A foam aluminum is a sort of foam metals. Foam metals have a cellular structure, and with their help it is possible to create objects of complex shape.

Foam metal manufacturing technology:

- Preparation of aluminum melt.
- Addition of silicon carbide particles to the melt.
- Injection into the gas melt using an impeller.
- Rolling through rolls.
- Quality control.

The sketches we created for further image formation and object design (see fig. 3, 4, 5, 6).

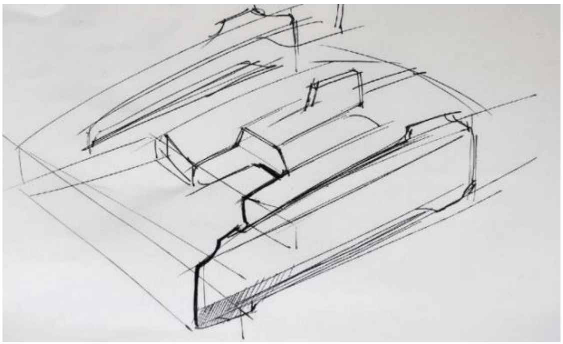

Fig. 3. Sketch of the designed satellite.

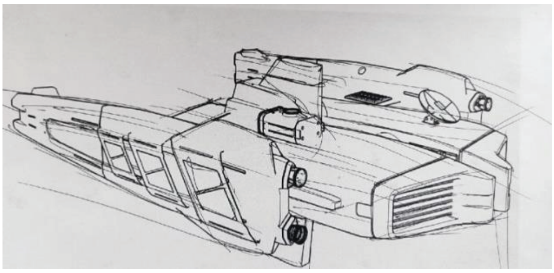

Fig. 4. Sketch of the designed satellite.

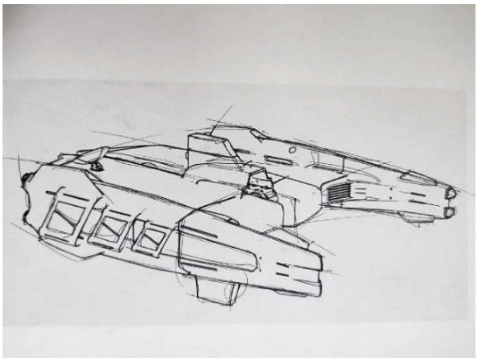

Fig. 5. Sketch of the designed satellite.

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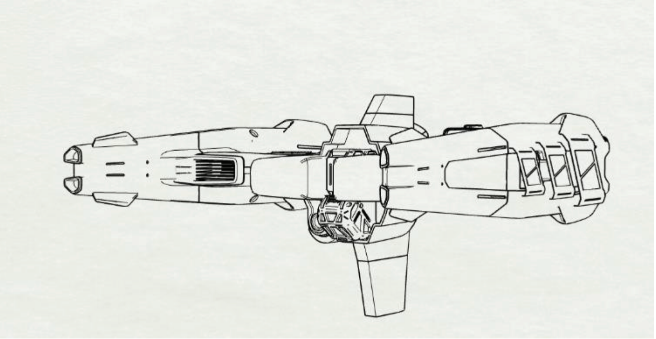

Fig. 6. Sketch of the designed satellite.

A CAD model was created on the base of the drawn sketches for further production and computer visualization.

In the course of further study, textures based on the description of the foam metal structure, have been created for further visualization of the satellite, and images were obtained from the model using a computer program (see Fig. 7, 8, 9, 10).

Fig. 7. Satellite design concept.

Fig. 8. Satellite design concept.

Fig. 9. Satellite design concept.

Fig. 10. Satellite design concept.

It is possible to use neural networks to predict the trajectory of "space debris".

A neural network is a sequence of neurons connected by synapses. The structure of a neural network came to the world of programming from biology. Thanks to this structure, the machine acquires the ability to analyze and even memorize various information. Neural networks are also capable of not only analyzing incoming information, but also reproducing it from its memory.

In conclusion, we can state, that today the problem of "space debris" has become already a threat and needs to be addressed. To date, we have the technologies and capabilities to solve it. They must be implemented in the near future. But the problem of "space debris" is multifaceted. Its solution involves the joint work of leading Russian researchers of both applied and fundamental profiles.

In order to improve the safety, ecology of outer space and prevent the Kessler effect in the conditions of the outer space development, it is necessary to implement a set of measures of a general nature for all the countries on the planet. To protect outer space from "space debris", it is necessary to turn conceptual solutions into practical ones.

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