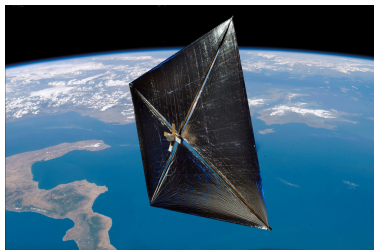


The History of the Birth of Cosmic Dynamics at St. Petersburg State University

E. N. Polyakhova, V. S. Korolev



Annotation

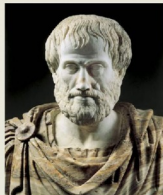
The story of how, on the basis of the departments of Theoretical Mechanics, Celestial Mechanics and Control Theory of the Faculty of Mathematics and Mechanics, a new department of Controlled Motion Mechanics appeared at the Faculty of Applied Mathematics and Control Processes of Leningrad University, which conducted work on the topics of cosmic dynamics.

Introduction

The beginning of the emergence of scientific fields of science can be seen in ancient times before our era. They were formed in philosophical schools by active scientists. Hypotheses, theories, and laws were born! Discoveries of new properties or patterns were obtained, as well as new experimental results. They remained in the memory of generations and in the history of sciences.

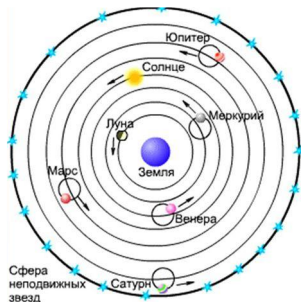
The history of origin

Aristotle (384–322 BC), a student of Plato, wrote the essay "Physics", in which the term "mechanics" was first introduced, formed the general principles of motion, created the theory of motion of the celestial spheres, the principle of virtual velocities, considered the source of motion to be forces caused by external influences.



Аристотель
(IV в. до н.э.)

Написал
сочинение
«Физика», в
котором
впервые введен
термин
«механика»



The history of origin

Ptolemy (100–178 AD), a mechanic and astronomer, proposed a geocentric system of the world, studied the apparent motion of the Sun, Moon and planets.

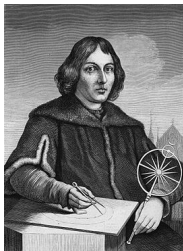
The Renaissance Period

Nicolaus Copernicus (1473–1543), developed the heliocentric system of the world and published his work “On the rotation of the celestial spheres”.

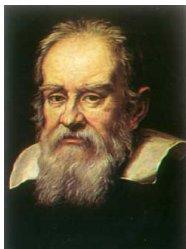
Galileo Galilei (1564–1642), conducted research on statics, dynamics and mechanics of materials, outlined the most important principles and laws, invented the telescope and discovered the moons of Mars, as well as the moons of Jupiter.

The history of origin

Johannes Kepler (1571–1630), transformed the tables that Brahe gave him, taking into account the Copernican theory of planetary motion around the Sun, proposed the laws of planetary motion and orbital parameters, outlined them in the work “New Astronomy or physics of the sky”, which marked the beginning of modern celestial mechanics.



Nicolaus Copernicus



Galileo Galilei



Johannes Kepler

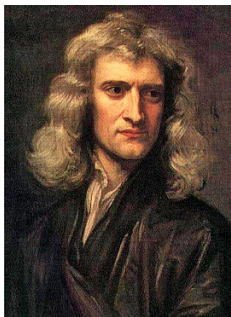
The history of origin

Isaac Newton (1643–1727), created the foundations of modern theoretical mechanics. In his work “Mathematical Principles of Natural Philosophy”, he defined the basic concepts and formulated the basic laws, and obtained a general solution to the two-body problem.

Leonhard Euler (1707–1783), laid the foundations of analytical dynamics in the book *Mechanics or the Science of Motion* in an analytical presentation, analyzed the case of movement of a heavy solid body fixed in the center of gravity, is the founder of hydrodynamics, developed the theory of projectile flight. For many years he worked at the St. Petersburg Academy of Sciences.

The history of origin

Konstantin Eduardovich Tsiolkovsky (1857–1935), the founder of modern cosmonautics, aerodynamics and rocket dynamics, created the theory of an air cushion train and the theory of motion of single-stage and multi-stage rockets.



Isaak Newton



Leonhard Euler



Konstantin
Tsiolkovsky

The history of origin

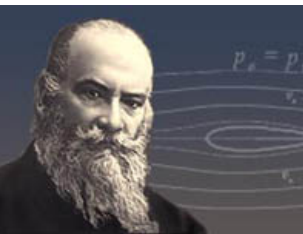
Nikolai Egorovich Zhukovsky (1847–1921), the founder of aerodynamics, studied the motion of a rigid body with a fixed point and the problem of stability of movements.

