Design analysis of the aerodynamic deorbiting system for Earth remote sensing small spacecraft

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***Abstract*—In recent years, the rapid increase in the number of Earth remote sensing small spacecraft as part of multi-satellite constellations has attracted more and more attention. Various methods are proposed for solving the problem of deorbiting such satellite at the end of their lifetime, including the use of aerodynamic devices. In this paper, we analyze several possible designs of the aerodynamic deorbiting system for Earth remote sensing small spacecraft not equipped with a propulsion system.**

***Keywords*— small spacecraft, Earth remote sensing, de-orbiting system, design, aerodynamic system.**

1. Introduction

The current trend towards the deployment of multi-satellite constellations of the Earth remote sensing has negative consequences. As a result of mass launches of small spacecraft, including nano- and micro-class, into low Earth orbits, the amount of potential space debris is increasing [1]. The desire to miniaturize optoelectronic equipment for spacecraft for Earth remote sensing leads to an increase in the number of nano- and microsatellites. Due to mass and dimension constraints, it is not always possible to equip such spacecraft with propulsion systems to deorbit them after the target function has been completed. Therefore, the use of aerodynamic devices for deorbiting has attracted special attention in recent years. They belong to the class of passive deorbiting systems, do not require significant power supply capacity on board, are simple in execution, and also have a sufficiently small mass and do not take up a large volume when folded. All this makes such systems promising means for deorbit of the Earth remote sensing small spacecraft.

Evaluation of the effectiveness and selection of the type of deorbiting system for small spacecraft for various purposes, carried out in previous studies, indicated the need to develop a reliable and efficient design of an aerodynamic device that can ensure the opening or inflation of the sails and the functioning of the deorbiting system after a collision with micrometeorites [2]. In order to select the most efficient option for deorbit of the Earth remote sensing, this study evaluates possible configurations of the aerodynamic system. After that, it becomes possible to develop a design appearance of a passive deorbiting system and create a flight model.

2. POSSIBLE CONFIGURATIONS FOR AERODYNAMIC DEORBIT DEVICE

A. Overview of existing designs for an aerodynamic deorbit device

Currently, aerodynamic devices are the most prevalent method to deorbit of satellites from low Earth orbit. With a certain midsection area to mass ratio at altitudes equal to or below 800 km, such devices can be deployed to increase aerodynamic drag. This accelerates of deorbiting and corresponds to the requirement to limit the ballistic lifetime of spacecraft to 25 years. Recently, aerobraking technology has been implemented in several small spacecraft missions, and prototypes are being developed by several companies and organizations that are becoming more advanced.

Most often, existing projects use an aerodynamic device in the form of a plane sail with various configuration options for composite segments (Fig. 1a). A similar design was used in such missions as NanoSail-D2, CanX-7, Inflatesail, RemoveDebris, TechDemoSat-1, Icarus-1, dragNET De-Orbit System [3]. Another option is an inflatable balloon with several sections (Fig. 1b) [4]. The main elements of this type of systems, as a rule, are an aerodynamic device, a storage subsystem, an inflation device, and a controller the deorbiting system. Among the proposed configurations of the aerodynamic device, in addition to a plane sail and an inflatable sphere, a pyramid is also distinguished (Fig. 1c). An example of a pyramidal sail is the Mayak Cubesat 3U small spacecraft of the Moscow Polytechnic University. In addition, more complex designs of an aerodynamic device for deorbiting (Fig. 1d) are proposed, containing inflatable rods or representing a toroid [5].

Two significant disadvantages of aerodynamic deorbiting systems are: (1) the vulnerability of the inflated balloon to small space debris and micrometeorites, and (2) the complexity of the deployment mechanism. In this regard, it becomes relevant to choose the shape and design of the aerodynamic device, which would ensure its performance even after the rupture of the shell.

