Space IT platforms: challenges of the XXI century

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Abstract. More than half a century of man-in-space exploration not only demonstrated the new manufacturing capabilities of the countries involved in the study of distant and near space, but also presented the main challenges that humanity will face in the exploration of the space in the first half of the 21st century. One of these challenges is the rapid growth in a number of satellites used not only by government structures, but also by private sector. This problem gives rise to another one – ensuring the safety of the satellites flights and contamination of the earth orbit by man-made objects. A particular problem is the growing militarization of the space. There is another natural challenge such as a cometary-asteroid hazard. In the near future, humanity has to answer these challenges. This is important for two reasons. Firstly, only overcoming them, we will be able to continue our expansion in the space. And, secondly, only by solving the encountered problems, we will be able to maintain the stability on the Earth. An important factor for a successful response to the challenges is international cooperation in space, which allows combining the resources of space powers including intellectual potential. In this case, we can rely on the soonest achievement of the set goals. Of course, this will mark new frontiers, which will be a challenge for the next generations.

1 Introduction

The farther humanity enters the depths of the Universe, the more challenges it has to face. We obtain some of them from the Nature, but most of them are due to the development of human civilization itself. In other words, every man sets the tasks, which he himself intends to solve. And it largely depends on us ourselves how adequate the answer to the challenges will be.

If we reject the political and philosophical aspects of the space exploration, and focus only on science and technology, then now we can formulate the following challenges which humanity has to response not to stop in its development:

1. Creation of new space technology that will allow us to live and work confidently in the space, being of benefit for all earthlings, regardless of their national, social, religious and gender identity.

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2. The beginning of the Moon and planets development of not only scientific research, but also with the intention to obtain practical benefits.
3. Sending of research probes to the solar system outskirts and into the interstellar space.
4. Non-admission of the space militarization.
5. Earth protection against comets and asteroids.
6. Clearing of the near Earth space from the man-made objects.

These are just the main challenges, but their solution is impossible without creating a new generation of space technology platforms.

2 Road map

The main leading players in space exploration have already been identified; they are the United States, China, Russia, the European Union, the UK, India and Japan. All these countries have adopted long-term space programs that are aimed both at supporting national security and substantially promoting private companies in the implementation of space programs.

Today, the space-related programs are an important part of the national economies. For example, the European Union in the period of 2012-2020 plans to invest €12 biln. in the space programs, having increased a number of its satellites from 18 to 30 pcs. in the period until 2035. In 2014, with employed 230,000 persons, the aerospace industry provided the output of products and services amounting to €45-54 biln. that makes 21% of the world market [1]. The UK estimates its aerospace industry at a level of £11.8 biln, with 35,000 employees, and has ambitious plans to bring the output of the sector up to £40 biln. by 2030 [2]. According to the Federal Aviation Service of the United States, only in 2009, space transportation generated the contribution to the US economy at a level of US$208.3 biln. [3]. In 2015, the world market of the space services was estimated at US$323 biln, of which 76% was for commercial infrastructure and systems [4].

The wide involvement of the economy in the implementation of the space programs is primarily due to the need to create **a new space technology**.

For more than 60 years in the space exploration, humanity has been using technical solutions that were adopted in the early years of the space age. Changes are insignificant – the measuring and computing systems became more powerful, new materials began to be used. However, the space technology has conceptually changed little.

As a result, by today, we have almost reached the limit of our capabilities in space exploration.

We can confidently launch satellites and spacecraft into low-earth orbit. We can send people to the same orbit. It is guaranteed to return them to the Earth.

We have developed the geostationary orbit and have learned to send scientific stations to the libration points.

We can send automatic interplanetary stations to almost any celestial body. Truly speaking, in some cases the flights will take many years before the research vehicle approaches the concern heavenly body. And the mass of these probes is not large.

But today this is not enough for humanity. It is necessary to flight to the planets not only for their study, but also for development. It is necessary to deliver not hundreds of kilograms but hundreds of tons of cargoes to the space depths. And it shall be performed not for long years, but in a few weeks or several months.

To solve these problems, it is necessary to create new models of space technology, first of all, new rocket engines, which will ensure the forward movement. If this does not happen, then we will "circle over the Earth" for a long time.

Since during interplanetary flights we often mean the presence of a man on the spacecraft, then it is necessary to create such crafts which will protect people against space radiation and against the adverse effects of long space flight factors [5].

