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STRATEGY OF SPACE DEBRIS TREATMENT

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Abstract

Purpose and Objectives of the Work: *this scientific article is devoted to space debris management issues. The aim of this scientific investigation is assessment of the protection methods from the influence of space debris on the Earth.* ***Methods of Research:*** *ground-based measurements, space-based measurements, analysis of the protection strategies.* ***Research Results:*** *providing of two protection strategies: shielding (space debris shields for both manned and unmanned spacecraft can be quite effective against small particles. Protection against particles 0.1-1 cm in size can be achieved by shielding spacecraft structures) and collision avoidance which is possible by reducing the amount of new debris created and, in the longer term, removing existing debris.* ***Discussion:*** *to improve the space environment we need to develop the complex approach, which, first of all, must include: 1) reducing creation of debris; 2) removing existing debris.*

Key words: space debris; ground-based measurements; space-based measurements; protection strategies.

1. Introduction

Space exploration comes with a growing environmental problem. Like the Earth's environment, the space environment is getting more and more cluttered. Satellites in orbit around Earth are used in many areas and disciplines, including space science, Earth observation, meteorology, climate research, telecommunication, navigation and human space exploration. They offer a unique resource for collecting scientific data, commercial opportunities and various essential applications and services, which lead to unrivalled possibilities for research and exploitation. More than 500,000 pieces of debris are tracked as they are on the Earth's orbit. They all travel at speeds up to 17,500 miles per hour, fast enough for a relatively small piece of orbital debris to damage a satellite or a spacecraft.

2. Analysis of the Latest Research and Publications, Problem Statement

As you know, space debris (junk, waste, trash, litter or garbage) is the collection of defunct human-made objects in the Earth orbit, such as old satellites, spent rocket stages, and fragments from disintegration, erosion, and collisions – including those caused by the space debris itself. As of December 2016, five satellite collisions have resulted in generating space waste.

As of 5 July 2016, the United States Strategic Command tracked a total of 17,852 artificial objects in orbit above the Earth, including 1,419 operational satellites [1, 2]. However, these are just objects large enough to be tracked. As of July 2013, more than 170 million debris smaller than 1 cm, about 670,000 debris 1–10 cm, and around 29,000 larger debris were estimated to be in orbit [3]. Collisions with debris have become a hazard to spacecraft; they cause damage akin to sandblasting, especially to solar panels and optics like telescopes or star trackers that cannot be covered with a ballistic Whipple shield (unless it is transparent) [4].

Taking into account the space debris generation and accumulation issue, there are number of

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organizations active in conducting research to reduce the negative impact of space debris. Thus, the primary purposes of the Inter-Agency Space Debris Coordination Committee (IADC), as an international forum of national and multi-national space agencies for the coordination of activities related to space debris, are:

– to exchange information on space debris research activities between member space agencies;

– to facilitate opportunities for cooperation in space debris research;

– to review the progress of ongoing cooperative activities;

– to identify debris mitigation options.

The IADC Protection Manual provides:

– a standard framework to assess space debris risks;

– validated ballistic limit equations;

– benchmark results for cross-calibration impact facilities and tests;

– reference cases for validation of numerical simulations;

– design guidelines for the protection of space assets [5].

According to the National Aeronautics and Space Administration (NASA) Orbital Debris Program Office, there are more than 19,000 pieces of debris in orbit bigger than 10 cm as of 2006, and half a million objects smaller than that. The Institute of Space Research (ISR) has a small program to investigate space debris using recently flown telescopes on satellites whose primary missions are to study other things. With the cameras on the Solar Mass Ejection Imager (SMEI), we discovered swarms of debris occasionally interfering with the detections of solar storms. These swarms turned out to be clouds of small particles ejected from the host spacecraft, Coriolis, probably due to impacts by other small pieces of space debris [6].

Although not life- or mission-threatening to most satellites, these small objects contribute, perhaps substantially, to the degradation and loss of efficiency of the outer layers on spacecraft, including thermal insulation and solar panels. Streaks from space debris also contaminate the data from NASA's Wide-field Infrared Survey Explorer (WISE). From the infrared measurements, the debris population can be assessed and characterized with different, possibly smaller, biases compared to those inherent in the standard radar-based observations [7].

3. Purpose and Objectives of the Work

The aim of this scientific investigation is assessment of the protection methods from the influence of space debris on the Earth and analysis of strategy to reduction of the satellite quantity on the Earth`s orbit.

