UDC 531.3:629.78 ; UDC 519.8 https://doi.org/10.15407/itm2026.01.003

A. P. ALPATOV, https://orcid.org/0000-0003-4411-2250

ON THE RESEARCH RESULTS OF THE SCIENTIFIC SCHOOL AT THE NATIONAL ACADEMY OF SCIENCES OF UKRAINE "DYNAMICS OF SPACE TECHNOLOGY OBJECTS" IN 2021–2025

Institute of Technical Mechanics
of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine,
15 Leshko-Popel St., Dnipro, 49005, Ukraine; e-mail: khoroshylov.s.v@nas.gov.ua

У цій статті представлено огляд робіт, виконаних у 2021–2025 роках вченими Національної академії наук України, що представляють дослідницьку школу «Динаміка об’єктів космічної техніки». Частина цих робіт стосується системного аналізу космічної галузі України. Дослідження динаміки космічних апаратів та систем проводилися за кількома напрямками. До них належать: розробка методів машинного навчання в задачах керування космічними апаратами, оптимізація керованого руху об’єктів космічної техніки, системи дистанційного зондування поверхні Землі, утилізації космічного сміття, методологія концептуального проєктування промислової космічної платформи, проблема обслуговування космічної техніки в умовах космічного простору, а також формування парадигми стабілізації клімату Землі на основі космічних систем затінення її поверхні.

Узагальнена багатомасштабна модель будь якого сигналу/змінної на засадах мультиформалізму, досвіду та консенсусного управління. Модель дозволяє диверсифікувати шляхи обчислень та засоби отримання первинної інформації. Розроблено схему застосування морфологічних обчислень для інтеграції та узагальнення первинної інформації. Розглянуто застосування сучасних інформаційних технологій для вирішення задач динаміки космічних апаратів. Показано, що вільне програмне забезпечення з відкритим вихідним кодом (GMAT, Basilisk, OreKit та ін.) є ефективною альтернативою пропрієтарним пакетам для моделювання орбітального руху космічного апарата, оптимізації траєкторій і візуалізації.

Створений алгоритм попереднього виділення набору ознак зображення, що використовуються як вхідна інформація нейронних мереж. Такий підхід дозволяє значно зменшити розмірність вхідних даних, тим самим знизивши обчислювальні вимоги. Показано переваги використання методів штучного інтелекту для космічних застосунків. Саме вони надають можливість знизити вимоги до елементів систем керування, таких як сенсори, виконавчі органи, відмовитись від використання спеціальних стендів для відпрацювання систем, зменшити терміни та вартість розробки.

Розроблено метод бортового визначення параметрів зміни відносного просторового положення некоoперованого об'єкта орбітального сервісу з невідомою формою на основі отриманих лідаром хмар точок поверхні цілі. Алгоритм методу оперує зі скороченим обсягом хмари. Параметри переміщення цілі визначаються як аргументи цільової функції. Запропонований варіант її формування відповідає правильно визначеному просторовому положенню цілі.

Розглянуто низку актуальних задач, які пов’язані з розвитком нових технологій, що використовуються при створенні супутникових систем. Це дає змогу суттєво підвищити ефективність супутників дистанційного зондування Землі та їх угруповань. Підвищення їх ефективності пов'язане з вирішенням задач проєктування робочих орбіт супутників, управління рухом супутників вздовж цих орбіт та формування угруповань. Запропоновано новий підхід щодо вирішення проблеми зростання космічного сміття на орбітах Землі. В його основу покладено зберігання космічного сміття як сировини на спеціальних орбітах зберігання для подальшої переробки.

Розроблено математичні моделі, що дозволяють проводити комплексну оцінку ефективності космічної системи затемнення поверхні Землі від сонячного випромінювання. Вони дозволяють дослідити довгострокову стабільність окремих орбітальних кластерів і структурну узгодженість глобальної хмари системи затемнення.

Ключові слова: *динаміки космічних апаратів, керування космічними апаратами, космічне сміття, космічна техніка, методи машинного навчання, промислова космічна платформа.*

This article presents a review of the work carried out from 2021 to 2025 by scientists from the National Academy of Sciences of Ukraine (NAS) representing the "Dynamics of Space Technology Objects" research school. Some of this work concerns a systems analysis of Ukraine's space industry. Research of spacecraft dynamics and systems was conducted in several areas. These areas are: the development of machine learning methods in spacecraft control, optimization of spacecraft controlled motion, systems for remote sensing of the Earth's surface, deorbiting of space debris, a methodology for conceptual design of an industrial space platform, the problem of space service technology and the formation of a paradigm for stabilizing the Earth's climate based on space systems for shading its surface.

A multiscale model of any signal/variable based on multiformalism, experience, and consensus management was generalized. The model allows for diversification of computational methods and means of obtaining primary information. A scheme for applying morphological calculations to integrate and generalize primary information was developed. The application of modern information technologies to solve problems of spacecraft (SC) dynamics was considered. It was shown that free open-source software (GMAT, Basilisk, OreKit, etc.) is an effective alternative to proprietary packages for modeling the orbital motion of SC, trajectory optimization, and visualization.

An algorithm for preliminary selection of a set of image features used as input information for neural networks was created. This approach allows one to significantly reduce the dimensionality of input data, thereby reducing computational requirements. The advantages of using artificial intelligence methods for space applications were shown. They make it possible to reduce the requirements for control system elements, such as sensors, actuators, to abandon the use of special benches for testing systems, and to reduce development time and cost.

A method was developed for onboard estimation of the relative spatial motion parameters of a non-cooperative orbital servicing target with unknown geometry, based on LiDAR-derived point clouds of the target surface. The algorithm operates on a reduced subset of the point cloud data. The target's motion parameters are determined as the arguments of an objective function. A formulation of this objective function was proposed such that its extremum corresponds to the correctly identified spatial pose of the target.

A number of current problems related to the development of new technologies used in the creation of satellite systems were considered. This makes it possible to significantly increase the efficiency of Earth remote sensing satellites and their constellations. Increasing their efficiency is associated with solving the problems of designing satellite working orbits, controlling the motion of satellites along these orbits, and forming constellations. A new approach was proposed to solving the problem of the growth of space debris in Earth orbits. It is based on the storage of space debris as raw material in special storage orbits for further processing.

A number of mathematical models were developed to provide a comprehensive assessment framework for a space-based solar radiation mitigation system. The framework enables investigation of the long-term dynamical stability of individual orbital clusters and the structural coherence of the global distributed shading configuration.

Keywords: *spacecraft dynamics, spacecraft control, space debris, space technology, machine learning methods, industrial space platform.*

The school "Dynamics of Space Technology Objects" was founded by Corresponding Member of the National Academy of Sciences of Ukraine Mykola Fedorovich Gerasyuta, one of M.K. Yangel's deputies, in 1987. The initial team consisted of researchers from scientific institutions in Dnipro (formerly Dnipropetrovsk). A significant number of scientists came from the Institute of Technical Mechanics of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine (the institute's current name). The research tradition of this school was further advanced at the Institute of Technical Mechanics of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine. Currently, the scientific leadership is provided by Corresponding Member of the National Academy of Sciences of Ukraine, professor Anatolii Alpatov.

Research focus: systems analysis of challenges in the space industry; investigation of free and controlled dynamic modes of space systems operating as space-based mechanical structures across a wide range of environmental conditions; analysis of near-Earth space debris pollution; development of a near-space debris recycling paradigm based on orbital platforms; and conceptual design of distributed LEO sunshade systems for solar radiation mitigation and albedo-based climate stabilization.

The main research areas of the scientific school include:

– systems analysis of challenges in the space industry;

– investigation of free and controlled dynamic regimes of deployable and spatially distributed mechanical systems for space and terrestrial applications under a broad range of external disturbances.

Over 40 researchers and 30 engineers have participated in the development of these areas at various stages of the school's existence. The main customers of the research are the National Academy of Sciences of Ukraine, the State Space Agency of Ukraine, and Ukrainian industrial enterprises.

The scientific work is grounded in fundamental research carried out within the framework of planned programs of the National Academy of Sciences of Ukraine at the Institute of Technical Mechanics of the National Academy of Sciences of Ukraine and the State Space Agency of Ukraine. The results of this research provide the scientific and methodological foundation for space technology development. These methodological developments are also used to assess the effectiveness of national space program projects and to prepare analytical materials for government agencies.

The results of research conducted by the "Dynamics of Space Technology Objects" scientific school over the past five years are summarized in the following areas:

1. Systems analysis of space industry problems.
2. Development and use of machine learning methods in spacecraft dynamics problems.
3. Comprehensive optimization of design parameters and rocket motion control programs.
4. Remote sensing systems for the Earth's surface.
5. Disposal of space debris
6. Methodology for conceptual design of a space industrial platform
7. The problem of service maintenance in space.
8. Deorbiting of space debris.
9. Space systems for shading the Earth from solar radiation for climate stabilization.

