Universal Rocket Space Engine and solving the problem of space debris

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Abstract. The total mass of only large fragments of space debris in low-earth orbits (LEO) exceeds 7,500 tons. The well-known concepts of solving the problem of space debris are considered. An approach to space debris as a valuable resource is formulated. It is proposed to use space debris as a propellant for the Universal Rocket Space Engine (URSE). The engine should consist of a thermal rocket engine in conjunction with accelerator – railgun, for example. The steam generated during the evaporation of space debris speeds accelerates to 10 – 50 km/s in this scheme. Power supply of the engine is planned to be implemented by solar energy or a nuclear power plant. When particles of debris passing through a high-temperature evaporator, it turns into steam. Then the steam passes into the nozzle, where the railgun is located. After railgun, the accelerating plasma expires in space. There are three methods to obtain high-temperature vapor in the evaporator: solar furnace (direct heating), electric arc heating or ion sputtering technology. The project is proposed to be divided into several stages, each characterized by the use of various technical solutions. URSE will allow using not only space debris, but also materials of small celestial bodies as fuel for space flights within the solar system. This will make it possible to radically change the schemes of space flight, since restrictions on the mass of fuel using the URSE are removed. For example, during flying from Mars to Earth, the material of the Martian satellites of Phobos and Deimos can be used as a propellant.

1. Introduction
The problems associated with the pollution of the Earth’s orbit by space debris have troubled the scientific community since the beginning of the space age. As follows from [1], since that time the number of objects classified as space debris in the Earth’s orbit has increased significantly. This happened both due to the natural accidents of space technology, and quite consciously. The Westford project is one of the first examples of space debris consciously littering near-Earth space. The US Department of Defense planned to bring 480 million copper needles into medium earth orbit (MEO) to create an artificial ionosphere around the Earth and provide a more reliable military communications system. Each needle - a dipole microantenna, its length was 1.78 cm, thickness - 17.8-25.4 microns. This was accomplished in 1963. Most of the needles burned in the Earth’s atmosphere over the next three years after the project was closed, but some remained in earth orbit. In 2007, the Chinese rocket destroyed the Fengyun-1C defunct satellite. As a result of this incident, a lot of new debris was formed, and about 3 thousand were tracked and cataloged. The collision of the satellites Cosmos-2251 and Iridium 33, which occurred in 2009, led to the forming of more than 600 debris in Earth's orbit. This incidents are the largest in ejections of space debris. Space debris is classified into large objects (old spacecraft, spent rocket stages), medium objects (space probes, micro, nano old defunct spacecraft).
and small objects (spacecraft debris, missile stages, containments). At the same time, according to [1], space debris stretches from 300 km to 36000 km above the Earth, the largest number of objects found at the level of 700 - 1100 km. According to [2], their speed ranges from 3 to 7 km / s. It is not difficult to imagine the destructive consequences of a collision of such an object with a spacecraft. In [3], an analysis of the composition of space debris materials was carried out on the basis of data on materials of launched satellites and data on the composition of materials of objects returned to Earth. It was found that about 74% of all objects of space debris are part of the rocket stages, the remaining 26% - the remnants of payloads delivered from Earth. For the purposes of this work, all space debris is divided into 3 groups, depending on the density of materials. The group with high density includes materials containing iron, gold, copper, medium density - aluminum and titanium, low density - plastic.

Maintaining flight safety by tracking the trajectories of spacecraft launches is now becoming increasingly difficult, as new satellites are reduced in size, and the launch process is simplified. This facts leads to an increase in the probability of emergencies in space. Being the main source of dangerous situations and collisions in the Earth’s orbit, space debris must be rationally recycled, and new ejections must be limited.

Now there are various solutions for this problem. According to [4], there are several options for space debris removal:
1) Using laser to destruct space debris and turning it into a plasma;
2) Using autonomous spacecraft and moving debris to the upper layers of the Earth’s atmosphere with subsequent combustion;
3) Remove of debris in spacecraft equipped with a grid that creates an electromagnetic field that will slow objects into the network and bring them to the upper layers of the Earth’s atmosphere with subsequent combustion.

In April 2018, the European Space Agency, under the “RemoveDebris” program, launched a satellite into LEO to demonstrate the possibility of capturing space debris. Three experiments are planned that are directly related to testing the performance of space debris capturing systems, as well as demonstrating the capabilities of visual recognition of space debris. The satellite will let out small satellites - cubsat, which will imitate space debris. The following experiments will be carried out: capturing space debris by a special network, then burning an object in the Earth’s atmosphere, using a harpoon to shoot a special retractable target, checking the working of the space debris coordinate recognition system and, at the very end, de-orbiting to the upper atmosphere of the satellite itself using a sail. If the experiments are successful, in the future, the European Space Agency is planning further launches of such satellites into Earth orbit.