The only acceptable way out from this situation may be a nuclear rocket engine. According to the calculations, its application will significantly shorten the time of interplanetary expeditions that minimizes the risks for manned flights.

The use of nuclear energy will also allow us to enter the interstellar space that is a vital necessity for humanity in the long term [6].

The creation of new models of space technology will make it possible to response the second challenge we formulated. Namely, to start **development of the Moon and planets from the practical point of view.**

Until today, all interplanetary expeditions were exclusively cognitive. We studied the Moon and planets with a view to obtain new information as much as possible: their structure, the presence of organic substances on them, the history of their origin and development.

Now, man is not enough to have knowledge only. He became interested in practical aspects of the development of other worlds – whether there are minerals there, whether it is possible to extract them at low cost, whether there is a sense to transport them to the Earth or to use them for long-range space flights.

And the nature of scientific research has undergone significant changes. If we studied the only celestial bodies in the XX century, now we intend to use them to study even more remote areas of the Universe.

Why should we develop the Moon and other celestial bodies of the solar system.

Firstly, they are unique scientific bases, where research and experiments impossible on the Earth and in near space can be carried out.

Secondly, they will become excellent test areas for new models of space technology, which we can use to reach remote corners of the solar system and exit into interstellar space.

Thirdly, they are ideal "intermediate spaceports", which make it possible to move forward more effectively when studying distant natural objects.

Fourthly, it is possible they will become a huge source of natural resources and will provide earthlings with raw materials for many and many years.

Fifthly, only by exploring the planets, we can really, and not in words, expand the range of humanity habitat.

Table 1. Possible periods for manned expeditions to other celestial bodies (assessment).

Celestial body	Moon	Mars	Venus	Asteroids	Jupiter's moons
Flight periods	2025-2028	not until 2040	not until 2100	About 2050	After 2150

In addition, the development of the Moon and the planets, primarily the natural satellite of the Earth, also means humanitarian activity. How so the psychology of humanity has changed after the first human flight into the space, so as it will change after we have moved from single landings to the constant presence of people on the Moon and Mars bases. Many already now perceive the earthlings as a galactic race. And after Moon and Mars are developed, they only "harden" to their view [7].

The third challenge considered in the paper, on the one hand, reechoes the first two ones – **sending of research probes to the outskirts of the solar system and to interstellar space** is possible only with the availability of new space technology and intermediate bases on the celestial bodies closest to the Earth. On the other hand, these works will be performed separately, but in parallel with the development of the Moon and the planets, since they have a more philosophical nature, rather than the hope of quick practical results.

We have not yet fully studied the structure of the solar system. Our vision of it constantly changes. Moreover, the more we learn, the more questions that require an answer arise.

Table 2. Spacecraft in flight.

Name of the craft (date of launch)	Pioneer-10 (March 3, 1972)	Pioneer-11 (April 6, 1973)	Voyager-1 (September 6, 1977)	Voyager-2 (August 20, 1977)
Distance from the Sun at present	18.3 biln. km	17.3 biln. km	21 biln. km	17.7 biln. km

More recently, we believed that interstellar space begins somewhere at a distance of 30-40 billion kilometers from the Sun. Now these estimates have grown by a factor of two or three. And there is no guarantee that the solar system does not extend even farther [8].

Notwithstanding we intend to break away interstellar spaces. This desire has deep historical roots. This is evidenced by mythology, literature of antiquity, the Middle Ages and modernity. Truly speaking, it is fantastic for the most part [9].

Man has always wanted to subdue faraway worlds, not always wondering how he can do it. Now we practically approach the frontier, which overcoming we can not only dream, but also begin to put our dreams in place [10].

Apparently, it will not be easy to do. And this event will require a very impressive cost. However, this must be done to lay the foundation for the future [11].

The first three challenges, which were mentioned in the paper, have a pronounced technogenic overtone and entirely depend on the level of science and technology development. In contrast, the fourth challenge is a result and a consequence of relations between states. It is about the intention of some countries to use the space for military purposes. The immediate task of humanity is to prevent the **militarization of the cosmic space**.

The political and military circles of the world's major powers began to consider the space, as a battlefield, even before the beginning of the space age. The first space launches, the first spacecraft launched into the earth orbit, only confirmed in their opinion.

In the 1960s military use of astronautics achievements was considered almost as a mandatory application to any space program. It was in those years that anti-satellite systems, survey and detailed photographic reconnaissance systems, partial orbital bombing system (in the USSR) were created and adopted, and the development of manned interceptor and combat orbital stations began [12].