Global trends in the development and operation of space technology are aimed at increasing its efficiency in various areas of human activity. In many cases, the increasing commercialization of space activities and the expected economic impact are decisive. Another powerful set of factors determining the development trends of space technology is its strategic and military significance. The rapid advancement of microelectronics, electric power systems, novel materials, and theoretical foundations for cognitive system modeling provides the basis for introducing new approaches to the development of component and technological platforms.

The emergence of new technological trends drives the modernization of engineering equipment and the revision of design standards. This creates the need for updated concepts of space sector development, including in Ukraine. A systems-based approach to evaluating new projects and assessing industry performance in key areas remains essential. Forecasting the sector’s development requires comprehensive efficiency criteria and multifactor analysis in order to assess new technologies in light of existing capabilities and national priorities.

1. Systems analysis of space industry problems. Technological breakthroughs, which of cause shape the industrial structure of the future, are fundamental to the development of modern society for the near future. Information technology, with its wide range of industrial applications, is becoming increasingly important. One of the key trends is a significant reduction in human physical involvement in technological processes. This also applies to the intellectual component of human activity. The National Academy of Sciences of Ukraine places great emphasis on the development of intelligent technologies. This is reflected in scientific research areas that are focused on the needs of current industrial production. The Information and Analytical System 'ITM-KOSMOS' was developed for benefits of Ukraine's space industry, and it contains the extensive database for the development of modern space-rocket technology and as well the set of engineering methodologies. These methodologies within the automatic mode are able to determine key design characteristics for new products. This significantly expands the capabilities of design organizations and identifies optimal technical solutions in a short time. This reduces a design time for complex systems and improves their quality. In this regard, a development of methodological aspects of artificial intelligence technologies is of particular interest.

One of the challenges in developing these artificial intelligence technologies is the need to develop transformations of complex information representations into ones more suitable for rapid decision-making. One such transformation is a technology based on the proposed limit generalization paradigm [1]. It has been significantly further developed as a basis for modeling and designing cognitive technical systems, particularly autonomous (intelligent) space applications [2]–[4]. A methodology for analyzing the functioning, development, and management of complex dynamic intelligent systems based on the limit generalization paradigm has been developed [5]–[8].

A fundamental general scheme of an information model of a distributed multi-agent computational intelligence of an autonomous space system based on the paradigm of limit generalizations has been developed [1].

The developed concept of autonomization of space technologies correlates with the NASA approach, but requires further development in the direction of creating tools for modeling digital twins of individual subsystems using a library of "smart" gadgets and processes. The flexibility promised by next-generation space systems necessitates a profound redesign of the very core of control systems [7]. Connectivity and data management capabilities enable the creation of more flexible and responsive control systems based on the collaboration of autonomous and connected objects in decision-making [9]. A stochastic fault-tolerant control scheme has been developed, specifically a sensor fault management scheme and a "task continuum" distinction model [8]. This scheme forms the basis of "agentive intelligence."

A generalized multiscale model of any signal/variable is based on multiformalism, experience, and consensus management, enabling complete diversification of computational paths and means of obtaining primary information [8]. A framework for applying morphological computations for the integration and generalization of primary information is developed. The model enables a comprehensive audit of information flows and embodied forecasting or deep intuition. A method for determining the optimal scale of input data for solving distinction problems has been developed.

A mathematical model of a distributed autonomous space system is proposed, in which individual satellites and devices are treated as software/smart agents [9]. This model allows for the satellite swarm to be viewed as a network of opportunity agents and need agents, self-organizing to solve any problem. The architecture of the autonomous space system takes the form of a "system of systems" with fractal properties of structure and information, enabling automatic scaling of any control processes and the identification and neutralization of threats. Recommendations for the implementation of the proposed approach, which can be used to create a "Platform for Autonomous Space-Based Systems," are developed [7].

One of the pressing issues remains the need of systems analysis of complex space system projects. The technical level and cost of developing space-rocket technology are the determining factors in assessing the competitiveness of such technology.

A significant drawback of existing methods for determining the technical level of complex civil and military technical systems is the significant influence of subjective factors. The process of calculating the technical level and cost indicators in Ukraine remains insufficiently streamlined and formalized, there is a significant level of uncertainty in the required initial data.

A methodological framework was developed for calculating the performance indicators of scientific and technical projects for advanced space systems, and this allows for quantitative analysis of the projects being developed:

– the mathematical model for calculating the technical level of promising models of space-rocket technology, which is based on the method of hierarchical analysis of T. Saaty being added formalized procedures, which made it possible to automatically have control over judgments of experts for errors checking and logical contradictions;

– the mathematical model for calculating the cost of R&D work on a spacecraft creation, which allows for determining the expected cost at the initial stages of experimental design work in the absence of the necessary statistical information, in contrast to the standardized calculation method and parametric methods.

A methodological framework was developed for quantitatively assessing the level of competence of experts in assessing the technical level of promising models of space-rocket technology.

Database projects has been developed for tasks of calculating the technical level of spacecraft using the Delphi programming system and for tasks of calculating the cost of experimental design work on a spacecraft creation of using the MS Access database management system.

The Delphi programming system was used for a computer implementation of the developed algorithmic support for previous mentioned calculations.

Based on space activity monitoring, there was conducted an analysis of trends of global space activity, specifically: the current state and development prospects of the service market providing space transportation systems, remote sensing systems for the Earth in space and space communication systems were determined; the dynamics of changes in the cost indicators for launching payloads into space were analyzed; the review and analysis of the satellite Internet of Things and systems of the satellite Internet of Things were conducted; the trends and the state of development in the field of orbital spacecraft servicing were identified.

There were used statistical data from the information system "World Fleet of Launch Vehicles and Spacecraft (MasterMarket)" by which was developed at the ITM.

The results of these studies are presented in research papers [10] – [16].

The results of this work will be able to provide a more informed selection of projects for a creation of advanced space-rocket technology.

2. Development and use of machine learning methods in spacecraft dynamics problems. The application of modern information technologies for solving spacecraft dynamics problems is considered. It is shown that free open source software (GMAT, Basilisk, OreKit, etc.) is an effective alternative to proprietary packages for modeling spacecraft orbital motion, trajectory optimization, and visualization [17]. An analysis of approaches to integrating machine learning methods and mathematical models based on differential equations has been carried out: their combined use increases the accuracy and speed of calculations when solving direct and inverse problems, generating data, and analyzing sensitivity [18]. The possibilities of using large language models (LLM) in spacecraft dynamics modeling tasks have been investigated [19]. LLM are capable of generating spacecraft motion equations based on text queries in natural language and converting them into code for symbolic modeling systems, simplifying the researcher's interaction with software tools. Although LLMs do not provide control over the correctness of conversions, they can increase the flexibility and efficiency of spacecraft dynamics modeling by offering the user a choice of coordinate systems and methods for simplifying equations, and by generating executable code in a variety of programming languages, taking into account specialized libraries.

Machine learning is promising for increasing the autonomy of spacecraft [19]. The development of appropriate dynamics models is relevant. Among the problematic issues that hinder the application of these methods to problems of spacecraft dynamics, it should be noted, first of all, that there are practically no analytical results that guarantee stability and control performance. The presence of such results is important for space technology developers to use such methods more actively in practice. It should also be noted that many spacecraft control problems do not allow for critical errors in the process of finding the optimal solution. In this regard, ideas from such a direction as safe reinforcement learning [20] should be more actively used for space missions. The relatively low learning efficiency inherent in deep learning methods is especially acutely manifested in space applications, which is due to limited capabilities for collecting and processing data on board the spacecraft. However, the use of reinforcement learning methods has the potential to reduce this problem. Despite the above problems, navigation, guidance and control algorithms based on artificial intelligence (AI) can simplify the development and increase the reliability of spacecraft control systems, since the same algorithm can be used for a large number of different missions. AI makes it pSDOible to develop control systems that can improve their characteristics as data accumulates during the operation of a particular object, which allows reducing the requirements for control system elements (sensors, actuators), eliminating special bench equipment, and reducing development time and cost. Despite the wide variety of methods covered by the AI concept [21], most of the industrial-level results have been obtained based on machine learning methods [19], which are used to develop algorithms that can solve a problem based on finding patterns in various data.

When modeling the processes of removing space debris from working orbits, neural network models were proposed that allow solving the problem of determining the force of the impact of the ion thruster plume on the space debris object (SDO). For most of the cases considered, the values of the force determination errors do not exceed 5 %. But even for cases where the value of the relative error is higher than this value, the value of the absolute error remains insignificant. This fact allows us to assume that such errors are insignificant in practice.

