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# DIFFERENT ASPECTS OF THE USE OF SMALL SATELLITES FOR OBSERVATION OF THE MODERN STAGE

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***Keywords:*** *Small satellite, Minisatellite, Microsatellite, Nanosatellite, Picosatellite, Standard „CubeSat"*

***Abstract:*** *The reasons for the appearance of small satellites have been revealed. The evolution of the military and civilian small satellites created in the 21st century for surveillance and intelligence, including dual-purpose ones, is reviewed. Three groups of tasks solved by small observation satellites are defined - applied, technological, and scientific, as well as their growing importance and areas of use. The need is substantiated, and steps are proposed in the Republic of Bulgaria, respectively in SRTI-BAS, to activate the activity of creating and using small satellites for observation for the needs of the economy, ecology, humanitarian, and other areas.*

## Introduction

The modern development of world cosmonautics is inextricably linked to the use of small space vehicles (SSVs), in the most general case small satellites (satellites) solving a wide range of tasks of a different nature. For example, 94% of the number of satellites launched in 2020 are small satellites [1].

At the end of the last century, the Arianespace Company proposed a conditional classification of small satellites according to their mass, as follows: minisatellite 500-100 kg; microsatellite 100-10 kg; nanosatellite 10-1 kg; picosatellite - under 1 kg. Recently, the mass of picosatellites (0.1-1 kg) has been refined. With the development of high technologies in the XXI century, the above classification is supplemented [2] with a new category of MCLA - femtosatellites with a mass of 10 to 100 grams, implemented on a crystal or in an integrated circuit.

Several reasons can be given for the appearance of small satellites. A large satellite is created in 2-5 years, while the SSVs take 6-9 months. Therefore, several small satellites can be prepared for the time of creation of a large satellite.

Small satellites' relative simplicity and short development time usually result in lower costs. The shorter time it takes to create small satellites allows them to be renewed when they are in low Earth orbit (LEO) because the term of their operation in space is significantly shorter (from one to several years) than that of large satellites. This also allows for the periodic introduction of new technologies.

The cost of creating a small satellite (for example, a nanosatellite) and putting it into Earth orbit is significantly less than that of a large satellite. For example, the Maxar company's 2,500 kg WorldView-4 commercial optoelectronic observation (OEO) satellite costs $850 million to build and launch, while the cost to build and launch a nanosatellite is in the hundreds of thousands or tens of thousands of dollars.

The increasingly high degree of miniaturization of electronic elements, reduced electrical consumption, advances in mechanical systems, batteries, and sensors are also prerequisites for creating and efficiently using small satellites.

The rapid development of the element base of small satellites predetermines their commercial use now and in the future.

In modern conditions, the leading space countries are increasingly launching SSVs, whose mass does not exceed 10 kg, into Earth orbit. An important role in this is played by the "CubeSat" standard (Cube Satellite - cubic satellite, CubSat), by which these miniature satellites with a modular cubic shape - mainly nanosatellites and picosatellites - are built. More specifically, the "CubeSat" standard (Fig. 1) was created in 1999 by scientists and specialists at the Stanford and California Universities in the USA to provide the possibility of launching small payloads (PL) into space.

In the "CubeSat" standard, several sizes of satellites are defined, the smallest of which is denoted by 1U (from unit) and has the shape of a cube with an edge of 10 cm. Specifically, the "CubeSat" standard is a format of small satellites for space exploration, having dimensions of 10×10×10 cm and a mass of no more than 1.33 kg.

The "CubeSat" standard allows the unification of two or three cubes in the composition of one satellite with designations 2U and 3U, respectively, having dimensions of 10x10x20 cm and 10x10x30 cm, respectively. Currently, links from nanosatellites and picosatellites are increasingly being launched into Earth orbit, respectively, according to the standards "CubeSat 6U", "CubeSat 12U" and "CubeSat 16U".