Henri Poincaré (1854–1912), Published more than 1 000 works in various scientific fields, including: celestial mechanics, theory of oscillations and stability conditions.

Alexander Mikhailovich Lyapunov (1857–1918), the main works devoted to the theory of stability of equilibrium and motion of mechanical systems, the founder of the modern theory of stability.

Viktor Sergeevich Novoselov (1926–2019), published the book “Analytical Theory of Optimization in Gravitational Fields”, which provides a general scheme for solving problems of optimizing the controlled motion of spacecraft.

The history of origin



Nikolay Zhukovsky



Henri Poincaré



Alexander
Lyapunov

The Birth of Cosmic Dynamics at Leningrad University

The history of the events of the next stage in the development of K. E. Tsiolkovsky's fantasies and first solutions to problems, F. A. Zander's scientific projects, as well as S. P. Korolev's practical work and developments for cosmonautics, which created the foundation for space exploration and flights to the planets of the solar system, leads to the creation of methods of cosmic dynamics. Leningrad University had departments of [theoretical mechanics](#), [control theory](#) and [celestial mechanics](#), whose heads were Professors Nikolai Nikolaevich [Polyakhov](#), Vladimir Ivanovich [Zubov](#), and Viktor Sergeevich [Novoselov](#). They proposed to form a new Faculty of Applied Mathematics-Control Processes at Leningrad State University

V. S. Novoselov



Victor Sergeevich Novoselov.

Honorary Professor, Honored Worker of Science and Technology of the Russian Federation, outstanding scientist and teacher of St. Petersburg State University

V. S. Novoselov actively participated in the creation of the faculty, as well as the Department of Controlled Motion Mechanics, which he headed until 1995, and Laboratories at the Research Institute of Computational Mathematics and Control Processes.

New Research Directions

Interest in the classical problems of celestial mechanics continued, but the forces of gravity were complemented by the action of other forces or perturbations that could be used to control orbital motion or rotation relative to the center of mass. The main ones were reactive forces and light pressure on special-shaped structural elements. The main research area was related to optimal control problems in cosmic dynamics.

Main Research Area

The mutual enormous influence of astronomy, mathematics, mechanics, and control theory on the practice of problem solving has been evident for a long time. It turned out that when the possibilities of theoretical, analytical and celestial mechanics were combined with control processes involving computer complexes of machines and algorithms, a scientific direction appeared at the University:

Cosmic Dynamics!

Use of Reactive Forces and Light Pressure

The use of reactive forces for mechanical systems of variable composition makes it possible to describe and control the movement of rockets, spacecraft, systems or structures.

The influence of light pressure forces on the surface of bodies led to the use of a special field of forces of photogravitational celestial mechanics (PGCM).

The appearance of solar sails in spacecraft helped to organize the control and creation of optimal orbits for interplanetary flights or to stabilize the positions of the system and the stability of trajectories.



Hypothesis of Light Pressure



The hypothesis of light pressure was first proposed by Kepler (1571-1630) to explain the deflection of the tails of comets passing near the Sun.



The very idea of using this effect for space flights was first put forward in 1924 by **Friedrich Arturovich Zander** (1887–1933). He reviewed the designs of solar sails and the fundamentals of the theory of motion of spacecraft with a solar sail.



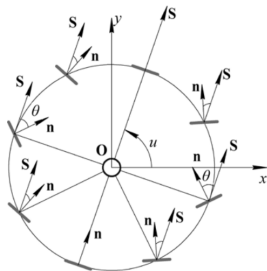
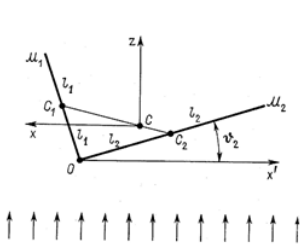
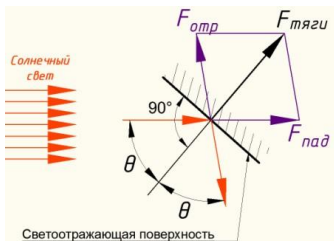
The history of the theory's creation

The principle of motion in space with a solar sail is based on the effect of light pressure, which was established, measured in 1899 and experimentally verified by P.N. Lebedev.