Fortunately, common sense even then prevailed over the desire to gain space supremacy. The international agreement – the Treaty Banning Nuclear Weapon Tests in Three Environments (including the space) was signed in 1963, and the treaty on principles governing the activities of states in the exploration and use of outer space, including the Moon and other celestial bodies – in 1967, which prohibited to deploy the nuclear and other types of mass destruction weapons in the space. The agreement on restrictions on anti-satellite systems was signed between the USSR and the USA a little later [13].

Truly speaking, the availability of these agreements only limited the military activities of the space powers. For example, there were never any restrictions on the creation and deployment of reconnaissance and auxiliary military systems. However, the ban on strike combat systems played a big role in the international tension detente.

Today the situation has not improved. Appearance of new space powers, consolidation of China's role in space exploration force once again to make efforts to prevent the space militarization. Initiatives with which Russia and other countries periodically advance in the UN and other international organizations are aimed at those aspects [14].

Nevertheless, the threat of space militarization remains high. Including and by means of the appearance of new technologies that allow to place weapons in the space virtually by stealth. This is the challenge that can be solved only by political means, only by agreements between the countries participating in the process of space exploration. And although we put this problem on the fourth place, full responses to the first three challenges are impossible without overcoming this one.

In recent years, the challenge of **Earth protection against comets and asteroids** has become very urgent. Awareness of the life's fragility on Earth, its high dependence on those processes that occur in the space made humanity to take the comet-asteroids hazard more seriously and to actively engage in the development of protection measures against it.

Meteorites have recently fallen to Earth as rarely as it was before. However, now we know more about the solar system structure and could more realistically assess the danger that small celestial bodies "roaming" through the great spaces.

Table 3. The probability of Earth collision with comets and asteroids in the next 100 years (assessment).

Body size	> 3 km	1-3 km	0.5-1 km	0.1-0.5 km	0.05-0.1 km	< 0.05 km
Probability	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-2}	1
Disaster scales	global	regional	local	local	regional	no consequences

In addition, the humanity technical potential has reached such a level when we can not only talk about confronting such a danger, but also develop a set of protection measures that reduce a probability of humanity destruction in case of natural disasters.

Now a probability of the human civilization disaster due to falling of asteroid with a size of several kilometers to the Earth is very low. Solar system spaces have been substantially "cleared" for billion years of its development. Everything that could fall has already fallen. Nevertheless, even though theoretically, but such a danger exists. If there is a collision threat, humanity will have no more than three years to respond to it. It's too little to have time to develop technologies that will allow protecting our planet against a space impact [15].

There is an insignificant probability, although it is much higher than the probability of global catastrophe, falling the celestial bodies of smaller sizes, about 1 km in diameter, to the Earth which are capable of causing the destruction of some countries or countries group, and creating significant problems for the "survivors". Parrying this danger also requires the development of new technologies.

However the probability of falling small meteorites of up to several tens of meters in diameter is significant. The example of the "Chelyabinsk meteorite" still sounds familiar.

And although a local catastrophe is only possible in case of falling the bodies of these sizes, the protection against them is also required. This protection is even more necessary than the one against hypothetical giant asteroids.

Moreover, technical means already exist for these purposes. Truly specking, their full deployment will require significant material costs, to which no country in the world is ready to go yet [16].

Protection from comet-asteroid danger is the only global challenge that the Nature has thrown down. Unless, the overcoming the vast spaces separating planets and stars are considered in such aspect.

The comet-asteroid danger is reechoed with another challenge being generated by every man – with the **space pollution by artificial objects**.

According to NASA estimates, there are more than 500,000 artificial objects in the Earth orbit [17]. These are operational and nonoperational satellites, booster stages, nose fairing half, fragments of space vehicles and other space debris. And this is only what we can see from the Earth or from the specialized satellites.

Many more artificial objects have smaller linear dimensions and can not be traced from the Earth. It is believed that fragments of 2 to 10 cm in the earth orbit are more than 250,000, and fragments of even smaller sizes are from 700,000 to 1 million [18]. The dynamics and forecast of space debris is shown in Fig. 1.