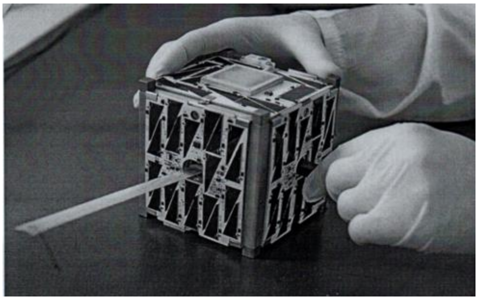

*Fig. 1. General view of a small satellite of the "CubeSat" standard*

After the emergence of the "CubeSat" standard, the even smaller "PocketCube" format appears with a mass of up to 250 grams and dimensions of 5x5x5 cm, and this size is designated as 1p.

Structurally, the satellite, according to the "CubeSat" standard, is an aluminum skeleton (Fig. 1), inside which the following elements are most often placed: PT; central processing unit; antenna-feeder devices; radio channel; power system including battery and charge controller; solar cells (surface or dissolving); satellite positioning system; satellite position correction system.

The CubeSat standard satellite is placed in a specialized container, usually located in the corresponding launch vehicle (LV). To launch the nanosatellite into Earth orbit, it is placed in a so-called "deployment device", which is a rectangular container. In this container, attached to the LV, the satellites of the "CubeSat" standard are placed.

CubeSat small satellites are currently launched into Earth orbit by the dozens, even over 100 SSVs at a time, either via RNs or aboard manned or automated cargo spacecraft (SC) and the International Space Station (ISS).

**Problem status and research area**

At the current stage, creating nanosatellites according to the "CubeSat" standard is significantly easier compared to the recent past, but putting them into orbit around the Earth is not within the power of the creators of these satellites alone. The delivery of nanosatellites into space requires the conclusion of a contract with a licensed rocket and space organization (NASA, ESA, Roskosmos, etc.).

The evolution of SSVs over the last ten years is closely related to the main producers of nanosatellite constellations in the USA - the private companies "Planet Labs" and "Spaceflight Industries". As a typical example of a satellite with a mass not exceeding 10 kg, a nanosatellite from the "Dove" series of the American private company "Planet Labs" can be cited (Fig. 2.).

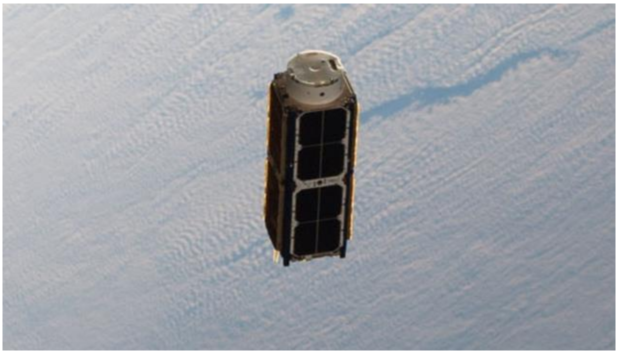

*Fig. 2. General view of a Dove-series nanosatellite in space flight*

These nanosatellites were used in the second decade of the XXI century; the mass of each of them is 4.7 kg, and the spatial resolution of the received images is 3.7 m in four spectral channels. (no panchromatic channel). Each of the "Dove" series nanosatellites is equipped with a telescope, digital camera, and software to image different areas of the Earth. They are intended for operational monitoring of deforestation, agricultural territories, harvests, urbanization processes, natural disasters, etc. Their term of active existence is three years. The nanosatellites of the "Dove" series, put into orbit with American and Russian RNs in 2013, provide images from heights of 250 - 580 km, and the dimensions at their launch are 10x10x32 cm (CubeSat 3U).

Since early 2014, Planet Labs has begun deploying an orbital configuration of first-generation Flock nanosatellites, using the Dove series nanosatellites as their prototypes. Nanosatellites of the "Flock-1" series are built according to the "CubeSat 3U" standard and do not have propulsion units (RU). They are characterized by a mass of 4 kg, dimensions of 10x10x30 cm (length, width, and height), an orbit height of 400 km, an inclination α=52°, a spatial resolution of 3-5 m, and a period of active existence of 2 years. In the following years of the second decade of the 21st century, the company "Planet Labs" continues to simultaneously launch dozens of nanosatellites of the "Flock-2", "Flock-3" and "Flock-4" series. Thanks to their low cost and the high efficiency of obtaining the data, these KLA are highly suitable for monitoring the environment, crops, forest areas, and emergencies.

