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ESTIMATION OF NECESSITY OF CREATION AND CAPACITY OF DEBRIS COLLECTOR WITH ELECTRIC PROPULSION SYSTEM CREATION TAKING IN A COUNT ENERGY RESPONSE OF THE EXISTING LAUNCH VEHICLES

Розглянуто проблему космічного сміття, представлено можливі способи зменшення забруднення космічного простору. Розглянуто космічний сміттєзбирач як один із можливих засобів вирішення цієї проблеми.

Ключові слова: *космос, сміттєзбирач, ракета-носій, корисний вантаж, космічне право.*

Рассмотрена проблема космического мусора, представлены возможные способы сокращения загрязнения космического пространства. Рассмотрен космический мусоросборщик как одно из возможных средств решения этой проблемы.

Ключевые слова: *космос, мусоросборщик, ракета-носитель, полезная нагрузка, космическое право.*

The problem of orbital debris is reviewed, possible ways of debris mitigation in space are presented. Orbital debris collector is considered to be one of the possible solutions of this problem.

Keywords: *space, debris collector, rocket-launcher, payload, space law.*

The problem of orbital debris becomes one of the global problems of humanity as its influence becomes more and more appreciable. The first artificial satellite was launched in 1957, and the first registered accident in space took place in 1961 – the stage of rocket-launcher Transit for orbital injection of the satellite burst. The first purposeful explosion of satellite Cosmos-50 was recorded in 1964.

The number of injected objects on various orbits increased sweepingly, and the number of orbital debris increased with it. Risk of collision of space apparatus among them and with debris also went up. That's why the Convention on Registration of Objects Launched into Outer Space was adopted 12.11.1974 to regulate the disposal of objects. Only since 1944 till 01.01.2012 995 satellites of various assignments with the expected period of operation 1 – 18 years were injected [1]. Even considering their trouble-free operation they will become debris after fulfillment of the scheduled missions if they are not removed, as the time of their descend on height of atmosphere where combustion takes place can last for hundreds of years. The scientists of the European Space Agency counted that 94% of all registered space objects had become debris up to 2005 [2].

Table 1

Number of space objects of different countries/ organizations on 03.10.2013 [3]

Country/ Organization	Payloads	Rocket Bodies & Debris	Total
China	152	3599	3751
CIS	1427	4758	6185
ESA	44	46	90
France	57	445	502
India	52	119	171
Japan	124	82	206
USA	1143	3775	4918
Others	634	139	773
Total	**3633**	**12963**	**16596**

Quantity of the objects on space orbits requires international cooperation in settlement of mutual displacement of active apparatus and tight restrictions on orbital debris generation.

Declaration on Principles Governing the Activities of States on the Exploration and use of Outer Space, 13.12.1963, Agreement on Principles Governing the Activities of States on the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, 19.12.1966 can be considered the beginning of international collaboration in branch of international space law. General principles of space usage, coordination of actions of the countries which carry out injections of flying apparatus without discussing the issues of neutralization of non-functioning objects (which completed their mission and which stopped functioning because of an accident). Presidential Directive on National Space Policy, 11.02.1988 can be considered the first document on problem of orbital debris.

Modern most informative regulatory documents on limiting of number of space debris:

– ISO 24113:2010: Space Systems – Space Debris Mitigation Requirements [4];

– NASA-STD-8719.14 NASA Technical Standard: Process for Limiting Orbital Debris,

– 28 August 2007 [5];

– NASA-HANDBOOK 8719.14 Handbook for Limiting Orbital Debris, 30 July 2007 [6];

– GOST R 52925-2008 Space technology items. General requirements for mitigation of near-earth space debris population [7];

– Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, United Nations Office of Outer Space Affairs, Vienna, 2010 [8];

– Position Paper on Space Debris Mitigation, IAA, ESA, 15 October 2005 [9].

These documents provide next ways of abbreviation of orbital debris:

– limiting generation of debris that appears during fulfillment of typical space operations;

- limiting of possibility of collision with other objects on orbit;
- limiting consequences of collision with existing space debris or meteoroids;
- abbreviation of threat of debris;
- passivation of on-board energy supply after mission completion;
- limiting term of functioning of objects on low near-Earth orbits after mission completion or maneuvering to distant orbits;
- decrease of risk of an accident with people from the elements of space systems moving to the atmosphere for postprocess placement.

Practically realizable ways of pollution control are rather limited today: avoidance of collisions is possible only with the large-size registered debris, it requires precise data of movement get due to tracking trajectories; operational and program limits have a great influence on calculations; shielding of the space transport is possible only from debris with low energy: objects with size more than 1 - 2 cm can make crucial damage.

Reduction of debris number is yet the best generally acknowledged strategy for long-term perspective of struggle against the results of space littering and possibility of trouble-free injection and placing space flying apparatus on target objects. The rule of 25-year postmission disposal remains the most effective in limiting the number of potential orbital debris. [3].