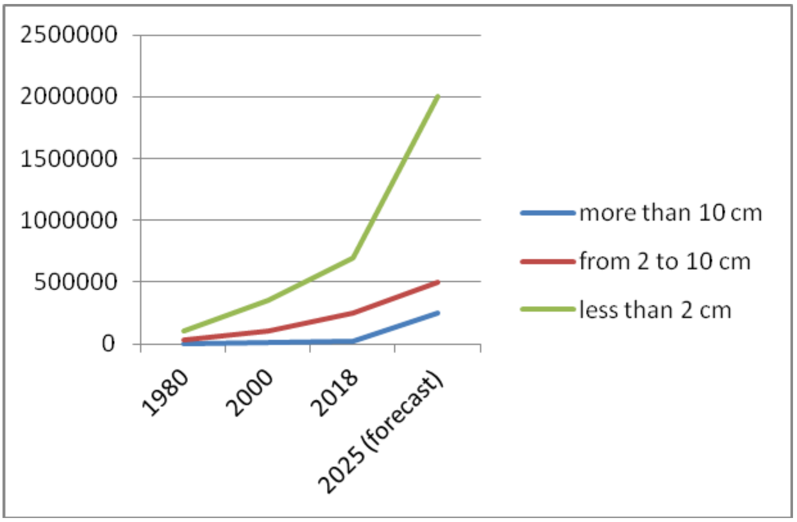

Fig. 1. Dynamics of space debris fragments growth by years.

Such a space contamination has already led to difficulties in space activities. For example, the International Space Station has regularly to maneuver to avoid probable approaching dangerous fragments approximately once every two months. Unmanned vehicles have to maneuver similarly.

For the past 25 years, at least 10 incidents related to space debris have been recorded in the space. In this case, space vehicles were seriously damaged and could not function properly, and sometimes they are completely failed.

Some experts also associate a number of incidents which have led to the loss of satellites with space debris. However, it was not possible to detect the real cause.

The most serious incident is the collision of Russian and American communications satellites, which occurred on February 10, 2009. This incident led to the appearance of several thousand fragments larger than 10 cm and, possibly, several tens of thousands of smaller fragments in the earth orbit [19].

The activation of military activities in the space, especially the testing of anti-satellite systems, could theoretically lead to more contamination of the Earth space. In this case, a threat of man exits into the space.

Now there are no approved methods for protection against space debris. The leading operators of launch services are recently trying to exclude the existence of booster stages in the low orbit, de-orbiting them after the task has been carried out and burning them in the terrestrial atmosphere. However, when the apparatus is put in the geostationary earth orbit, this technique is not used.

Rather exotic methods (laser guns, nets, harpoons – see Table 4) for cleaning the earth orbit are considered as perspective. But none of them is currently used and is considered only as a prospective one [20].

Table 4. Prospective methods for cleaning of the earth orbit.

Method description	Operating Principle	Note
ElectroDynamic Debris Eliminator	Satellites capture using harpoon and network.	Low efficiency. It can only be used to recycle large objects.
Gossamer Orbit Lowering Device	Increase of satellite aerodynamic drag due to the inflatable shell.	It is applicable only for large objects.
CleanSpaceOne	Robotic system using a jet tug.	High price. It is applicable only for large objects.
HybridSail	Satellites moving to other orbits using a light sail.	Difficulties with sail installation on unappropriated objects.
Low orbit rebooting with tungsten dust	Creation of tungsten dust cloud (no more than 30 mm particles) in the low orbit, increasing of aerodynamic braking of satellites.	It works only for small objects.
Laser Orbital Debris Removal	Using powerful pulse lasers to push satellites from the orbit.	Technical implementation complexity.

At the same time, the space debris problem requires its immediate solution, if we intend to continue using the astronautics in our life.

One last thing to be said about. As previously stated, all the challenges discussed in the paper are of a global nature. That is, it is a challenge for all humanity. Not only one country but the whole humanity has to response these challenges.

Thus, international cooperation is a fundamental factor in the space development. The cooperative efforts of the space powers will allow not only to unite their intellectual potential, but also to reduce each cost loading, as well as rationally to distribute the work in the selected aspects, to eliminate duplication in the development of space technology samples and when addressing the global challenges.

The practice of recent years has shown the possibility and justification of such cooperation even with escalating the tension in interstate relations. And this process does not and should not have an alternative.

On responding to all these "cosmic" challenges, humanity will be able not only to preserve the potential that has been acquired over the years of the space age, but also to reach new frontiers, the overcoming of which is a vital necessity for us. In addition, we will be able to save the peace on our planet and to solve many economic and social problems.

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