By creating a Flock constellation of nanosatellites, Planet Labs intends to obtain operational images from any region of the globe to solve humanitarian, environmental, and commercial tasks. At the same time, the evolution of generations of nanosatellites from the "Flock" family takes place very quickly - practically in a few months. As a result, based on nanosatellites of the "Dove" series, a unique constellation of several hundred MCLAs of the "Flock" series was built, flying in a sun-synchronous orbit (SSO) and providing for one-day imaging of more than 200 million $km^2$ of the earth's (sea) surface. By 2021, the number of Flock series nanosatellites is approaching 400.

As a result of the modernization of the "Doves/Flock" series nanosatellites, 36 "SuperDoves Flock 4u 1/36" nanosatellites were also included among the 114 SSVs launched by the USA on 01/03/2023 in Earth orbit with the "Falcon-9FT Block-5" launch vehicle" according to the standard "CubeSat 3U" of the company "Planet Labs.", each of which has a mass of 5 kg. These nanosatellites include a telescope and a CCD-sensor camera in their onboard equipment, providing 8-band multispectral imaging and obtaining images with a spatial resolution of up to 50 cm/pixel.

In April 2017, the American multinational company "Google" acquired a stake in the company "Planet Labs" and concluded a multi-year agreement for the purchase of images from the "SkySat" satellites. The "SkySat" family of satellites serves to monitor the Earth's surface in the optical range with sub-meter spatial resolution and are dual-purpose. They are based on the "CubeSat" concept, but in size and mass exceed those of the "CubeSat 3U" standard (Fig. 3). Their length is about 80 cm, and the mass is not less than 100 kg. Their onboard equipment includes panchromatic, multispectral, and video sensors, with a spatial resolution of 0.9 m, 2 m in four areas of the spectrum and 1.1 m, respectively. For the period 2013–2022, 21 mini-satellites of the "SkySat" family, located in four orbital planes, were launched into Earth orbit.

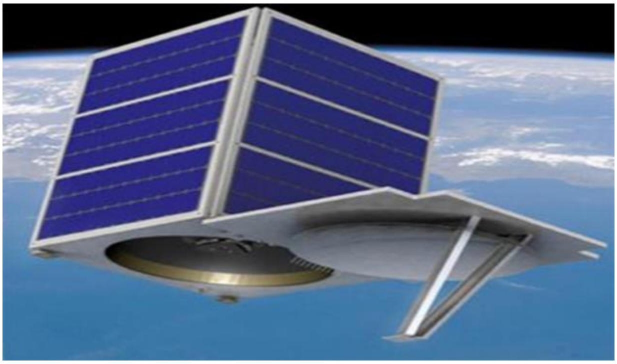

*Fig. 3. General view of the "SkySat-1" optoelectronic observation minisatellite*

With the help of these minisatellites, monitoring is carried out in the economic and humanitarian fields.

Another well-known American private operator for the production of small satellites is the company "Spaceflight Industries", whose microsatellites for the UEN "Black Sky" (Fig. 4.) have a mass of 55 kg and a period of operation of 3 years. Through these dual-purpose microsatellites, optical images are obtained initially with a spatial resolution of 50-90 cm from an orbit height of 430 km and an inclination α=42°, and later, the spatial resolution reaches up to 30 cm per pixel. As of March 2023, their orbital constellation includes 16 satellites.

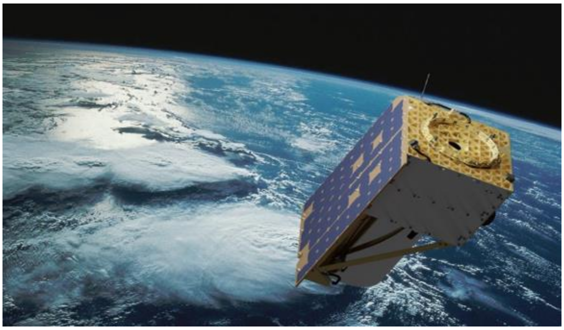

*Fig. 4. General view of the Black Sky optoelectronic surveillance microsatellite*

According to mass media (mass media), the orbital configuration of the Black Sky SSVs is characterized by the highest frequency of reshooting in the world - 15 times a day. The number of these satellites for the UN is expected to reach 60 SSVs. Monitoring in the economic and humanitarian fields is also carried out with the help of the OEO microsatellites of the Black Sky family.