The results of the research demonstrate that the artificial neural network (ANN) models can determine the force without prior information about the relative location and orientation of the SDO. In addition, ANNs allow obtaining results much faster compared to traditional methods that were used earlier. Thus, the

ANN models are an alternative method for solving the problem of determining the force of the ion beam transmitted to the SDO for its removal from orbit, which has satisfactory accuracy and requires less time to obtain the result compared to the traditional methods.

The creation of an algorithm for preliminary selection of a set of features of the SDO image, which are used as input information of the ANN [22], is considered. This approach allows to significantly reduce the dimensionality of the input data, thereby reducing the computational requirements. To obtain such features, computer vision methods were used, namely, determining the contour of the SDO image and the moments of the contour of the SDO image. As a result, at the output of the algorithm for preprocessing the SDO image, a tuple of 31 features has been obtained, consisting of the following moment values: (1–10) – spatial moments, (11–17) – central moments, (18–24) – normalized central moments, (25–31) – Hue moments.

The proposed method is almost twice as fast as the traditional ones, but somewhat slower than the convolutional neural network based method. The reason is that the total time of the proposed method also includes preprocessing of images. However, the time spent on image processing is insignificant. But, despite this, it must be said that image processing can still impose additional requirements on the hardware of the active spacecraft (for example, memory bandwidth or processor instruction set), which computing system developers must keep in mind.

For ANNs with fully connected layers, hidden layers play a key role in the accuracy of calculations (the more layers and their dimensionality, the more accurate the calculations). Therefore, the parameters of the dimension of the hidden layers and the number of neurons in them were chosen as parameters affecting the accuracy. For ANNs, the accuracy of calculations depends on the number of feature maps and neurons in the fully connected layer. The following were chosen as key parameters: the dimensions of the convolutional and max-pooling layers, the number of feature maps, the dimension of the fully connected layer. For the analytical method, the larger the size of the input vector, the more accurately the contour of the automated control system is approximated. Recent studies have shown the advantages of using AI methods for space applications. They provide an opportunity to reduce the requirements for control system elements, such as sensors, actuators, to abandon the use of special stands for testing systems, and to reduce development time and cost. These results provide grounds for further research in this direction, as much work needs to be done to make AI methods effective and reliable for use in space.

3. Comprehensive optimization of design parameters and rocket motion control programs. A complex problem of optimizing the design parameters and motion control programs of guided rockets is formulated in the framework of the optimal control theory. An approach is proposed to forming rocket motion control programs in different trajectory segments and programs for the time variation of the thrust and consumption characteristics of main solid rocket motors in the form of polynomials, thus reducing the problem of the optimal control theory to a simpler problem of nonlinear mathematical programming [23]. The proposed approach to the construction of control programs can be used at the initial design phase for the formation of a wide range of trajectories of guided rockets [24] – [26].

For the initial design phase, a package of mathematical modes is developed for the estimation of the dimensions, mass, and energy, and aerodynamic, and ballistic characteristics, motion control programs and trajectory parameters in different segments of ballistic and aeroballistic trajectories [23].

Algorithms of implementation of deterministic and random cooperative methods for the optimization of the design parameters and control programs of a guided rocket have been developed [23]:

– Monte Carlo method;
– genetic random search algorithm;
– zero-order configuration method (Hook-Jeeves);
– zero-order deformed polyhedron method (Nelder-Mead);
– first- and second-order gradient descent methods.

The created package of applied programs for methodology implementation makes it possible to perform the automatic optimization of a large number of optimized parameters of a guided rocket, which allows one to obtain a better design solution for the investigated variants of guided rockets [24] – [26].

Estimates of the accuracy and speed of algorithms for the cooperative optimization of design parameters and control programs of a guided rocket based on various approaches and methods for optimal solution search have been obtained [23].

The method of configurations (Hooke–Jeeves) is proposed for use, which gives the optimization parameter vector closest to the global optimum of the objective function [23]. The method does not require the calculation of partial derivatives of the objective function with respect to the optimization parameters, which significantly reduces the optimal design solution search time. The deterministic method of configurations was used to optimize of the typical composition-layout schemes of the investigated guided rockets [23] – [25].

The developed package of applied programs for methodology implementation makes it possible to study the dependence of the objective function of flight range on variations of the trajectory parameters, design parameters and characteristics of various composition-layout schemes of guided rockets.

4. Remote sensing systems for the Earth's surface. A number of current issues were considered which are caused by the emergence of new technologies used in the creation of satellite systems and which make it possible to significantly increase the efficiency of Earth remote sensing (ERS) satellites and their constellations. Improving the efficiency of ERS satellites is largely related to solving the problems of designing working orbits of satellites, controlling the movement of satellites along working orbits, forming ERS satellite constellations, and controlling their motion.

The solution to the listed problems is associated with the need to determine the basic regularities of motion of satellites in low Earth near-circular orbits (LECO). Using a special form of perturbed Keplerian motion equations allowed us to study the influence of perturbations on satellite motion by integrating systems of linear equations. An averaging method was used to determine the long-term and secular motions of the satellite. The results obtained differ from classical theories of satellite motion in that they describe the motion laws in a simpler and clearer form [27]–[31].

In [27], the parameters of orbits with minimal radius change (OMRC) were determined and the properties of these orbits were studied. OMRCs are the closest to Keplerian circular orbits. The practical interest in such orbits is determined by their potential use for scientific research and Earth observation systems. The effectiveness of applying a previously developed theory for describing the motion of satellites in nearly circular orbits (NCO) to determine the OMRC parameters is demonstrated. For this purpose, first-approximation solutions for the motion of satellites in NCO under the influence of the second zonal harmonic of the geopotential were refined. These solutions allow for the easy determination of OMRC parameters. Second-approximation averaged equations for the influence of the second zonal harmonic on satellite motion were constructed, and their stability was demonstrated. It was shown that the second approximation for small parameters completely describes the fundamental patterns of long-period satellite motion under the influence of the second zonal harmonic of the geopotential. Numerical studies demonstrated the instability of OMRC when taking into account the influence of higher-order geopotential harmonics. An analysis of the potential application of OMRC showed that such orbits could be of practical value for very low and ultra-low orbits, where control action on satellite motion is performed at least once every two days.

In [28], an analytical model of the influence of zonal harmonics on the motion of satellites in LECO is constructed. This model consists of formulas describing the change in osculating elements and averaged equations of motion. An algorithm for constructing a second approximation of the influence of zonal harmonics of the geopotential on the motion of satellites in NCO is presented. For the second and third zonal harmonics, formulas are given for osculating and average elements, describing the satellite motion in the second approximation with respect to small parameters. The introduction of special variables for NCO made it possible to significantly simplify the procedure for constructing the second approximation of the influence of zonal harmonics. A justification for the accuracy of the analytical model for the orbits under consideration is given. The constructed model of changes in the average elements of the orbit describes the main patterns of motion. Possessing a sufficiently high accuracy, this model describes changes in the average elements of the orbit using simple analytical formulas and is convenient for analyzing the properties of orbits and pre-selecting a working orbit for a specific mission.

In [29], an algorithm for the preliminary selection of operational orbits for remote sensing satellites is developed. A simple model of satellite motion in low-Earth orbits (LEO) is proposed, taking into account the main regularities of this motion. The features of choosing the inclination angle, shape, altitude, and orbital period are considered. A simple model for calculating the coverage of the Earth's surface by swaths and their visualization is proposed. In general, a simple algorithm for the preliminary selection of operational orbits for remote sensing satellites in LEO, which provide satisfactory coverage of the target Earth's surface, is proposed.

In [30], the influence of solar pressure on the motion of a satellite in LECO is considered. Simple analytical expressions are constructed that describe the main regularities of short-term (several days) changes in the orbital parameters. It is shown that the change in the orientation of the orbital plane is determined by the action of the gyroscopic moment, and that the main effect of solar pressure forces is the excitation of forced oscillations of the orbital radius with amplitude that linearly increases with time. The maximum (apogee) of these oscillations is located at the point where the forces of light pressure maximally decelerate the motion of the satellite (directed against the velocity), and the minimum (perigee) is at the point of maximum acceleration of the motion. It is shown that the annual motion of the Sun can qualitatively change the pattern of the evolution of the orbital parameters. For sun-synchronous "dawn-dusk" orbits, compact analytical solutions for the change in orbital parameters are constructed, and it is shown that the annual movement of the Sun's declination leads to a change in the direction of the evolution of the orbital shape to the opposite.

