Modern methods of solving environmental space junk problems

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Abstract. A review of the literature on modern problems of space debris arising in the design of rocket and space technology has been carried out. The article considers possible ways to solve these problems. The analysis of the article literature on the problems of space debris carried out by the authors made it possible to identify methods for preventing the formation of space debris, methods for protecting existing spacecraft from space debris, as well as the main regulatory and technical documents in this area.

1 Introduction

Space junk is all objects of anthropogenic origin that are in outer space and do not perform any useful functions [1]. The problem of clogging the near-Earth space with "space debris" arose immediately after the launches of the first artificial Earth satellites in the late fifties [2-6].

The main sources of space junk:

- space activities of the countries of the world;
- accidental destruction of space objects due to explosions, etc.;
- collisions of space objects;
- intentional destruction.

Space junk is a forced phenomenon of space activity. Throughout the space age, the number of spacecraft objects is continuously growing. The most significant growth was observed in 2019-2021. Space junk poses a danger to active satellites, further space exploration and the Earth's ecology, and therefore it is necessary to monitor it.

Space junk monitoring tools are divided into:

- ground-based optical means;
- ground-based radar facilities;
- space-based facilities.

The main tasks of the spacecraft monitoring tools are measuring the parameters of the movement of space objects to determine the trajectory and enter them into the catalogs of space objects.

To assess the current level of technogenic pollution of near-Earth space and its prediction, generally accepted models are used:

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- ORDEM (NASA);
- MASTER (ESA);
- SDPA (Roscosmos).

The main tasks they solve:

- assessment of CM particle flows of different sizes relative to given areas of outer space or relative to a spacecraft in a given orbit for risk assessment and design of spacecraft protection from high-speed impact;
- prediction of technogenic contamination of the near-Earth space under various scenarios of space activity.

Space junk does not include those parts of the spacecraft that fall to the ground after the start of the flight. Such parts may be in hard-to-reach places and their transportation will require special equipment [7-9].

2 Problem statement

Urgent applied problems in the solution of which it is necessary to take into account the data on space junk require the assessment of the current level of technogenic pollution of the near-Earth space and its forecasting; danger of collisions between spacecraft and space junk; the probability of breakdown of the spacecraft structural elements, as well as the design of specialized measuring instruments and determining the time and place of the fall of hazardous spacecraft objects [10]. This paper does not consider the issues of reliability and probability of system failures. [11-14].

3 Research questions

3.1 Regulatory documentation

To solve environmental problems associated with space debris, it is necessary to have appropriate legal documents regulating the activities of the rocket and space industry, enterprises and organizations in this industry. In the framework of this study, we will review the relevant regulatory documents.

3.2 Space junk prevention challenges

Preventive actions are the most effective in the fight against space junk [15,16]. In this regard, the issues of application of methods and technologies for limiting the formation of space debris, which will be discussed below, are particularly relevant.

3.3 Methods for dealing with already existing space junk

In cases where preventive actions have not brought the desired result or, for some reason, are not applicable, it is necessary to use methods to combat space junk that is already in orbit and poses a potential threat to spacecraft located there. One of these methods is to ensure resistance to the effects of space junk in the design of rocket and space technology.

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3.4 Problems of appropriate training

Workers in the rocket and space industry, namely the engineering and technical staff involved in the design of rocket and space technology, must have the competencies to find the right solutions in the face of the problem of space junk. Since the situation may change from year to year, it is relevant for such workers to systematically undergo advanced training in the relevant additional professional programs [17-20]. Such advanced training programs should contain up-to-date statistical information on the quantitative volume and qualitative composition of space junk in orbit, as well as information on the methods and techniques for designing rocket and space technology that is resistant to the effects of space junk in orbit, to a possible collision with it. The category of students for such programs is design engineers, process engineers and engineers involved in strength calculations of assemblies and assemblies of spacecraft.

4 Research purpose

The purpose of the study is to review the existing methods for solving the problems of space junk in the design of rocket and space technology, as well as to review the regulatory framework in this area.

5 Research methods

The following theoretical research methods were used analysis, generalization [21-22].