Along with the discussed small satellites with civil and/or dual purposes, since the 90s of the 20th century and the first decade of the 21st century, the Pentagon has been creating and launching into Earth orbit experimental SSVs, based on which to build space systems with small satellites with a tactical purpose. The management of the program is entrusted to the "ORS" (Operationally Responsive Space Office) management, and the developed "ORS" program aims to accelerate the implementation of innovative technical solutions to shorten the terms for developing and putting tactical KLA into orbit. As of 2012, within the framework of the ORS program and platform, two mini-satellites for tactical optoelectronic reconnaissance (OER) - TacSat-3 and ORS-1 - have been launched into orbit and are in use. More specifically, the TacSat-3 tactical air defense system is equipped with two optoelectronic cameras - hyperspectral and panchromatic. At the same time, the hyperspectral camera allows the detection of masked and hard-to-detect ground objects in the infrared part of the spectrum, and the panchromatic camera is characterized by a maximum image resolution of 1 m in the visible part of the spectrum, which ensures the detection and identification of tactical targets.

Another system for tactical OER is "Kestrel Eye", which includes dozens of small satellites of the same name. According to [3], an orbital configuration of 40 microsatellites of the system can provide the relevant battlefield commander with an interval of 10 minutes and fewer images of the areas of interest with a spatial resolution of 1.5 m in panchromatic mode. The main merits of the MKLA of the "Kestrel Eye" series are their small mass (50 kg), compact dimensions, low cost, and the ability to provide images of the battlefield on mobile devices of servicemen in real-time scale (RTS). The "Kestrel Eye" project was stopped in 2018 at the "prototype" stage, and three new programs were launched on its basis - "Gunsmoke", "Lonestar", and "Polaris". In this way, the efforts to develop new MCLAs for the OEO on the battlefield in the Russian Federation continue.

For observation from space of land and sea objects in any weather and day conditions, the most suitable are the MKLA with on-board radar stations (BRLS) with a synthesized aperture (SA) for radar surveillance (RLN) and radar reconnaissance (RLS). Among them, the American minisatellites and microsatellites for the "Capella" and "Umbra" RLSs, as well as the Finnish microsatellites for the "ICEYE" RLD, stand out at the moment. The listed SSVs are dual-purpose.

The American company "Capella Space" realized its intention to replace the traditional heavy and expensive satellites for air defense and anti-aircraft defense, equipped with radar SA (for example, "Lacrosse") with significantly smaller mass and dimensions MKLA with a relatively low value. For this purpose, the space radar system of the Capella Space company was created, solving the tasks of ensuring a high periodicity of observation from space and operational delivery of the relevant radar images to users, primarily in the interest of defense and security. This is realized with a phased deployment of an orbital configuration consisting of 36 satellites equipped with a SA radar, which is why the considered space radar system acquires the name "Capella 36", as well as through the possibility of "retargeting" the corresponding satellite with a high-speed SA radar from one shooting object to another object. The beginning of operational use of the Capella 36 space radar system was laid in August 2020, when the Capella 2 satellite with a SA radar with a mass of 107 kg was launched into an Earth orbit at an altitude of 525 km (Fig. 5). In the period January 2021 - January 2022, the "Capella 3, 4, 5, 6, 7 and 8" satellites, which are in operational use, enter Earth orbit. The satellites' orbit inclination (α=45°) provides high-frequency monitoring of the Middle East, DPRK, PRC, Japan, and USA regions.

The Capella 36 space radar system allows for obtaining radar images with a spatial resolution of 50 cm. According to SMI, the system can also provide a spatial resolution of 25 cm, but American legislation currently blocks this possibility.

Capella Space is the first commercial operator of SAR satellite imagery in the United States. It is assumed that with its full orbital configuration of 36 satellites (expected by the end of 2023), it is possible to obtain a radar image of any part of the Earth at an interval of no more than one hour.