In [31] the studies of the main regularities of controlled and uncontrolled motion of a satellite along the NCO under significant aerodynamic influence are presented. For a number of well-founded assumptions about the aerodynamic influence on the satellite, the main regularities of its influence are determined, taking into account the variability of the atmospheric density along the orbit. It is shown that the proximity of the solar-synchronous orbit to the atmospheric hump leads to a change in the eccentricity and argument of perigee. Estimates are constructed for the change in the kinetic momentum depending on the average atmospheric density along the orbit. The main regularities of the change in the satellite motion parameters under a small transversal control action are determined. Estimates of the duration of the thrusters switching on for compensation of the angular momentum are constructed It is shown that only turning the thrusters on and off changes the amplitude and phase of the oscillations of the orbit radius. Formulas describing these changes are constructed. Based on certain regularities of movement, recommendations are given for the creation of control algorithms. For an ultra-low initially circular orbit, calculations were made and the possibility of autonomous control to maintain the height and shape of the orbit was shown.

In [32], [33], together with colleagues from the Oles Honchar Dnipro National University, the possibilities of statistically processing satellite position and velocity measurements to improve their accuracy were examined.

In [34], the emergence of stochastic motion in deterministic systems was demonstrated using a simple mechanical system.

An analysis has been conducted of the status and prospects for the application of optical and microwave methods of Earth observation in small spacecraft constellations [35] – [37]. Optical methods – multispectral, hyperspectral, and lidar imaging, as well as chlorophyll fluorescence recording – are developing due to an increase in the number of spectral channels, improved spatial resolution, and repeat imaging frequency, thanks to the use of numerous inexpensive small spacecraft. Hyperspectral and lidar data face the problem of large amounts of information, a promising solution to which is on-board processing. Lidar clusters can provide annual global land coverage. Microwave methods provide all-weather observations and independence from the illumination of the underlying surface. Radar imaging is developing particularly rapidly: single large satellites are being replaced by constellations of small satellites. In the coming years, hyperspectral microwave radiometers, which are in demand for national security tasks, are expected to appear in orbit. Altimeters and scatterometers are not yet in demand on small spacecraft, but may find application in military meteorology. The development of small Earth observation satellite constellations is showing significant growth: by the end of 2025, 81 constellations are expected to be in operation, almost 12 times more than in 2015. The United States and China are the leaders in the development of commercial Earth observation constellations.

Another area of research was devoted to determining the requirements for target Earth observation payload for solving applied problems in agriculture and forestry, as well as in the field of greenhouse gas monitoring [38] – [41]. High imaging repeatability and spatial resolution are particularly important for agriculture, as they enable intra-field monitoring and the calculation of spectral and textural features. Analysis of the requirements has shown that for the vast majority of agricultural and forestry tasks, the following are sufficient optical data with a spatial resolution of (2–

3) m, a sampling period of 3 days, and a swath width of (20–30) km; thermal data with a spatial resolution of 20 m, as well as radar data with a spatial resolution of (3–5) m, a sampling frequency of 3–6 days, and a swath width of 100 km (in ScanSAR mode). When monitoring greenhouse gases (CO_2, CH_4, N_2O, etc.), a key requirement for the equipment is high spectral resolution. Spatial resolution is selected to ensure quantitative assessment of gas concentrations at local, regional, and global levels. Limitations of existing satellite products have been noted, including insufficient spatial detail and difficulties in validating measurements.

5. Space debris disposal. Currently, promising ways of space debris removing are considered: descent into the Earth's atmosphere, relocation to an orbit with a lifetime less than twenty-five years, relocation to an utilization orbit, and orbital disposal. Orbital utilization considers space debris as a resource for the industry in orbit. The article [42] analyses the prospects for the use of orbital utilization of space debris and the assessment of the possibilities of using orbital storage and subsequent reuse of dismantled space objects, instruments and materials. A number of problems of planning and organizing the orbital utilization of space debris are formulated and solved.

The active removal of space debris is associated with high energy costs of service space vehicles for moving space debris objects. In this regard, the task of estimating the energy costs of service space vehicles for moving space debris objects becomes important. The purpose of the article [43] is a comparative assessment of the energy costs of moving space debris objects into disposal orbits using service spacecraft with electrojet propulsion systems. The methods of solving the problem are methods of flight dynamics, averaging and mathematical modeling.

The number of spacecraft operating in Solar synchronous orbits is constantly growing. When planning emergency orbital services, it is necessary to meet the following restrictions: not to exceed the allowable time of convergence of the service spacecraft with any of the serviced spacecraft and at the same time not to exceed the allowable energy costs of the service spacecraft. The paper [44] considers the problem of finding acceptable in time and energy constraints emergency orbital services. The method of solving the problem is minimax optimization with constraints.

The paper [45] developed a technique for the optimal synthesis of the orbital structure and optimal operational planning of the low-orbit OOS complex in near-Earth orbits with a small eccentricity. Methods for solving the problem are the averaging method, the branch-and-bound method, and the multi-objective optimization method. The novelty of the obtained results lies in the development of a technique for optimal synthesis of the orbital structure and optimal operational planning of the low-orbit space OOS complex in near-Earth orbits with low eccentricity. The developed technique can be used in the previous planning and design of space OOS complexes in low near-Earth orbits with a small eccentricity. The results of studies on the problem of choosing orbits for storing space debris over the past five years are presented in [42] – [50].

6. Methodology for conceptual design of a space industrial platform. As part of the development of scientific and methodological support for the conceptual design of space industrial platforms, the current state of development of key component modules of the orbital industrial platform was analyzed, and it was concluded that space conditions make it possible to produce new materials and substances with improved characteristics compared to their terrestrial counterparts [51].

To obtain the initial data for calculating the design parameters of the platform, it is necessary to combine the characteristics of technological processes in an appropriate manner [52]. To achieve this goal, [52] proposes clustering the characteristics of technological processes and their further classification according to relevant criteria.

The design of a space industrial platform (SIP) largely depends on the requirements of the technological processes implemented on it: The formation of a SIP design largely depends on a number of criteria arising from the functional features of the platform. These criteria are [53]: modularity of the structure, type of hull frame, method of hull formation, type of sealing, availability and need for a special gas environment, availability of special technological compartments, type of orientation and stabilization, type of power supply system, type of temperature control, availability of microclimate, type of preliminary preparation of raw materials and their components. Using these criteria, a classification of the functional features of the SIP shell has been proposed [53].

The tasks of optimizing the parameters of the SIP have been formulated. The stages of optimization are as follows: analysis of technological processes implemented on the SIP; formation of clusters of design parameters to be optimized; construction of a matrix of correspondence between the parameters of the SIP modules and the parameters of technological processes; determination of the optimal vectors of the parameters of the platform modules [53].

A weighted model of the industrial platform and its modules has been developed, during which the platform and its components were broken down to the level of system elements [54]. The design of the space industrial platform has been completed. The model for determining the mass of the main and auxiliary modules of the platform has been refined and expanded [55].

An analysis of the configurations of existing orbital stations as prototypes of space industrial platforms was carried out, and the ranges of the main parameters of their modules were determined [56]. A set of parameters for technological processes in a vacuum and weightless conditions that can be implemented on a space industrial platform was formed. The relationship between the technological and basic modules of the industrial platform has been shown. The structure of a comprehensive mathematical model of the functioning of a space industrial platform has been developed. For successful work at the preliminary design stage, a general formulation of the task of optimizing the mass of a space industrial platform has been formulated. The minimum mass and dimensions of the space platform obtained as a result of optimization are used further to refine the optimal parameters of the platform and, therefore, influence the formation of conditions for the implementation of the technological process. A general algorithm of the sequence of operations for solving the problem of optimal design of a space industrial platform is shown.

A new paradigm for solving the problem of space debris growth in Earth's orbits is proposed. Within this paradigm, a method for processing space debris fragments into raw materials for further use is proposed.

7. The problem of service maintenance in space. The problem of determining the pose of an orbital service object relative to a servicing spacecraft represents both theoretical and technological challenges, which are related to finding the most suitable algorithmic solution and sensor architecture, respectively. The degree of complexity of pose determination tasks largely depends on the type of service objects, which can be cooperative or non-cooperative, but known or unknown space objects. Although the cooperative case has successfully demonstrated pose determination in orbit, the uncooperative case is still under study by research centers, space agencies, and private companies. Before performing a service operation, as a rule, the relative motion of the orbital service object is slowed down, and during the operation, its motion is controlled. This is due to the trend in conducting research related to improving methods for on-board determination of the parameters of the relative motion of an object.