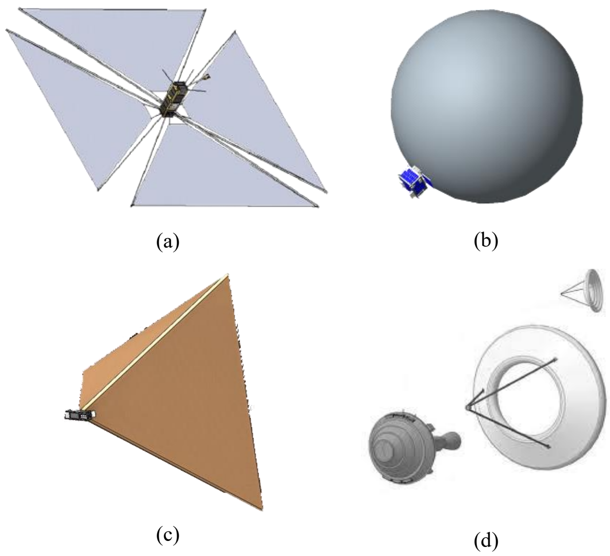


Fig. 1. Forms of the existing aerodynamic deorbiting system

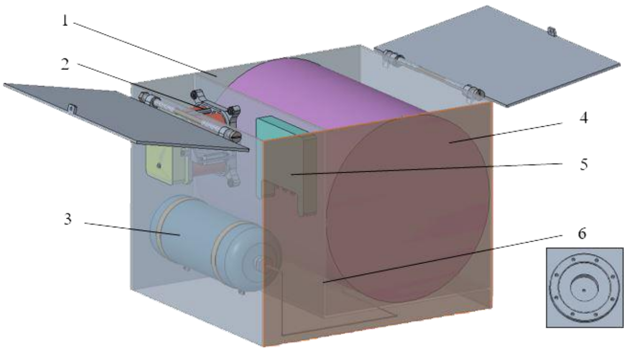
Б. Design of an aerodynamic deorbiting for Earth remote sensing small spacecraft

In the framework of this paper, an original design of a spherical inflatable device is proposed as part of an aerodynamic deorbiting system for nano- and microsatellites for Earth remote sensing.

To ensure the deorbiting process, the following design of the aerodynamic system is proposed:

- An aerodynamic device, which is a spherical inflatable balloon, divided from the inside into segments.
- Storage container, in which the folded aerodynamic device is located during the execution of the target function of the small spacecraft.
- Deployment and inflation subsystem, which is a gas generator with gas supply tubes.
- Control subsystem for managing the deorbiting system, which is a controller. After the end of the lifetime of the satellite, a command is issued to open the storage container, then to open the aerodynamic device, turn on the gas generator and fill each segment of the shell in turn with gas through a double-leaf valve at the place where the tube is attached to the shell.

The storage container contains the aerodynamic device, the gas generator, the additional power supply of the deorbiting system, and the controller (Fig. 2).



1 - storage container; 2 - power supply; 3 - gas generator; 4 - folded aerodynamic device; 5 - controller; 6 - flange mounting aerodynamic device

Fig. 2. Design of the aerodynamic deorbiting system for Earth remote sensing small spacecraft

During the operation of a small spacecraft in orbit, various factors of outer space act on it, and therefore it is necessary to ensure reliable storage of the inflatable shell of the aerodynamic device. For this, a storage container is proposed that can be integrated into the onboard composition of a microsatellite or an additional unit of a nanosatellite, providing it with additional solar panels if necessary.

3. Conclusion

As a result of the study, an analysis was made of existing projects and missions that implement aerodynamic braking technology to deorbit of the small spacecraft. The main forms of the aerodynamic device and the configuration of the system are considered. An original design of an aerodynamic deorbiting system of nano- and microsatellites for Earth remote sensing is proposed. This configuration takes into account the constraints of such devices in terms of mass, power supply capacity and dimensions, as well as the risk of rupture of the inflatable shell when space debris or micrometeorites enter it.

References

[1] IADC Space Debris Mitigation Guidelines [Electronic resource]. – Access mode: https://www.unoosa.org/documents/pdf/spacelaw/sd/IADC-2002-01-IADC-Space_Debris-Guidelines-Revision1.pdf (01.11.2021).

[2] Krestina, A.V. Determining design characteristics of the de-orbiting system for the small satellite / A.V. Krestina, I.S. Tkachenko // AIP Conference Proceedings. – 2021. – Vol. 2318.

[3] State-of-the-Art Small Spacecraft Technology [Electronic resource]. – Access mode: https://www.nasa.gov/smallsat-institute/sst-soa/deorbit-systems#references (01.11.2021).

[4] Roddy, M. Development of a Solid-State Inflation Balloon for Aerodynamic Drag Assisted Deorbit of CubeSats [Electronic resource]. – Access mode: http://unisec-global.org/ddc/pdf/1st/06_MorganRoddy_pre.pdf (01.11.2021).

[5] Alpatov, A.P. The development of structural design and the selection of design parameters of aerodynamic systems for deorbiting upper-stage rocket launcher / A.P. Alpatov, O.S. Paliy, O.D.Skorik // Sci. innov. – 2017. – Vol. 13(4). – P. 29-39.