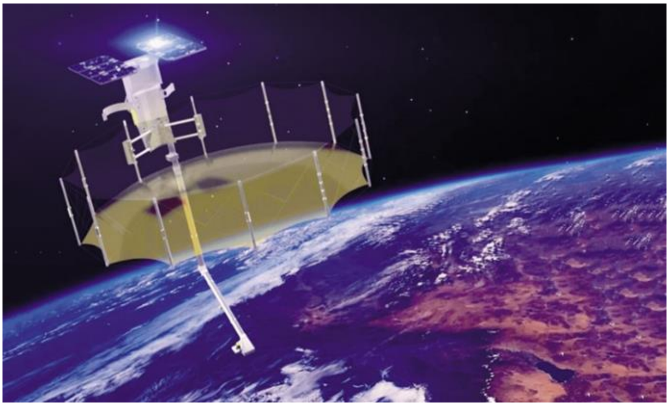

*Fig. 5. General view of the Capella 2 radar surveillance satellite (Sequoia)*

The American company "Umbra Lab" is creating and launching into Earth orbit a constellation of commercial microsatellites "Umbra", with surface-to-air radar (SAR) operating in the X-band. As of June 2023, three "Umbra" microsatellites with a 70 kg SAR have been launched into Earth orbit, which are dual-purpose. In 2018, this company received a license for permission for a spatial resolution of

25 cm per pixel from the satellites of the same name flying on the SSO at an altitude of 515 km and plans to increase the spatial resolution of radar images to 15 cm per pixel.

The Finnish start-up company "ICEYE" is creating a constellation of "ICEYE" series microsatellites equipped with X-band SA radars. The orbital configuration created by the SSVs mentioned above is intended for the RLS of the Earth, and the resulting radar images have a spatial resolution better than 1 m and are dual-purpose. After the first launch into Earth orbit on 12.01.2018 of a microsatellite with a mass of less than 100 kg, as of January 2023, the orbital configuration of microsatellites of the "ICEYE" series includes more than 20 SSVs.

## Research method

The analysis of crises and conflicts in the 21st century from the point of view of their information provision shows that the military mentioned above and civilian SSVs, including dual-purpose ones, successfully complement the strategic space systems for OEE and RLR of the USA, Russia, China, and other leading space states, because the latter provides no more than 30% of the entire volume of intelligence-related information [3].

The theory of systems analysis is a major method of studying the modern use of small satellites for observation.

The analysis of the experience of using SSVs for observation in the XXI century for various applications and their creation concepts shows that the corresponding small satellites can be successfully used to solve mainly three groups of tasks (Fig. 6) - applied, technological, and scientific.

The tasks that the MKLA applies for surveillance can, in turn, be divided into three subgroups - military, civil, and educational.

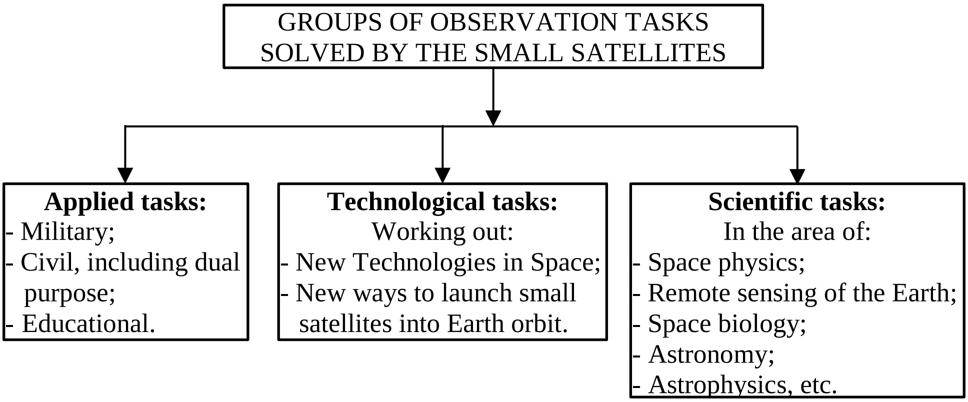


*Fig. 6. Groups of tasks solved by small observation satellites*

The military tasks of SSVs for surveillance as part of the applied ones are solved by small satellites for tactical OEO and RLS, as well as commercial small satellites for OEO and dual-purpose RLS.