It’s possible to classify the next popular features of neutralization of debris:

- space debris collectors;
- ground laser apparatus;
- space laser apparatus;
- made of polymeric materials nets;
- space rope;
- space sail;
- magnetic field generators;
- explosive materials for generation of wave to move debris contactless.

DC is proposed to reduce the number of space garbage and to obey international standards. It should collect small-size, middle-size, large-size orbital garbage. This space apparatus is equipped with retrieval system for collecting and disposal of space debris on low earth orbits and electric propulsion system. DC is injected by rocket-launcher on circular orbit of 800 – 1200 km and it descends to height of 500 – 700 km braking by the instrumentality of electric propulsion system of low thrust.

The methodology of design of DC’s power, thrust and mass characteristics is presented below [10].

Iteration procedure is proposed to solve the problem. Type of rocket-launcher which is able to put load with mass M_0 into certain height of near-earth orbit and upper-stage rocket with liquid-propellant rocket engine (with known specific impulse and ratio of dry solid matter α to mass of fuel) are chosen in first approximation. Heights of circular orbits are set for upper-stage rocket and DC.

DC’s characteristic velocity W_{LPE} is calculated to provide preliminary estimate of mass characteristics:

$$W_{LPE} = A\sqrt{\frac{\mu}{r_0}}; \tag{1}$$

$$A = \frac{\sqrt{2}(\tilde{r}_e - 1)}{\sqrt{\tilde{r}_e}(1+\tilde{r}_e)} + \frac{1-\sqrt{\tilde{r}_e}}{\sqrt{\tilde{r}_e}}; \tag{2}$$

$$\tilde{r}_e = \frac{r_e}{r_0}; \tag{3}$$

$$r_e = H_e + R_E; \tag{4}$$

$$r_0 = H_0 + R_E, \tag{5}$$

where r_0 – radius of primary orbit; H_0 – the lowest height of orbit; R_E – earth's radius; r_e – radius of end orbit; H_e – height of end orbit; μ – gravitation constant of earth.

Received value of characteristic velocity is used to determine fuel margin:

$$M_F = M_0\left(1 - \frac{1}{e^{W_{LPE}/J_{spLPE}}}\right), \tag{6}$$

where M_0 – payload mass; J_{spLPE} – specific impulse of liquid propellant engine.

Then summary propulsive burn of liquid-propellant rocket engine is calculated:

$$I_\Sigma = M_F J_{spLPE}. \tag{7}$$

Time of operating of with liquid-propellant rocket engine:

$$\tau_{lpr} = \frac{I_\Sigma}{P}, \tag{8}$$

where P – thrust of upper-stage rocket.

Then dry matter of upper-stage rocket is defined:

$$M_{USRdm} = \alpha M_F. \tag{9}$$

It is supposed that upper-stage rocket without worked out fuel remains a part of DC. DC's mass:

$$M_{DC} = M_0 - M_F. \tag{10}$$

Calculation of characteristics of electric propulsion

Expected characteristics of electric propulsion are defined in first approximation:

$$W_{EP} = \sqrt{\frac{\mu}{r_0^*}}\left(1 - \frac{1}{\sqrt{r_e^*}}\right); \tag{11}$$

where W_{EP} – characteristic velocity of electric propulsion:

$$r_e^* = \frac{r_e}{r_0^*}, \tag{12}$$

where r_0^* – radius of orbit where electric propulsion stops working.

The prototype of electric propulsion with the time of active work τ_{EP} is chosen, and the power consumption N, and thrust P are counted:

$$N = \frac{J_{spEP}^2 M_{ws}}{2\eta_T \tau_{EP}}; \tag{13}$$

$$P = N/\xi, \tag{14}$$

where J_{spEP} – specific impulse; η_T – tractive ratio; ξ – charge of thrust [11]; M_{ws} – working substance's mass:

$$M_{WS} = M_{DC}\left(1 - \frac{1}{e^{W_{EP}/J_{spEP}}}\right). \tag{15}$$

For DC with electric propulsion:

$$M_{DC}^* = M_{PL} + M_{PS} + M_{\mathbf{constr}} + M_{SCCS} + M_{SE} + M_E + M_{WS} + M_{ssfs}, \tag{16}$$

where M_{PL} – mass of payload; M_{PS} – mass of power supply system; $M_{\mathbf{const}}$ – mass of construction; M_{SCCS} – mass of system of converting and control system of electric propulsion; M_{SE} – mass of service equipment; M_E – mass of engine; M_{ssfs} – mass of storage system and feed system.

If catching element is considered to be a sphere then its mass:

$$M_{PL} = 4 \cdot \pi \cdot R^2 \cdot \delta, \tag{17}$$

where R – radius of catching element; δ – density of shell:

$$R = \sqrt{\frac{M_{PL}}{4\pi\delta}}\,. \tag{18}$$

Types of rocket-launchers and type of electric propulsion are reviewed in next approximations up to meet compliance of results of previous and following iterations.