Existing concepts and ideas for removing space debris from Earth orbit have significant drawbacks:
1) The destruction of large elements of space debris can lead to the emergence of small objects that are more dangerous for spacecraft and more difficult to track as well as destroy;
2) The moving of objects from LEO into the layers of the Earth’s atmosphere can lead to incomplete combustion and fall to the Earth;

There are alternative options for removing and recycling space debris. Let us consider in more detail several works. To maintain a space station weighing about 100 tons in a given near-earth orbit, it is necessary to compensate the aerodynamic drag, which is about 1 N. As a result, more than 3 tons of propellant is consumed per year for the ISS to maintain orbit. In work [5], the authors propose to use a solar thermal rocket engine to compensate for aerodynamic drag. It’s intended to use water-based waste and plastics that accumulate on board the orbital station as propellant. After grinding, the particles passing through a high-temperature crucible heated by solar radiation. In a crucible, water turns into steam, and plastic undergoes thermal destruction. The resulting mixture of gases and small particles expires in the nozzle, accelerates there and expires in open space. Since the flow velocity vector is
directed against the station's motion, solid particles emitted from the nozzle of the solar thermal engine immediately go out from the orbit and burn in the atmosphere.

In paper [6], it is proposed to create a spacecraft that, by capturing and processing space debris into pseudo-liquid fuel. The spacecraft will be powered by solar cells. This concept of the device will allow to solve issues related to the recycling of space debris, as well as to provide continuous operation in space through the independent production of propellant. However, the oxidizer for this fuel is still planned to be delivered from Earth.

The paper [7] describes the project of a spacecraft equipped with an engine whose propellant is recycled space debris. It is assumed that space debris will grinding to a state of powder, and then passing to the charging system. There, fine powder particles will acquire an electric charge. Then they enter the electric field of the accelerator. Charged particles fly out of the engine nozzle, the spacecraft acquires acceleration and moves to the next object. To achieve electroneutrality, a neutralizer is located at the nozzle exit. During a computational analysis, the authors suggest that aluminum is the main material for space debris, and the characteristic particle size of the debris powder is 1 µm. Taking into account the fact that the electric field of the accelerator will be tens of kilovolts, it is assumed that the rate of emitting particles will be small, as well as engine thrust. Also, this concept does not eliminate the problem of space debris because a cloud of tiny particles will form behind the engine. During maneuvering in orbit, not all particles will quickly go out of orbit. In our opinion, this is the main disadvantage of this project.

It can be reasonably concluded that the existing ways of utilization of space debris have a number of significant drawbacks. Moreover, we believe that the destruction of space debris is impractical and irrational. Delivering a payload to Earth orbit and above is extremely expensive, while several thousand tons of metal, ceramics and semiconductors (estimated at about 7,500 tons) are already in orbit. The destruction of such a valuable resource will entail serious economic costs without any economic benefit. It is more reasonable to use this resource as a source of mass to create thrust.

2. URSE concept

The main idea - using space debris as propellant for an electric rocket engine (ERE). It is proposed to create a system consisting of a space station with a URSE with propellant in form of space debris, and a space vehicle equipped with a similar engine. The vehicle should search for relatively large fragments of space debris and move them to the space station. The URSE should consist of a thermal rocket engine (TRD) in conjunction with plasma accelerator–railgun in our concept. The block diagram of the engine is presented in fig. 1. It is planned to power the engine due to solar energy or a nuclear power plant (NPP) on board of spacecraft.

![Figure 1. Block diagram of URSE](image)

Let's consider the proposed concept in more details. It is proposed to use tiny particles of space debris as the initial working fluid in the URSE. Passing through the area of high-temperature heating, small particles turn into steam. Steam expires through a nozzle, accelerates and run out in open space. In order to save propellant, it is necessary to achieve the highest possible flow rate of the working fluid from the
engine. Plasma accelerators, the rate of plasma outflow from which can reach more than 10 km / s, are quite suitable for creating the desired thrust. One of these accelerators is the railgun. Railgun is a constructively simple type of plasma accelerator, its scheme is shown in Fig. 2

![Figure 2. Scheme of railgun](image)

Railgun consists of two parallel electrodes - a rails connected to a DC source. A sufficiently powerful current is supplied to the electrodes, which is enough to immediately ignite the plasma arc between the rails. A current flows through the plasma from one electrode to another and an electromagnetic field arises that affects the accelerator. Under the action of the Ampere force, a conductor with current (plasma) begins to move rapidly along the electrodes, accelerating to high speeds. Ampere force acts on the rails, leading them to mutual repulsion. The advantages of this accelerator are the ability to accelerate plasma bridges to speeds of 10 km / s, low cost and ease of production. Acceleration of solids in the railgun does not seem perspective, since it is not possible to achieve a velocity of a solid greater than 2 km / s, and there is a rapid wear of the rails due to great overloads. But with the acceleration of metal vapors, these disadvantages are disappeared.