One of the most important new directions in the development of small satellites is their use as satellite-inspectors [4, 5], since a significant part of them are MCLA, as well as for OER [6, 7].

Several innovative military surveillance ICBMs continue to operate [8], some of which fall into the microsatellite (100–10 kg) and nanosatellite (10–1 kg) classifications. As noted, the SSVs' military surveillance tasks are also handled by commercial small satellites for OEO and dual-purpose RLS. For example, the "Black Sky" minisatellites for the UN discussed above (Fig. 4), in addition to services for private companies, also perform tasks in the interests of the Pentagon. Through these satellites, the US discovered a secret anti-satellite laser weapons test site in China - specifically, two laser installations in hangars with removable roofs. Through "Black Sky" satellites, two bases for launching high-altitude balloons in China were discovered - on Hainan Island and North China.

A major trend in the military space activities of the USA, China, and Russia at present is the development of multi-satellite systems based on SSVs with different purposes and the formation of corresponding orbital groupings (OG). Essential reasons for this are that, according to the Pentagon, large multi-ton satellites (e.g., Lacrosse) are vulnerable to the anti-satellite means of a likely adversary and are economically unprofitable. Against the backdrop of US successes in the use of commercial small satellites, the country's Ministry of Defense (MoD) is considering their use [8] within multi-satellite space systems (clusters of small satellites) for intelligence, communication, and control for early warning of missile attack, for reconnaissance, as well as for active anti-satellite combat (Fig. 7).

*Fig. 7. Orbital grouping of small satellites for military purposes*

The main reasons for this are that, due to the short production time and relatively low price of SSVs, in the event of a military-political crisis and military conflict, it is possible to quickly replace them in orbit to launch new ones for specific tasks, to restore damaged ones, as well as to increase the number of small satellites on a specific orbit to increase the observation time. In this way, OG can be restored or improved, increasing the resistance of clusters of small satellites to external influences. Along with the stated motives, clusters of a significant number of small satellites provide the necessary periodicity (frequency) in obtaining images, facilitating decision-makers and shortening the process duration.

To implement the above considerations, the US Space Development Agency "SDA" (Space Development Agency) of the Ministry of Defense and the Defense Advanced Research and Projects Agency (DARPA) are developing the "Blackjack" program, which envisages putting a large number of small satellites into orbit around the Earth solving various military tasks - from monitoring and communication to early warning of a missile attack. The program basis is the unification of a single sensor network of small satellites to perform combat tasks, where each SSV performs a specific task.

It should be noted that the well-known private satellite operators Black Sky, Maxar Technologies, and Planet, which have SSVs, entered into a contract in May 2022 with the National Reconnaissance Office (NRO) of the USA for a 10-year delivery of optoelectronic images from its satellites with ultra-high image resolution. More specifically, the American company "Maxar Technologies", also profiled in Earth observation, periodically fulfills orders of the American government, especially the Ministry of Defense, to photograph various crisis and conflict areas (Fig. 8).


*Fig. 8. Image of Russian military equipment involved in the war in Ukraine in a deployment area, obtained by the company "Maxar Technologies"*

Civil surveillance tasks of SSVs as part of applied tasks are broad-spectrum and are generally aimed at space monitoring in various areas of society's life and activity. So, for example, the following tasks are solved with the help of minisatellites for OEO from the "SkySat" family (Fig. 3): agricultural monitoring, oil infrastructure monitoring, monitoring of sites from the extractive industry; monitoring of natural disasters (detection of victims, coordination of rescue activities, planning of restoration works). Some of the civilian tasks are closely related to the military tasks and have dual purposes.

The ICEYE series of RLS microsatellites provide an effective toolkit for land and sea surface observation in thematic areas such as monitoring land, ocean, and atmosphere; mitigating the consequences of natural disasters and man-made accidents; ensuring safety and assessing the impacts of climate change in other areas as well.