This methodology gives a possibility to choose necessary type and characteristics of rocket-launcher, electric propulsion for a space system for collecting and removing orbital debris (table 2).

Table 2

Load-carrying capacity of rocket-launchers on the height of 200 km

Rocket-launcher	State of development	Load-carrying capacity on orbit with the height of ~200 km, ton	Mass of space apparatus, M_{SA}, ton
1	2	3	4
«Cosmos»	Russian Federation	1,40	1,17
«Titan-2SLV»	The USA	2,36	1,97
«Molniya»	Russian Federation	2,50	2,08
«CZ-2C»	People's Republic of China	2,75	2,29
«Cyclone-2»	Ukraine	3,07	2,56
H-1	Japan	3,20	2,67
«Икар-2»	Russian Federation	3,21	2,68
«CZ-2D»	People's Republic of China	3,35	2,79
«Titan-34B»	The USA	3,60	3,00
Rocket-launcher	State of development	Load-carrying capacity on orbit with the height of ~200 km, ton	Mass of space apparatus, M_{SA}, ton
PSLV	India	3,70	3,08
«Delta-2» (7920)	The USA	3,72	3,10
«Dnepr-1»	Ukraine	3,82	3,18
«Cyclone-3»	Ukraine	4,00	3,33

Table 2 continuation

1	2	3	4
«CZ-4B»	People's Republic of China	4,16	3,47
«CZ-3»	People's Republic of China	4,80	4,00
«Arian-40»	France	4,85	4,04
«Vostok»	Russian Federation	5,07	4,23
«GSLVMK1(KVD-1)»	India	5,35	4,46
«Arian-42P»	France	6,00	5,00
«CZ-3A»	People's Republic of China	6,00	5,00
«Atlas-2»	The USA	6,60	5,50
«Arian-44P»	France	6,82	5,67
«Atlas-2A»	The USA	7,00	5,83
«Arian-42L»	France	7,30	6,08
«Long March»	People's Republic of China	7,40	6,17
«Soyuz 2-1Б»	Russian Federation	7,85	6,54
«Delta-4M»	The USA	8,20	6,85
«Arian-44LP»	France	8,25	6,88
«Delta-3/8930»	The USA	8,30	6,92
«Atlas-3A»	The USA	8,66	7,22
«CZ-2E»	People's Republic of China	8,80	7,33
«CZ-2F»	People's Republic of China	9,00	7,50
«CZ-3C»	People's Republic of China	9,30	7,75
«Arian-44L»	France	9,60	8,00
«H-2A/202»	Japan	9,75	8,13
«Atlas-33»	The USA	10,00	8,33
«H-2»	Japan	10,50	8,75
H-2A/2022	Japan	10,60	8,83

Table 2 continuation

1	2	3	4
«Delta-4M+(4,2)»	The USA	11,00	9,18
«CZ-3B»	People's Republic of China	11,20	9,33
«Atlas-5 (401)»	The USA	12,50	10,42
«Zenit-2»	Ukraine	13,00	10,67
«Titan-405A»	The USA	13,40	11,17
«Atlas-5» (521)	The USA	15,10	12,57
«Zenit-3»	Ukraine	17,30	14,00
«Titan-404B»	The USA	17,60	14,07
«Titan-403A»	The USA	17,70	14,75
Rocket-launcher	State of development	Load-carrying capacity on orbit with the height of ~200 km, ton	Mass of space apparatus, M_{SA}, ton
«Arian-5G»	France	19,45	16,20
«Proton-K/DM»	Russian Federation	19,77	16,47
«Atlas-5» (551)	The USA	20,50	17,10
«Proton D-1»	Russian Federation	20,90	17,42
«Proton-M»	Russian Federation	21,00	17,50
«Titan-402A»	The USA	21,00	17,89
«Delta-4H»	The USA	24,00	20,00
«Ares-1»	The USA	25,00	20,83
«Space Shuttle»	The USA	28,80	24,04
«Angara»	Russian Federation	35,00	29,17
«Ares-V»	The USA	188,00	156,68

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ДВИЖЕНИЕ ЖИДКОСТИ ВО ВРАЩАЮЩИХСЯ ЕМКОСТЯХ ПОД ДЕЙСТВИЕМ ОБРАТНОГО УСКОРЕНИЯ

Запропоновано математичну модель та алгоритм розрахунку динаміки рідини у ємності під дією повздовжнього додатного прискорення з одночасним обертанням ємності навколо поперечної осі, що проходить через її центр мас.

Ключові слова: *вісесиметрична ємність, обертання, лагранжевий підхід.*

Предложена математическая модель и алгоритм расчета динамики жидкости в емкости под действием продольного положительного ускорения с одновременным вращением емкости вокруг поперечной оси, проходящей через ее центр масс.