Determining the relative pose of an uncooperative orbital object (target) based on video systems is a classic approach due to the advantages of low weight and low power consumption. Algorithms for pose estimates based on a video camera usually require prior knowledge of the features of the target, require complex calculations, and their performance is affected by lighting conditions. The main methods for estimating relative pose remain traditional approaches based on the extraction of image features and subsequent comparison of image features of consecutive frames or on the comparison of image features and features of the target model. Another major approach to relative pose determination is LIDAR sensor-based navigation, where common methods are feature recognition and matching based on a LIDAR-derived cloud of target surface points. Regarding the suitability of the methods described in the publications for estimating the target pose for use in the case of an unknown target, it should be noted that the implementation of the obvious approach, which is based on the creation of a 3D model of the target in orbit by processing a series of images and which precedes the process of estimating the spatial movement of the target, is time-consuming. This can be critical in close proximity operations. It was noted that the 3D nature of LIDAR point cloud data is conducive to pose estimation without the need for a target model. Another major approach to relative pose determination is LIDAR sensor-based navigation, where common methods are feature recognition and matching based on a LIDAR-derived cloud of target surface points. Regarding the suitability of the methods described in the publications for estimating the target pose for use in the case of an unknown target, it should be noted that the implementation of the obvious approach, which is based on the creation of a 3D model of the target in orbit by processing a series of images and which precedes the process of estimating the spatial movement of the target, is time-consuming. This can be critical in close proximity operations. It was noted that the 3D nature of LIDAR point cloud data is conducive to pose estimation without the need for a target model.

An analysis of the applicability of methods for remotely determining the pose and motion parameters of an uncooperative unknown object from aboard a servicing spacecraft shows that they are currently under study [57], [58]. To validate the methods proposed by researchers, their numerical simulations or data from ground experiments or previous missions are used as input data.

The institute's department developed a method for onboard determination of the parameters of change in the relative pose of an uncooperative orbital service object (target) with an unknown shape based on the target surface point cloud obtained by a LIDAR. The algorithm of the method operates with a reduced cloud volume. The parameters of changing the target pose are determined as arguments of the objective function that give it the maximum possible value. A variant of the objective function formulation is proposed, the maximum value of which corresponds to the correct determination of the target pose. The effectiveness of the developed method has been confirmed by the results of computational experiments.

The accuracy of determining the parameters of the target's pose change depends on the accuracy of measuring the coordinates of the cloud points, i.e., on the characteristics of the video camera sensor, for example, a camera based on time-of-flight technology. Recommendations were provided on the application of the developed method for constructing a procedure for estimating (filtering) the relative spatial motion of an orbital service object with an unknown shape. Models of the dynamics of the relative motion of the spacecraft and target that can be used in the prediction step of the estimation procedure were considered. A relationship was obtained for constructing an observation model for the filtering procedure.

The problem of determining the pose of an orbital service object relative to a servicing spacecraft represents both theoretical and technological challenges, which are related to finding the most suitable algorithmic solution and sensor architecture, respectively. The degree of complexity of pose determination tasks largely depends on the type of service objects, which can be cooperative or non-cooperative, but known or unknown space objects. Although the cooperative case has successfully demonstrated pose determination in orbit, the uncooperative case is still under study by research centers, space agencies, and private companies. Before performing a service operation, as a rule, the relative motion of the orbital service object is slowed down, and during the operation, its motion is controlled. This is due to the trend in conducting research related to improving methods for on-board determination of the parameters of the relative motion of an object.

Determining the relative pose of an uncooperative orbital object (target) based on video systems is a classic approach due to the advantages of low weight and low power consumption. Algorithms for pose estimates based on a video camera usually require prior knowledge of the features of the target, require complex calculations, and their performance is affected by lighting conditions. The main methods for estimating relative pose remain traditional approaches based on the extraction of image features and subsequent comparison of image features of consecutive frames or on the comparison of image features and features of the target model. Another major approach to relative pose determination is LIDAR sensor-based navigation, where common methods are feature recognition and matching based on a LIDAR-derived cloud of target surface points. Regarding the suitability of the methods described in the publications for estimating the target pose for use in the case of an unknown target, it should be noted that the implementation of the obvious approach, which is based on the creation of a 3D model of the target in orbit by processing a series of images and which precedes the process of estimating the spatial movement of the target, is time-consuming. This can be critical in close proximity operations. It was noted that the 3D nature of LIDAR point cloud data is conducive to pose estimation without the need for a target model. Another major approach to relative pose determination is LIDAR sensor-based navigation, where common methods are feature recognition and matching based on a LIDAR-derived cloud of target surface points. Regarding the suitability of the methods described in the publications for estimating the target pose for use in the case of an unknown target, it should be noted that the implementation of the obvious approach, which is based on the creation of a 3D model of the target in orbit by processing a series of images and which precedes the process of estimating the spatial movement of the target, is time-consuming. This can be critical in close proximity operations. It was noted that the 3D nature of LIDAR point cloud data is conducive to pose estimation without the need for a target model.

An analysis of the applicability of methods for remotely determining the pose and motion parameters of an uncooperative unknown object from aboard a servicing spacecraft shows that they are currently under study [57], [58]. To validate the methods proposed by researchers, their numerical simulations or data from ground experiments or previous missions are used as input data.

The institute's department developed a method [59], [60] for onboard determination of the parameters of change in the relative pose of an uncooperative orbital service object (target) with an unknown shape based on the target surface point cloud obtained by a LIDAR. The algorithm of the method operates with a reduced cloud volume. The parameters of changing the target pose are determined as arguments of the objective function that give it the maximum possible value. A variant of the objective function formulation is proposed, the maximum value of which corresponds to the correct determination of the target pose. The effectiveness of the developed method has been confirmed by the results of computational experiments. The accuracy of determining the parameters of the target's pose change depends on the accuracy of measuring the coordinates of the cloud points, i.e., on the characteristics of the video camera sensor, for example, a camera based on time-of-flight technology. Recommendations were provided on the application of the developed method for constructing a procedure for estimating (filtering) the relative spatial motion of an orbital service object with an unknown shape. Models of the dynamics of the relative motion of the spacecraft and target that can be used in the prediction step of the estimation procedure were considered. A relationship was obtained for constructing an observation model for the filtering procedure.

8. **Deorbiting of space debris.** Methods and tools for passive deorbiting of space debris from near-Earth orbits are also being developed [61] – [63]. In particular, works [61], [62] propose original structural concepts for aerodynamic deorbiting systems intended for spacecraft and launch vehicle upper stages. A distinctive feature of these systems is the use of compact deployable aerodynamic sails on Earth observation spacecraft [61], as well as cellular storage structures and spatial three-dimensional sails for upper stages [62]. These studies aim to minimize system mass while maintaining deorbiting effectiveness within a time frame not exceeding 25 years. Study [63] focuses on selecting optimal trajectories that maximize upper-stage burn-up in dense atmospheric layers.

Research is also devoted to attitude control of aerodynamically unstable spacecraft using various magnetic actuators and control strategies [12] – [15]. The proposed approaches include improved sliding-mode control [64] – [67], robust control techniques [66], linear–quadratic regulators [67], and combined use of electromagnets and reaction wheels under off-nominal conditions [65]. The obtained results significantly extend the operational limits of spacecraft attitude control using different actuator configurations.

Advances in mathematical and computational modeling also find application in socio-economic analysis and systems studies [68], [69]. Using differential equations, Fourier series, stochastic processes, and correlation and regression analysis, the methodology has been developed to forecast economic indicators of investment projects and support informed managerial decision-making.

A combined system for contactless removal of space debris with a service spacecraft is proposed, on board of which are installed electrojet engines and an aerodynamic compensator in the form of plates. Such a combined space system can be used for removing space debris from low Earth orbits into dense layers of the atmosphere. The feasibility of using an aerodynamic compensator for contactless removal of space debris objects from low Earth orbits, taking into account aerodynamic disturbance in the direction perpendicular to the plane of the orbit, is investigated. The object of the study was a modified scheme of the "shepherd with an ion beam" concept of diversion. The modification consisted in replacing the aerodynamic compensator of the additional electrojet engine, which is designed to compensate for the motion of the shepherd spacecraft caused by the reactive force of the main electrojet engine, the ion flux of the flare of which causes a "braking" effect on the space debris object. The relatively large area of the midsection of the shepherd spacecraft when using an aerodynamic compensator necessitates the control of the relative motion caused by the aerodynamic disturbance in the direction perpendicular to the orbital plane. This control requires additional costs of the working fluid of the engine of the relative motion control system of the shepherd spacecraft. The calculation of the working fluid costs is carried out using a number of simplifying assumptions. The validity of these assumptions is checked by numerical integration of the equations of relative motion. The feasibility of using an aerodynamic compensator in the non-contact removal of space debris objects, taking into account the aerodynamic disturbance in the direction perpendicular to the orbital plane [70] – [74].The study of the features of the operating modes of space power devices was carried out in terms of synchronization with the cyclograms of the operation of the space industrial platform. The synthesis of angular motion control controllers of the space power device in the solar battery charging mode, the mode of pointing at the apertures of the receiving spacecraft during contactless energy transfer and standby mode was carried out. Methodological recommendations were developed for the synthesis of cyclograms of the operation of space power devices of the distributed power supply system in terms of synchronization with the cyclograms of the operation of the space industrial platform. The design parameters that should be selected when designing spacecraft with contactless energy transfer to the space industrial platform were determined [75] – [77].