The educational tasks solved by the SSVs for observation are aimed at the student community and, recently also, at the students of the upper classes of high schools. Along with the cognitive nature and the acquisition of new knowledge, the creation of empathy for space technology and technology. These tasks also aim to form the trainee's practical habits in the construction or assembly of the SSVs. In this way, for example, students get the opportunity for 1-2 years to participate in the entire cycle of activities on an actual space project related to the creation and use of the SSVs.

The technological tasks of the SSVs for observation allow the development of new technologies in space, the testing of systems and assemblies of rocket-space technology, including new methods of launching small satellites into Earth orbit (Fig. 6). At the same time, it is the SSVs that make possible the implementation of these technologies and approaches, which is impossible for traditional spacecraft with their mass-dimensional characteristics.

Of the new methods for launching small satellites into Earth orbit, the most common in recent years are three: through the implementation of the "Air Launch" program, from a specialized module on board the ISS, from the `SC board for multiple uses.

Of the modern "Air Launch" programs for putting small satellites into orbit using aerospace systems, the American "Pegasus" and the related program of the American company "Virgin Orbit" [9] are functioning. The Virgin Orbit program continues today, using a new ultralight liquid-propellant rocket.

It should be noted that in 2020, SRTI-BAS developed and adopted a concept for implementing the "Air Launch" project for launching a small satellite (small satellites) into Earth orbit from a carrier aircraft (MiG-29 UB) in the conditions of the Republic of Bulgaria [10–11].

The second method of launching small satellites into Earth orbit was implemented for the first time with the prototype of the microsatellite for tactical OEO "Kestrel Eye" located on the ISS since 08/14/2017. After completing the relevant technological time and preparatory activities, on 10/24/2017, the prototype microsatellite "Kestrel Eye" was launched into Earth orbit by the Japanese module of the ISS, after which its tests began.

In some cases, cosmonauts or astronauts from the ISS, during a planned exit into open space, manually "launch" small satellites of the "CubeSat" standard into space.

The third way to launch small satellites into Earth orbit was implemented on board the X-37B OTV unmanned minishuttle [12], which performed six orbital missions of increasing duration from 2010 to 2022. According to the press, from the board of this orbital plane, SSVs with different purposes were taken into open space under conditions of secrecy.

Currently, the SSVs also solve several other technological tasks for monitoring.

The scientific tasks solved by the SSVs for observation can be related to conducting research in the field of space physics, remote studies of the Earth, space biology, astronomy, astrophysics, etc. (Fig. 6). For this purpose, most satellites of the "CubeSat" standard include in their PL at least one or two scientific instruments.

Due to its specificity, each of the listed scientific fields imposes its own requirements on the PL of the SSV. The aspects of using small satellites for observation are not the only ones discussed.

## Conclusion. Need to use small satellites from the Republic of Bulgaria.

In our country, respectively in SRTI-BAS, it is imperative to study and evaluate the benefits and costs of creating and using small satellites. In case of positive results, the purpose and areas of their application should be formulated for the conditions of the Republic of Bulgaria, young and promising staff should be identified for work on this issue, and their training should be carried out at home and/or abroad (up to the level of assembly of small satellite), to create the necessary laboratory base and to accelerate the development of national and international projects in the various fields of application of small satellites.

Small satellites have become increasingly popular in recent years and dominate the total number of spacecraft launched into Earth orbit, and this trend is currently accelerating.

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**РАЗЛИЧНИ АСПЕКТИ НА ИЗПОЛЗВАНЕТО НА МАЛКИ СПЪТНИЦИ ЗА НАБЛЮДЕНИЕ НА СЪВРЕМЕННИЯ ЕТАП**

***П. Пенев***

**Резюме**

Разкрити са причините за възникване на малките спътници. Разгледана е еволюцията на създаваните през XXI век военни и граждански малки спътници за наблюдение и разузнаване, включително с двойно предназначение. Дефинирани са три групи задачи, решавани от малките спътници за наблюдение – приложни, технологични и научни, както и нарастващото им значение и сфери на използване. Обоснована е необходимостта и са предложени стъпки в Република България, респективно в Института за космически изследвания и технологии към Българската академия на науките, да се активира дейността по създаването и използването на малки спътници за наблюдение за нуждите на икономиката, екологията, хуманитарната и в други области.