Using a rail accelerator led to the erosion of the channel walls with which the electric arc contacts. In the usual scheme of using a plasma gun, this effect is purely negative, it leads to a quick installation failure. However, in our case, when high-temperature metal vapor of iron, aluminum or titanium is used as the propellant, the erosion of the walls will be compensated by the condensation of these vapors on the walls of the plasma accelerator.

As a source of high-temperature steam can be a device, the design is quite similar to a solar furnace. A solar furnace - is a device that uses concentrated solar energy to produce high temperatures using parabolic mirrors that concentrate light at the focal point. An example of a simpler solar collector for a general understanding of the effect of solar heating is presented in Fig. 3. The solid substance used as a working fluid (one of the options is space debris) is grinded to the state of powder, placed in a heat-resistant crucible, melted, boiled and evaporated. Due to the difference of the material of which the space debris consists, the temperature in the crucible should be close to 3000 K. The material from of crucible must withstand such temperatures. In [5] and [8] it is proposed to use graphite, tungsten with a melting point of 3695 K may also be suitable. A solar furnace may provide such temperatures.
Figure 3. Simple solar collector

Similar furnace has existed for a long time in Odeillo in the Pyrenees in France, and the maximum temperature in this furnace can reach up to 3500 °C.

The use of direct solar heating is associated with certain technical difficulties:
1) it’s necessary to achieve effective heating and melting of fragments of space debris in conditions of weightlessness is required;
2) we have to provide to organize an intensive circulation of the melt near the heated walls of the crucible in order to prevent the formation of a vapor film near the walls;
3) it is necessary to study of the hydrodynamics of a three-phases (solid fragments, melt and steam) in the volume of the crucible with intensive heating under zero gravity conditions and the search for optimal ways to control the motion of such medium are required;
4) it’s necessary to conduct a detailed study of the issue of preventing the condensation of vapors of refractory components on the engine construction elements is required;
5) we must pay attention on preventing solid and liquid from escaping with the steam into the engine nozzle.

Another option for direct heating and evaporation of the working fluid in the URSE is to use devices similar in construction to the so-called electric arc furnaces. These furnaces are widely used for melting metals and other materials and use the thermal effect of an electric arc as the basis of their work. In direct-acting furnaces, the electric arc burns between the electrodes and the heated material, heating takes place directly when energy is released in the arc and current flows through the melt, as well as due to heat exchange processes between the arc and materials. During indirect action, the electric arc burns between the electrodes located above the molten materials, heat exchange between the arc and the materials is due to radiation and convection. In vacuum arc furnaces, an electric arc burns in an inert gas or vapor of the metal being remelted between a consumable electrode (of remelting material) and a bathing liquid metal or between a non-consumable electrode and a bath of the metal being remelted.

Ion sputtering - another way to get the vapor phase in URSE. The essence of this phenomenon is as follows: ions of high energy knock out particles of the material from the surface. However, the sputtering
coefficients are small and the ion points are limited, so the deposition rate during ion sputtering is lower than with thermal evaporation. The simplest method of generating ions is associated with the creation of a normal glow discharge at a residual pressure of the sputtering gas (most often argon), approximately 1 Pa and at a certain voltage between the cathode and the anode. More intense ion generation with increasing gas pressure is accompanied by increased scattering of sputtered particles as a result of collisions with gas atoms, therefore there is an optimum pressure range of 3.3–10 Pa. When using ion sputtering technology as a source of high-temperature steam, it is possible to avoid the drawbacks that have been described in the case of using direct heating. Noting the following: in space, under vacuum, it will be possible to avoid the problems of creating special vacuum systems that make up the most complex and expensive part in ion sputtering installations.

3. Stages of concept realization
The project implementation is proposed to be divided into several stages, each of which is characterized by the use of various technical solutions.

3.1. First stage
At the first stage, it is proposed to create an experimental installation that simulates URSE, as well as to conduct a set of tests on Earth. The block diagram of the experimental setup is showed in fig. 4.

![Block diagram of the experimental setup](image)

Figure 4. Block diagram of the experimental setup: 1 – Archimedean screw, 2 – heating elements, 3 – heat resistant crucible

As the working fluid is proposed to use a mixture of organic matter and water. The working fluid will flow into heat-resistant crucible, for example, by means of an Archimedean screw. Possible materials of crucible - molybdenum, tungsten, graphite. Such materials have a high melting point and withstand strong heat. Heated to a high temperature gas enters the nozzle and expires. It is proposed to heat the crucible at the expense of solar energy. Further tests are possible for melting and evaporation of materials whose composition is similar to that of space debris. It is also possible to create a system for the evaporation of materials based on ion sputtering technology and their subsequent testing.