9. Space systems for shading the Earth from solar radiation for climate stabilization. The steady increase in the average global temperature over the past century has raised serious concern within the international scientific community. This phenomenon, known as global warming, is recognized as a significant threat to the global economy and human activity. Consequently, leading researchers worldwide are exploring various mitigation approaches. In this context, the Institute of Technical Mechanics of the NAS of Ukraine and the SSA of Ukraine conducts research aimed at addressing global warming through the design of space-based Earth surface shading systems [78] – [81]. Mathematical models are being developed to provide a comprehensive assessment of shading system performance, including long-term stability of individual orbital clusters and structural coherence of the global shading cloud. These models describe orbital motion of elementary shading modules, apply cluster analysis to distributed orbital formations, and use wavelet techniques to study their temporal stability. The combined application of these approaches enables stability analysis of distributed orbital shading clusters over both short- and long-term intervals, as well as rational selection of deployment orbit parameters.

10. Conclusions. The research achievements of the scientific school "Dynamics of Space Technology Objects" of the National Academy of Sciences of

Ukraine for the period 2021–2025 address a broad spectrum of key challenges in the space sector. The work integrates both fundamental and applied aspects of modern astronautics.

Fundamental studies focus on advanced approaches to control system synthesis based on artificial intelligence methodologies. Among the applied directions, particular attention is given to the urgent challenge of space debris mitigation. The growing presence of debris in near-Earth orbits poses a serious obstacle to the sustainable use of space. Accordingly, a significant part of the school's research efforts has been devoted to this issue.

Notable results include the development of a new paradigm for space debris management based on in-orbit recycling concepts. This work addresses methodological aspects of creating space-based industrial platforms and provides substantiated approaches for selecting orbital configurations suitable for debris collection and storage as a recyclable resource.

Another important research direction concerns solar radiation mitigation using dedicated space-based systems. Initial findings were presented and discussed at a session of the UN Committee on the Peaceful Uses of Outer Space [81].

This review summarizes the scientific contributions of the members of the "Dynamics of Space Technology Objects" school, including: A. V. Pirozhenko (Dr. Sci., Phys. & Math.), Yu. A. Prokopchuk (Dr. Sci., Eng.), S. V. Khoroshilov (Dr. Sci., Eng., Professor), O. L. Voloshenyuk (Ph.D., Eng.), Yu. M. Goldshteyn (Ph.D., Eng.), E. O. Lapkhanov (Ph.D.), A. I. Maslova (Ph.D., Phys. & Math.), A. V. Mishchenko (Ph.D., Eng.), A. S. Palii (Ph.D., Eng.), S. V. Siutkina-Doronin (Ph.D., Eng.), O. A. Fokov (Ph.D., Eng.), D. A. Khramov (Ph.D., Eng.), V. T. Marchenko (Researcher), V. V. Kostra (Junior Researcher), N. P. Sazina (Junior Researcher), D. S. Svorobin (Junior Researcher).

The authors express sincere gratitude to all contributors.

1. *Prokopchuk Yu. O.* Intuition: The Experience of Formal Research. Dnipro : PSACEA Press. 2022. 724 pp. (In Ukrainian).

2 *Prokopchuk Y., Nosov P., Ben A.* Problems of meaning, understanding, computability and adaptability in artificial cognitive systems. Proceedings of the 16th Scientific and Practical Conference Modern Information and Innovative Technologies in Transport (MINTT–2024), Odesa, May 29–30, 2024. Odesa: Kherson State Maritime Academy, 2024. Pp. 19–25.

3 *Prokopchuk Yu.* Sketch of the autonomous/cognitive system behavior model. Automatics 2024: Abstracts of the XXVII International Conference of Automatic Control. Dnipro, November 20–22, 2024. Dnipro: DNU, 2024. Pp. 176–177. (In Ukrainian).

4. *Prokopchuk Y.* Designing ecosystems of intelligence: Logic of fast distinction. Materials of the 17th International Scientific and Practical Conference "Modern Information and Innovative Technologies in Transport (MINTT–2025), Odesa, May 28–30, 2025. Odesa: Kherson State Maritime Academy, 2025. Pp. 29–34.

5. *Prokopchuk Y.* Combinatorial, expanding phase space of cognitive dynamic systems. XXVII International Scientific and Practical Seminar "Combinator Configurations and Their Applications", Zaporizhzhia–Kropyvnytskyi–Kiev, Ukraine: National University "Zaporizhzhia Polytechnic", 2025. Pp. 175–183.

6. *Prokopchuk Yu. O.* Open–ended evolution of self–improving systems/agents: LGP–Machine. Materials of the XX Scientific Readings "Dneprovskaya Orbita–2025", Dnipro, October 22–24, 2025. Dnipro: NCAOM named after O.M. Makarov, 2025. Pp. 117–124. (In Ukrainian).

7. *Prokopchuk Yu. O., Poshyvalov V. P.* Development of a methodology for analyzing the functioning, development, and management of complex dynamic intelligent systems. Proceedings of the Fifth International Scientific and Practical Conference "Problems of Sustainable Development of the Maritime Industry (PSDMI–2025)". Odesa, Ukraine: Kherson State Maritime Academy, 2025. Pp. 46–50. (In Ukrainian).

8. *Prokopchuk Y. A.* Mathematical model of the meaning/gist of the signal/variable. Abstracts of the XIX International Conference "Modern Information and Communication Technologies on a Transport, in Industry and Education". Dnipro, Ukraine: Ukrainian State University of Science and Technology, 2025. P. 63.

9. *Prokopchuk Y., Nosov P.* Trusted autonomous systems: organization of the "thinking swarm". Proceedings of the International Scientific Conference Information Technologies and Computer Modelling, Ivano–Frankivsk, July 6–8, 2023. Ivano–Frankivsk: Vasyl Stefanyk Precarpathian National University, 2023. Pp. 104–107.