The very idea of using this effect for space flights was first put forward by F. A. Zander in 1924. He considered the designs of solar sails and laid the foundations for the theory of motion of spacecraft with a solar sail. F. A. Zander discussed his projects and proposals in a conversation with K. E. Tsiolkovsky.

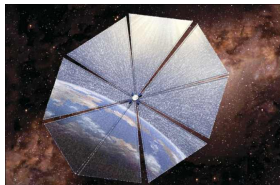
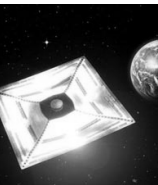


Formation of Forces and Moments of Light Pressure



If the solar sail is a mirror and reflects part of the rays, then the force will be directed almost normal to the plane of the sail element and create a moment of force relative to the center of mass of the spacecraft. This allows you to rotate the spacecraft around a certain axis and maintain a given rotation or position.

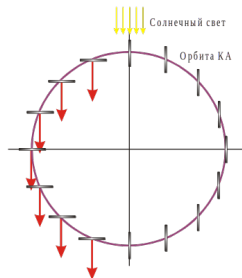
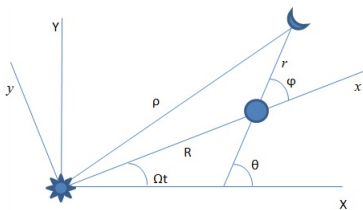
A Variety of Sail Models



This includes solid flat film sails, parachute sails, inflatable balloons, helicopter propeller-type sails, camomile or sunflower petal sails, honeycomb sails based on individual mirror elements and modules, or a system of transfer mirrors.

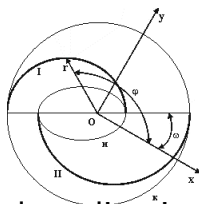
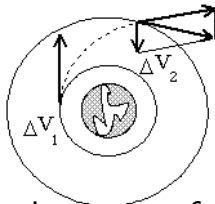
Equations of Motion

Perturbation-adjusted equations of motion can be presented in various forms based on models of the two- or three-body problem using convenient coordinate systems and basic parameters. When creating orbits near the Earth or for placing spacecraft at libration points, it is necessary to use a more general model of the three-body limited photogravity problem, which takes into account the motion of the main bodies and the direction of the light flux.

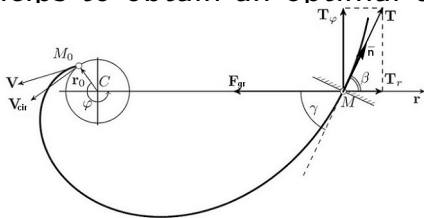


The development of methods and applications of theory to computing systems and algorithms for solving complex control problems allows us to obtain remarkable results in cosmic dynamics.

V.S.Novoselov's monograph "Analytical theory of optimization in gravitational fields" provides a general scheme for solving problems of optimizing the controlled motion of spacecraft. The results were presented in a report at the XXIV Congress of the International Federation of Astronautics. The initial approximation within the framework of the two-body problem gives a two-pulse transition between specified circular orbits or orbits with low eccentricity. Step-by-step refinement of the points of application of impulses allows you to take into account the effect of additional forces.



The development of methods and applications of theory to computing systems and algorithms for solving complex control problems allows us to obtain remarkable results in cosmic dynamics. The trajectory of the spacecraft under the influence of gravitational forces in the presence of a tangential component of the light pressure forces on the sails helps to obtain an optimal energy solution.



Problems and equations of motion I

It is worth noting the active efforts and successful results of Elena Nikolaevna Polyakhova in the formation of a special direction of the scientific school within the framework of cosmic dynamics to solve the problems of photogravitational celestial mechanics. The appearance of solar sails in spacecraft helps to organize the management and creation of optimal orbits for interplanetary flights and the stabilization of the space system and the stability of positions on trajectories.

Problems and equations of motion II

Perturbation-adjusted equations of motion can be presented in various forms based on models of the two- or three-body problem, using convenient coordinate systems and parameters of elements of spacecraft orbits. When creating launch or geostationary orbits near the Earth or to place a spacecraft at the libration point of the three-body problem, it is necessary to use a general model of the photogravitational limited three-body problem, which takes into account the movement of the main bodies and the relative direction of the luminous flux.

Problems and equations of motion III

A multitude of problems of cosmic dynamics to solve the problems of photogravitational celestial mechanics brought together colleagues of scientific teams. The research results have been published in print or reported at scientific conferences. The development of qualitative and computational methods or applications of theory to systems and algorithms for solving complex problems allows us to obtain new results in cosmic dynamics [1-12].

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Examples of printed publications in the list of references





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