3.2. Second stage
At the second stage, it is proposed to use a URSE as an engine for maintaining parameters of the space station orbit, for example, the ISS. It is assumed that water-containing waste will be used as the working fluid for engine. The structural diagram of this engine is presented in Fig. 5 and describes the idea.
presented in [5]. For heating and subsequent evaporation of recycled waste is proposed to use a solar furnace.

![Diagram of the engine of second stage](image)

**Figure 5.** The structural diagram of this engine of second stage: 1 – shredder, 2 – heat insulated graphite block, 3 – separator, 4 – nozzle, 5 – solar collector

Using this engine will allow you to maintain orbit of the space station and reduce the amount of fuel that must be delivered from Earth. The estimated power of the propulsion system is 10 - 15 kW. This corresponds to a solar collector with a total area of about 20 m².

### 3.3. Third stage

The third stage also involves the use of URSE on the ISS to maintain the specified orbit parameters of the space station, but in combination with the use of a space vehicle to search and transport space debris to the ISS. The collected space debris will used as the working fluid of the engine. In [9], a description of the space vehicle project is described, which may well become a prototype, with the replacement of propulsion system with a URSE.

### 3.4. Forth stage

The next stage of the project includes equipping the space vehicle with a nuclear reactor of about 1 MW. Reactor with similar power - Nuclear megawatt-class nuclear propulsion with the official title “Transport and Energy Module” (TEM), is currently being developed jointly by Roskosmos and Rosatom, the lead contractor for the reactor installation is NIKIET. Works carried out since 2009, flight tests planned in the 2020s.

### 3.5. Fifth stage

At a later stage of realization, the longer-term perspectives for using URSE are considered - equipping it with spacecraft for long-haul flights, for example, an expedition to Mars. Such a technical solution will allow to reduce the starting mass of the fuel and to provide a flight back to Earth. URSE will allow using any material as a propellant, the saturated vapor pressure at which at a temperature of the order of 2500 K allows to create a pressure of at least several Pa. Material for fuel in the form of soil can be taken directly from the satellites of Mars - Phobos and Deimos.
4. Conclusion
In this article, we present a description of the problem of debris on Earth orbits, which has been worrying humanity since the very beginning of the space age. The well-known concepts of solving the problem of space debris considered, serious drawbacks of these concepts also described. An approach to space debris as a valuable resource formulated. It is proposed to use space debris as a working fluid for the Universal Rocket Space Engine (URSE). The engine should consist of a thermal rocket engine with a superstructure in the form of a rail plasma accelerator - railgun. This scheme will allow accelerating the steam of space debris to speeds of 10-50 km / s. Power supply of the engine is planned to provide by solar energy or a nuclear power plant. We plan to obtain high-temperature steam, that serves as a working fluid for railgun, by three alternative ways: using a solar furnace (direct heating), heating with an electric arc, or using ion sputtering technology. URSE will allow using not only space debris, but also small celestial bodies as propellant for space flights within the solar system. This will make it possible to change the schemes of space flight, since restrictions on the mass of propellant using the URSE are removed. For example, when flying from Mars to Earth, the material of the Martian satellites of Phobos and Deimos can used as a working fluid.

5. References
[1] Morin J 2019 Four steps to global management of space traffic Nature 567 25-7
[2] Su S Y 1990 The velocity distribution of collisional fragments and its effect on future space debris environment Advances in Space Research 10 389-92
[3] Opiela J N 2009 A Study of the material density distribution of space debris Advances in Space Research 43 1058-64
[4] Emanuelli M, Federico G, Loughman J, et al 2014 Conceptualizing an economically, legally and politically viable active debris removal option Acta Astronautica, 104 197-205.
[5] Glazkov V V and Sinkevich O A 1998 High Temperature 36-5 820–2
[6] Barkova M E 2018 Trudy MAI 103
[7] Lei Lan, Jingyang Li and Hexi Baoyin 2015 Debris Engine: A Potential Thruster for Space Debris Removal Cornell University
[8] Nakamura T, Krech R, McClanahan J, Shoji M, Partch R and Quinn S 2005 Solar Thermal Propulsion for Small Spacecraft – Engineering System Development and Evaluation American Institute of Aeronautics and Astronautics
[9] Khamits I I, Filippov I M, Burylov L S, Tenenbaum S M, Perfiliev A V and Gusak D I 2017 A concept of space transportation and power generating system based on a solar electric propulsion orbital transfer vehicle Space Engineering and Technology 1 32-40