10. *Marchenko V. T., Petlyak O. A., Sazina N. P., Khorolsky P. P*. Methodological approach to the creation of a domestic industry methodology for calculating the cost of experimental design work on the creation of spacecraft. Teh. Meh. 2021. No. 3. Pp. 83–98. (In Ukrainian). https://doi.org/10.15407/itm2021.03.083
11. *Alpatov A. P., Marchenko V. T., Sazina N. P.* Quantitative assessment of the risk level of increasing costs for the development of space technology samples. Teh. Meh. 2022. No. 4. Pp. 51–66. (In Ukrainian). https://doi.org/10.15407/itm2022.04.051
12. *Alpatov A. P., Marchenko V. T., Khorolsky P. P., Sazina N. P.* Status and directions for improving regulatory and procedure framework for rocket and space technology development in Ukraine. Sci. Innov. 2022. V. 18. No. 1. Pp. 76 – 88.
13. *Sazina N. P., Zhukova L. G.* Features of calculating the expected cost of experimental design work on the creation of spacecraft. Teh. Meh. 2023. No. 3. Pp. 58–67. (In Ukrainian). https://doi.org/10.15407/itm2023.03.058
14. *Marchenko V. T., Sazina N. P*. Methodological features of assessing the level of competence of experts in a group when determining the effectiveness of rocket and space systems. Teh. Meh. 2024. No. 1. Pp. 93–104. (In Ukrainian). https://doi.org/10.15407/itm2024.01.093
15. *Zhukova L. G*. Quality and reliability of expert assessments in determining the technical level of complex systems. XXVII International Conference "Automatics–2024", Dnipro, November 20–22, 2024. Abstracts. Pp. 108–109. (In Ukrainian).
16. *Sazina N. P.* Methodological features of assessing the level of competence of a group of experts in solving some difficult–to–formalize problems. XXVII International Conference "Automatics–2024", Dnipro, November 20–22, 2024. Abstracts. Pp. 182–183. (In Ukrainian).
17. *Khramov D. A*. A review of free software for spacecraft modeling. Sciences of Europe. 2021. No. 82–1. P. 63–68. (In Russian).
18. *Khramov D. A*. Analysis of methods for joint use of machine learning methods and differential equations in dynamics problems. Sciences of Europe. 2021. No. 83–1. Pp. 41–47. (In Russian).
19. *Khramov D. O., Voloshenyuk O. L., Pirozhenko O. O.* Experience in the use of large language models in the study of spacecraft dynamics. XXVII International Conference "Automatics–2024", Dnipro, November 20–22, 2024. Abstracts. Pp. 86–87. (In Ukrainian).
20. *Khoroshylov S. V., Redka M. O.* Relative control of an underactuated spacecraft using reinforcement learning. Teh. Meh. 2020. No. 4. Pp. 43–54. https://doi.org/10.15407/itm2020.04.043
21. *Khoroshylov S., Redka M.* Deep learning for space applications. In: Potapov I. et al. Communications in Computer and Information Science. V. 2647. Cham: Springer, 2025. Pp. 39–46. https://doi.org/10.1007/978-3-032-04731-1_5
22. *Redka M. O.* Determination of the force exerted by an ion beam on a space debris object from the edges of its images using deep learning. Teh. Meh. No. 2. Pp. 51–63. (In Ukrainian).
23. *Siutkina–Doronina S. V.* Methodology for the Optimization of the Design Characteristics of Single–Stage Guided Rockets with a Solid–Propellant Sustainer Engine. PhD Thesis: Approved on June 26, 2021. Dnipro, 2021. 168 pp. (In Ukrainian).
24. *Siutkina–Doronina S. V*. Determination of a pitch control program for a solid–propellant missile. Teh. Meh. 2023. No. 3. Pp. 18–34. (In Ukrainian). https://doi.org/10.15407/itm2023.03.018
25. *Siutkina–Doronina S. V.* Effect of a guided rocket object's lateral maneuver on the flight range and lateral deviation. Teh. Meh. 2024. No. 4. Pp. 97 – 109. (In Ukrainian). https://doi.org/10.15407/itm2024.04.097
26. *Siutkina–Doronina S. V.* Modeling and analysis of trajectories of a solid–propellant rocket object. XXVII International Conference "Automatics–2024", Dnipro, November 20–22, 2024. Abstracts. Pp. 193 – 194. (In Ukrainian). http://automatika2024.dp.ua/files/Автоматика–2024%20 (тези%20доповідей).pdf.
27. *Maslova A. I., Pirozhenko A. V., Vasyliev* V. V. Minimum altitude variation orbits. Analysis of characteristics and stability. Teh. Meh. 2021. No. 4. Pp. 44–55. https://doi.org/10.15407/itm2021.04.044
28. *Pirozhenko A. V., Maslova A. I., Vasyliev V. V.* Analytical model of satellite motion in almost circular orbits under the influence of zonal harmonics of geopotential. Space Science and Technology. 2022. V. 28. No. 4 (137). Pp. 18–30. https://doi.org/10.15407/knit2022.04.018
29. *Alpatov A. P., Maslova A. I., Pirozhenko A. V*. Preselection of the reference orbit for an Earth remote sensing satellite. Teh. Meh. 2023. No. 1. Pp. 14–24. https://doi.org/10.15407/itm2023.01.014
30. *Maslova A. I., Pirozhenko A. V., Pyrozhenko O. O.* Effect of the solar radiation pressure on the motion of satellites in almost circular Earth orbits. Teh. Meh. 2024. No. 2. Pp. 41–54. https://doi.org/10.15407/itm2024.02.041
31. *Pirozhenko A. V., Maslova A. I.* Regularities of controlled and uncontrolled satellite motion in low Earth orbit. International Applied Mechanics. 2025. V. 61. Pp. 393–402. https://doi.org/10.1007/s10778–025–01362–5
32. *Turchyn V. M., Volkov H. Y., Pirozhenko A. V.* Estimation of near–circular orbital motion parameters. Problems of Applied Mathematics and Mathematical Modeling. 2023. V. 23. Pp. 246–253. https://doi.org/10.15421/322325
33. *Turchyn V. M., Ashbel H. V., Pirozhenko A. V.* Estimation of Kepler orbital motion parameters. Problems of Applied Mathematics and Mathematical Modeling. 2024. V. 24. Pp. 229–239. https://doi.org/10.15421/322424
34. *Turchyn V. M., Pyrozhenko O. V*. Stochasticity and determinicity of mechanical systems. Scientific Bulletin of Uzhhorod University. Series of Mathematics and Informatics. 2025. V. 47. No. 2. Pp. 82–90.
35. *Khramov D. O., Pyrozhenko O. O.* Optical methods of Earth remote sensing and prospects for their use in commercial spacecraft. Teh. Meh. 2024. No. 4. Pp. 17–30. (In Ukrainian). https://doi.org/10.15407/itm2024.04.017

36. *Khramov D. O., Volosheniuk O. L.* Commercial constellations of small satellites for Earth remote sensing. Teh. Meh. 2025. No. 1. Pp. 36–52. (In Ukrainian). https://doi.org/10.15407/itm2025.01.036
37. *Khramov D., Maslova A. I., Pyrozhenko O. O*. Microwave methods of Earth remote sensing and the prospects for their use. Teh. Meh. 2025. No. 3. Pp. 98–113. (In Ukrainian). https://doi.org/10.15407/itm2025.03.098
38. *Kavats O., Khramov D., Sergieieva K., Vasyliev V.* Open satellite data for global greenhouse gas monitoring. System Technologies. 2022. No. 3. Pp. 47–59. https://doi.org/10.34185/1562-9945-3-140-2022-05
39. *Kavats O., Khramov D., Sergieieva K., Vasyliev V.* Analysis of methodologies for carbon stock estimation in forests. System Technologies. 2022. No. 4. Pp. 56–73. https://doi.org/10.34185/1562-9945-4-141-2022-05
40. *Khramov D., Volosheniuk O.* Analysis of the state and trends in the development of target characteristics of orbital constellations of small spacecraft for agricultural tasks. Proceedings of International Scientific Conference "Actual Problems of Mechanics–2023" for the 145th birth anniversary of S. P. Timoshenko, Kyiv, Dnipro, Lviv, Kharkiv, November 14–16, 2023. Pp. 199–200. (In Ukrainian).
41. *Khramov D. O., Volosheniuk O. L.* Analysis of the state of the art and the trends in the development of the target characteristics of orbital constellations of small agriculture–oriented Earth remote sensing spacecraft. Teh. Meh. 2023. No. 4. Pp. 31–39. (In Ukrainian). https://doi.org/10.15407/itm2023.04.031
42. *Holdshtein Yu. M.* On the choice of a parking orbit for a service spacecraft. Teh. Meh. 2020. No. 3. Pp. 30 – 38. (In Ukrainian). https://doi.org/10.15407/itm2020.03.030
43. *Alpatov A. P., Goldshtein Yu. M*. Assessment perspectives for the orbital utilization of space debris. Space Science and Technology. 2021. V. 27, No. 3. Pp. 3–12. https://doi.org/10.15407/knit2021.03.003
44. *Holdshtein Yu. M.* Minimax model of transport operations of emergency on–orbit servicing in heliosynchronous orbits. Teh. Meh. 2021. No. 3. Pp. 4–56. (In Ukrainian). https://doi.org/10.15407/itm2021.03.048
45. *Holdshtein Yu. M., Fokov O. A.* Optimization of transfers between low orbits with significantly different longitudes of ascending nodes. Teh. Meh. 2022. No. 3. Pp. 63–74. (In Ukrainian). https://doi.org/10.15407/itm2022.03.063
46. *Holdshtein Yu. M.* Energy expenditures for moving space debris objects from low–Earth orbits to utilization orbits. Teh. Meh. 2023. No. 2. Pp. 41–50. (In Ukrainian). https://doi.org/10.15407/itm2023.02.041
47. *Goldshtein Yu. M.* Orbital structure optimization technique of the low–orbit complex of on–orbit service. Space Science and Technology. 2023. V. 29, No. 4. Pp. 3–11. https://doi.org/10.15407/knit2023.04.003
48. *Alpatov A. P., Holdshtein Yu. M.* Reusable low–orbit service complex. Orbital structure synthesis and operational service planning. Space Research in Ukraine 2022–2024. Report to COSPAR. 2024. Pp. 149–154.
49. *Alpatov A. P. Holdshtein Yu. M.* Ballistic planning technique for low–orbit servicing missions with low constant thrust propulsion systems. Teh. Meh. 2024. No. 2. Pp. 3–12. (In Ukrainian). https://doi.org/10.15407/itm2024.02.0039 https://doi.org/10.15407/itm2024.02.003
50. *Holdshtein Yu. M.* Two-criteria optimization of sequential routes of multi–target low–orbit service and space debris removal missions. Teh. Meh. 2025. No. 3. Pp. 87–97. (In Ukrainian). https://doi.org/10.15407/itm2025.03.087
51. *Palii O. S.* State of the art in the development of orbital industrial platforms. Teh. Meh. 2021. No. 3. Pp. 70–82. https://doi.org/10.15407/itm2021.03.070
52. *Palii O. S.* Classification of technological processes according to their implementation on the space industrial platform. Teh. Meh. 2022. No. 2. Pp. 123–136. (In Ukrainian). https://doi.org/10.15407/itm2022.02.123
53. *Palii O. S.* Classification of functional features of the shell of a space industrial platform. Teh. Meh. 2023. No. 2. Pp. 3–11. (In Ukrainian). https://doi.org/10.15407/itm2023.02.064
54. *Palii O. S.* Models for estimating the mass of a space industrial platform and its modules. Teh. Meh. 2022. No. 3. Pp. 75–84. (In Ukrainian). https://doi.org/10.15407/itm2022.03.075
55. *Palii O. S.* Formation of the project design of the space industrial platform. System Design and Analysis of Aerospace Technology Characteristics. 2023. V. XXXII. Pp. 78–88. (In Ukrainian). https://doi.org/10.15421/472307
56. *Alpatov A. P., Palii O. S., Syutkina–Doronina S. V.* Conceptual design of a space industrial platform. Problem statement. Space Science and Technology. 2023. V. 29, No. 6. Pp. 1–25. (In Ukrainian). https://doi.org/10.15407/knit2023.06.013
57. *Fokov O. A., Savchuk O. P.* The problem of controlling the angular motion of an uncooperative orbital service object. Teh. Meh. 2021. No. 1. Pp. 37–50. (In Ukrainian). https://doi.org/10.15407/itm2021.01.037
58. *Fokov O. A.* Analysis of the state of research into the problem of determining the parameters of the relative position of orbital service objects. Teh. Meh. 2023. No. 1. Pp. 54–67. (In Ukrainian). https://doi.org/10.15407/itm2023.01.054
59. *Fokov O. A.* Method for determining the change in the spatial position of an orbital service object with an unknown shape. Teh. Meh. 2024. No. 4. Pp. 35 48. (In Ukrainian). https://doi.org/10.15407/itm2024.03.035
60. *Fokov O. A.* Method for determining the change in the spatial position of an orbital service object with an unknown shape. XXVII International Conference "Automatics–2024", Dnipro, November 20–22, 2024. Abstracts. Pp. 207–208. (In Ukrainian).
61. *Alpatov A. P., Lapkhanov E. O., Palii O. S.* Designing the configuration and selecting the design parameters of drag systems for deorbiting spacecraft created by Pivdenne Design Office. Sci. Innov. 2022. V. 18, No. 4. Pp. 55–63.
62. *Alpatov A. P., Kuznetsov O. P., Palii O. S., Lapkhanov E. O.* Development of R&D framework for the modernization of the aerodynamic deorbit system for the use in the upper stage of Cyclone–1M launch vehicle. Sci. Innov. 2022. V. 18, No. 6. Pp. 60–71.