5.1 Review of normative and technical documents that set requirements for limiting the formation of space debris and ensuring resistance to the effects of space debris, as well as their application in the development of technical specifications for the creation of a promising rocket spacecraft

The main requirements for limiting the generation of space junk are set out in the following documents:

- United Nations Space Debris Mitigation Guidelines;
- IADC Space Debris Mitigation Guidelines;
- ISO 24113 standard;
- GOST R 52925-2018.

The Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (item 1) include the following:

- limiting the generation of debris during regular operations;
- minimizing the potential for disruption during flight operations;
- reducing the probability of an accidental collision in orbit;
- avoidance of intentional destruction and other harmful actions;
- minimizing the possibility of damage after the completion of the flight program caused by the energy reserve;
- limiting the long-term existence of spacecraft and orbital stages of launch vehicles in the region of low Earth orbit (LEO) after the completion of their flight program;
- limiting the long stay of spacecraft and orbital stages of launch vehicles in the geosynchronous orbit (GSO) after the completion of their flight program [23].

5.2 Issues of application of methods and technologies for limiting the formation of space debris and for ensuring resistance to the effects of space debris in the design of a promising rocket spacecraft

The following main measures are applied to limit the generation of space junk:

- prevention of space junk formation in the course of routine operations;
- prevention of space junk formation at the end of operation;
- prevention of collisions of space objects;
- removal after the end of operation from protected areas of near-Earth outer space to disposal orbits.

To solve complex problems we use the decomposition method. [24] Active junk removal techniques are used. Active removal of space junk is used to reduce man-caused contamination of near-Earth and outer space and is currently at the stage of experimental research. Active deletion is classified by the size of the space junk to be deleted:

1) removal of a large-sized space junk (carried out in the following ways):

- use of specialized spacecraft equipped with robotic arms, or a harpoon, or a net, or other contact means for capturing an object and its subsequent removal; [25]
- installation of evasion devices on the spacecraft using a specialized spacecraft;
- remote exposure using a laser, ion beam, magnetic interaction using a specialized spacecraft;
- remote impact using a laser from the Earth's surface).

2) removal of a small-sized space junk (performed using):

- creating areas of increased density using gas or frost;
- creating shells of a large area with gas or foam).

There is another significant problem - the problem of the uncertainty of goals and incompleteness of information. Moreover, the traditional way of accounting for uncertainty factors based on probabilistic and statistical modeling often turns out to be inadequate for the tasks being solved and can lead to incorrect results, since the functioning of complex organizational and technical systems in practice is characterized by uncertainty of a “non-stochastic” type [26-27].

5.3 Issues of application of mathematical models and technologies for ensuring resistance to the effects of space junk in the design of a promising rocket space technologies

The main regulatory and technical documents that define the space junk environment model:

- GOST R 25645.167-2022 Space environment (natural and artificial). Model of spatio-temporal distribution of man-caused matter flux density in near-Earth outer space;
- GOST R 52925-2018 Space technology products. General requirements for limiting technogenic pollution of the near-Earth space.
- ISO 14200-2021 Space environment (natural and artificial) — Process-based implementation of meteoroid and debris environment models (orbital altitudes below GEO + 2 000 km) (orbit altitudes below GEO + 2 000 km)]

6 Conclusion

Methods for protecting spacecraft from space junk are classified into:

- active - collision avoidance maneuver;

- passive - installation of protective screens, designing spacecraft, taking into account the screening of critical subsystems.

Methods for ensuring the withdrawal of the rocket and space technologies at the end of operation in the OKP are divided into:

- active - using propulsion systems;
- passive - using inflatable structures, deployable cables, solar sails, etc.

Space junk mitigation measures can be divided into two broad categories measures that reduce the generation of potentially harmful space debris in the short term, and measures that limit the generation of such debris in the long term. Measures of the first category are associated with reducing the generation of space debris as a result of flights and avoiding destruction in orbit. The second category of measures relates to procedures after the completion of flight programs that allow the removal of spent spacecraft and orbital stages of launch vehicles from areas densely loaded with functioning spacecraft.

Prospects for the development of research in providing a solution to space junk problems include the study of the location of space debris and modeling for predictive purposes. The following tasks remain relevant:

- development of international cooperation on space junk problems;
- development, study and subsequent implementation of measures aimed at reducing the contamination of outer space;
- monitoring, forecasting and development of methods for protecting space devices from the influence of space junk particles;
- ensuring resistance to space junk in the design of rocket and space technology.

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