4. Methods of Research

Measurements of space debris. Using of several types of measurements of space debris such as:

A. Ground-based measurements.

Radar measurements. Ground-based radars are well suited to observe space objects because of their all-weather and day-and-night performance. The radar power budget and operating wavelength are limiting factors for detection of small objects at long ranges.

Optical measurements. Debris can be detected by a telescope when the debris object is sunlit while the sky background is dark. For objects in Low Earth Orbit (LEO), this period is limited to an hour or two just after sunset or before sunrise. However, for objects in High Earth Orbit (HEO), such as those in geosynchronous orbit, observations can often be continued during the entire night. The requirement of clear, dark skies is another limitation on optical measurements.

B. Space-based measurements.

Retrieved surfaces and impact detectors. Information on submillimetre-sized particles can be gained with the analysis, after return to Earth, of surfaces or spacecraft exposed to the space environment. Similar information can also be obtained through dedicated debris and dust detectors. Most of them contain, as a key element, a detection surface. Some of them are designed to catch an impact particle for further analysis. For cost reasons, surfaces are retrieved for later analysis only from LEO.

Space-based debris measurements. Space-based measurements in general have the advantage of higher resolution because of the smaller distance between the observer and the object. Also, there is no disturbing effect of the atmosphere (extinction and absorption of electromagnetic signals). The costs of space-based systems are in general higher than the costs of ground-based systems, and careful cost-performance trade-offs are needed.

5. Research Results

Protection Strategies. Space debris protection systems must include protecting satellites from debris.

Shielding. Space debris shields for both manned and unmanned spacecraft can be quite effective against small particles. Protection against particles 0.1-1 cm in size can be achieved by shielding spacecraft structures. All objects 1-10 cm in size cannot currently be dealt with by on-orbit shielding technology, nor can they be routinely tracked by operational surveillance networks. However, protection against particles 1-10 cm in size can be achieved through special features in the design of space systems (redundant subsystems, frangible structures, pressure vessel isolation capabilities, maximum physical separation of redundant components and paths of electrical and fluid lines etc.). Physical protection against particles larger than 10 cm is not yet technically feasible.

Collision avoidance. Current space surveillance systems do not reliably track objects in LEO with a radar cross-section of less than 10 cm in equivalent diameter. In addition, it is difficult to maintain orbital parameters on small catalogue objects due to factors such as a high area-to-mass ratio and, consequently, a higher susceptibility to atmospheric density variations. For space objects large enough to be tracked by ground-based space surveillance systems, collision avoidance during orbital insertion and on-orbit operations is technically possible.

Risk assessments include the probability of an event, as well as its subsequent consequences. With the assistance of models of the space debris environment, the risk of collision among operational spacecraft and space debris can be evaluated. Spacecraft in LEO are routinely bombarded by very small particles (<100 μm) because of the large number of such debris, but the effects are normally slight due to the small masses and energies involved. Because of the smaller population of large debris objects, the likelihood of collision decreases rapidly as the size of the debris increases. However, the severity of collisions between large objects increases.

The graph (Fig. 1) shows the cumulative number of accidental collisions with objects larger than 10 cm in LEO expected over the next century. In the next 40 years, such a collision is expected to occur every 5 years on average. Mitigation measures reduce the number of collisions (middle line), but even if no satellites are launched from now on, the number of collisions will continue to increase (lower line). Current trends lie somewhere between the upper and middle lines [8].

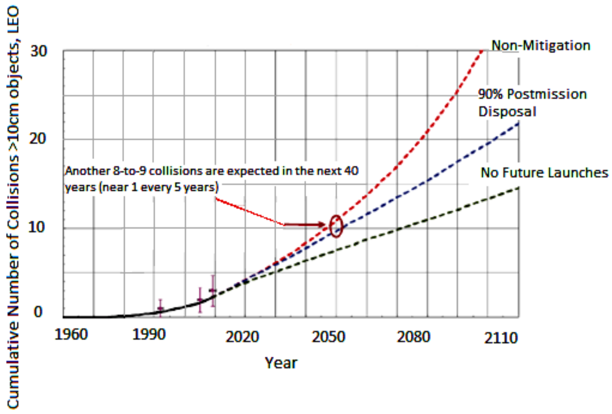

Fig.1. Future Probability of Collisions

6. Discussion

To improve the space environment we need to develop the complex approach, which, first of all, must include:

1) reducing creation of debris;
2) removing existing debris.

To reduce the amount the debris we have proposed the next:

1. Limit debris released during normal operations. France is particularly strict, requiring no more than one object to be released per launched satellite.