63. *Dron M., Lapkhanov E., Golubek A., Dreus A., Kositsyna O., Dubovik L.* Estimating the degree of disposal of a launch vehicle casing made from polyolefins in the Earth's atmosphere. Eastern–European Journal of Enterprise Technologies. 2025. V. 1, No. 1 (133). Pp. 33–43. https://doi.org/10.15587/1729-4061.2025.319437
64. *Zheliabov P., Lapkhanov E., Faizullin D., Kulabukhov A., Hiraki K.* Electromagnetic stabilization system algorithm during energy restriction mode for the near–symmetric satellites. International Review of Aerospace Engineering (IREASE). 2022. V. 15, No. 1. Pp. 62–70. https://doi.org/10.15866/irease.v15i1.20429
65. *Zheliabov P., Lapkhanov E.* Development of the methodological approaches for the attitude control system of the Earth remote sensing satellite in the conditions of the onboard equipment partial failures. EUREKA: Physics and Engineering. 2022. No. 5. Pp. 77–90. https://doi.org/10.21303/2461-4262.2022.002020
66. *Alpatov A., Dron' M., Golubek A., Lapkhanov E.* Combined method for spacecraft deorbiting with angular stabilization of the sail using magnetorquers. CEAS Space J. 2023. V. 15. Pp. 613–625. https://doi.org/10.1007/s12567-022-00469-6
67. *Khoroshylov S. V., Lapkhanov, E. O.* Time–periodic spacecraft attitude control with the use of slewing permanent magnets. Sci. Innov. 2022. V. 18, No. 5. Pp. 38–48. https://doi.org/10.15407/scine18.05.038
68. *Kabachenko D., Lapkhanov E.* Development and justification of the system methodological approach to assessing the investment business project implementation efficiency under conditions of the external market environment factors impact. Eastern–European Journal of Enterprise Technologies. 2023. V. 3, No. 3(123). Pp. 6–21. https://doi.org/10.15587/1729-4061.2023.279621
69. Lapkhanov E., Kabachenko D. Peculiarities of the net present value and profit index calculations using continuous functions and differential equations models. Traditional and Innovative Approaches in Economics: Theory, Methodology, Practice: Scientific Monograph. 2024. Pp. 547–565.
70. *Fokov O. A., Khoroshilov S. V., Svorobin D. S*. Relative motion of a spacecraft with an aerodynamic compensator in a direction perpendicular to the orbital plane during contactless removal of space debris. Space Science and Technology. 2021. V. 27, No. 2 (129). Pp. 15–27. (In Ukrainian). https://doi.org/10.15407/knit2021.02.015
71. *Svorobin D. S.* Review of methods and means of removing space debris objects from low–Earth orbits. Teh. Meh. 2023. No. 3. Pp. 110–123. (In Ukrainian). https://doi.org/10.15407/itm2023.03.110
72. *Svorobin D. S., Fokov O. A., Khoroshilov S. V.* Determining the advantages of a system for contactless removal of space debris objects from low–Earth orbits. The First Scientific and Practical Internet Conference "Space Horizons" Technical Sciences: Development Directions and Achievements. Collection of Abstracts. Dnipro, March 1–3, 2021. Pp. 39–40. (In Ukrainian).
73. *Svorobin D. S.* Removal of space debris from near–Earth orbits and an alternative to its further processing in space. The First Scientific and Practical Internet Conference "Space Horizons" Space for Humanity. Collection of Abstracts. Dnipro, December 1–3, 2021. Pp. 26–27. (In Ukrainian).
74. *Svorobin D. S.* Combined system for removing space debris from low–Earth orbits. International Scientific Conference "Actual Problems of Mechanics–2023" for the 145th birth anniversary of S. P. Tymoshenko, November 14–16, 2023. Conference materials. Kyiv, Dnipro, Lviv, Kharkiv. 2023. Pp. 247–248. (In Ukrainian).
75. Lakhanov E. O., Paliy O. S., Svorobin D. S. Determination of design parameters of the control system of energy spacecraft for contactless power supply of a space industrial platform. Teh. Meh. 2023. No. 4. Pp. 15–30. (In Ukrainian). https://doi.org/10.15407/itm2023.04.015
76. *Lakhanov E. O., Paliy O. S., Svorobin D. S.* Features of control of space energy vehicles of the distributed power supply system of a space industrial platform. XXVII International Conference "Automatics–2024", Dnipro, November 20–22, 2024. Abstracts. Pp. 137–138. (In Ukrainian).
77. *Svorobin D. S.* Application and prospects for the development of wireless energy transmission. Teh. Meh. 2025. No. 2. Pp. 87–104. (In Ukrainian). https://doi.org/10.15407/itm2025.02.087
78. *Alpatov A. P., Lapkhanov E. O.* Features of the development of space–based shading and lighting systems for the Earth's surface. Teh. Meh. 2023. No. 1. Pp. 25–39. https://doi.org/10.15407/itm2023.01.025
79. *Lakhanov E. O.* The main problems of creating space systems to reduce the flux of solar radiation to the Earth's surface. Teh. Meh. 2025. No. 1. Pp. 52–62. (In Ukrainian). https://doi.org/10.15407/itm2025.01.052
80. *Lakhanov E. O.* Estimates of the general parameters of the orbital cluster system of reducing the flux of solar radiation to the Earth's surface. XXVII International Youth Scientific and Practical Conference "Man and Space", Dnipro, April 16-18, 2025. Dnipro. 2025. Pp. 127–129. (In Ukrainian). https://doi.org/10.62717/2221-4550-2025-1-040
81. *Alpatov A. P., Lapkhanov E. O.* The general issues of space sunshade system creation. United Nations Office for Outer Space Affairs (UNOOSA). 2025. URL:https://www.unoosa.org/documents/pdf/copuos/stsc/2025/ListOfTechnicalPresentations/3_%20Wednesday5th%20/6b_-_UKRAINE_The_general_issues_of_space_sunshade_system_creation_ppt.pdf

Received on February 23, 2026;
approved on March 12, 2026;
published on March 31, 2026