2. Implement collision avoidance procedures while a satellite is in use.

3. Avoid intentional destruction of satellites in orbit (such as the missile launches).

4. Avoid explosions, currently the main source of fragments, by "passivation" of satellites and rocket bodies at the end of their useful life. This includes burning or venting remnant fuel, venting pressurised gases and short-circuiting batteries.

5. Reduce the orbital lifetime of satellites and rocket bodies. Objects in LEO should be designed to leave orbit within 25 years of ending their life. This can occur naturally if the orbit is low enough, or by using drag devices or propulsion to speed their re-entry.

To remove existing debris several techniques have been proposed:

1. Attaching a propulsion device to a debris object to push it out of orbit;
2. Using a robotic grappling device on another spacecraft to tug an object to a new orbit or to cause it to re-enter the atmosphere destructively;
3. Using a momentum exchange tether, which acts like a swing, to pull an object out of orbit;
4. Using an electrodynamic tether, which causes a drag on the satellite due to the magnetic field of the Earth;
5. Slowing objects using high-powered lasers fired from Earth, so that they move out of orbit.

We have analyzed protection strategies which have been discussed before (Table 1, 2).

Table 1

Shielding

Positive	Negative
High level of protection Resistant materials for equipment	Bigger weight of the satellite Less maneuverable Not available for old satellite

Table 2

Collision avoidance

Positive	Negative
Avoidance from the big objects	Slow avoidance reaction for small objects

With the use of ground-based optical and radar surveillance systems around the world, space objects with diameters larger than 10 cm in LEO and larger than 1 m in GEO can be observed and tracked. More than 8,500 catalogued objects are in Earth orbit. The number of in-orbit catalogued objects has been increasing at a relatively linear rate for the past several decades.

7. Conclusion

Many organizations involved in space operations have become aware of the potential threats of space debris, and some of those organizations have initiated efforts to mitigate debris generation and to share the results of those efforts with the international community. The activities of international organizations such as IADC and IAA have made positive contributions to space debris research and education. In most cases, man-made space debris today poses little risk to the successful operations of approximately 600 active spacecraft now in Earth orbit. However, the known and assessed population of debris is growing, and the probabilities of potentially damaging collisions will consequently increase. Because of the difficulty of improving the space environment with existing technologies, the implementation of some debris mitigation measures today is a prudent step towards preserving space for future generations. In some cases, technical work remains to be done to determine the most effective and cost-efficient solutions.

That's why the scientific direction concerning to space debris treatment requires the further development.

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Стратегія поводження з космічним сміттям

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Мета і завдання роботи: ця наукова стаття присвячена питанням управління космічним сміттям. Метою цього наукового дослідження є оцінка методів захисту від впливу космічного сміття на Землю. **Методи дослідження:** наземні вимірювання, космічні вимірювання, аналіз стратегій захисту. **Результати досліджень:** передбачається дві захисні стратегії: захист (захист космічного сміття як для пілотованих, так і безпілотних космічних апаратів, може бути досить ефективним проти дрібних частинок. Захист від частинок розміром 0,1-1 см може бути досягнутий за допомогою захисних конструкцій космічних апаратів) та запобігання зіткнення, що є можливим завдяки зменшенню кількості нового сміття і, у довгостроковій перспективі, видалення існуючого сміття. **Обговорення**: для поліпшення космічного середовища нам потрібно розробити комплексний підхід, який, в першу чергу, повинен включати: 1) зменшення утворення сміття; 2) видалення існуючого сміття.

Ключові слова: космічне сміття; наземні вимірювання; космічні вимірювання; стратегії захисту.

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Стратегия управления космическим мусором

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Цель и задачи работы: эта научная статья посвящена вопросам управления космическим мусором. Целью этого научного исследования является оценка методов защиты от воздействия космического мусора на Землю. **Методы исследования:** наземные измерения, космические измерения, анализ стратегий защиты. **Результаты исследований:** предусматривается две стратегии защиты: экранирование (экраны космического мусора как для пилотируемых, так и для беспилотных космических аппаратов, могут быть весьма эффективными против мелких частиц. Защита от частиц размером 0,1-1 см может быть достигнута путем экранирования конструкций космических аппаратов) и предотвращение столкновения, которое возможно за счет уменьшения количество нового мусора, созданного и, в более долгосрочной перспективе, удаления существующего мусора. **Обсуждение:** для улучшения космической среды нам необходимо разработать комплексный подход, который, прежде всего, должен включать: 1) сокращение образования мусора; 2) удаление существующего мусора.

Ключевые слова: космический мусор; наземные измерения; космические измерения; стратегии защиты.

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