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**Federal State Autonomous Educational Institution of Higher Education
Peoples' Friendship University of Russia named after Patrice Lumumba**

Academy of Engineering

(name of the main educational unit (MEU) that developed the educational program of higher education)

WORKING PROGRAM OF THE DISCIPLINE

SPACE FLIGHT MECHANICS

(name of discipline/module)

Recommended for the field of study/specialty:

27.03.04 CONTROL IN TECHNICAL SYSTEMS

(code and name of the field of study/specialty)

The discipline is mastered within the framework of the implementation of the main professional educational program of higher education (EP HE):

DATA SCIENCE AND SPACE SYSTEMS

(name (profile/specialization) of the educational institution of higher education)

1. THE GOAL OF MASTERING THE DISCIPLINE

The "Space Flight Mechanics" course is part of the "Data Science and Space Systems" bachelor's program, focusing on 27.03.04 "Control in Technical Systems." It is studied in semesters 3, 4, 5, 6, and 7 of years 2, 3, and 4. The course is offered by the Department of Mechanics and Control Processes. It consists of 12 sections and 56 topics and focuses on the theoretical foundations of spaceflight mechanics, spacecraft motion prediction, maneuvering theory, trajectory measurements, and interplanetary flights. Particular attention is paid to the analysis of methods for solving typical problems and their application in professional activities.

The purpose of mastering the discipline is to develop fundamental knowledge and skills in applying methods of spaceflight mechanics to solve problems in astronautics, which are necessary for professional activity and mastering subsequent disciplines.

2. REQUIREMENTS FOR THE RESULTS OF MASTERING THE DISCIPLINE

Mastering the discipline "Space Flight Mechanics" aimed at developing the following competencies (parts of competencies) in students:

Table 2.1. List of competencies developed in students while mastering the discipline (results of mastering the discipline)

Cipher	Competence	Indicators of Competency Achievement (within this discipline)
GPC-1	Able to analyze the tasks of professional activity based on provisions, laws and methods in the field of natural sciences and mathematics	GPC-1.1 Possesses basic knowledge obtained in the field of mathematical and (or) natural sciences; GPC-1.2 Able to use them in professional activities; GPC-1.3 Has the skills to select methods for solving problems of professional activity based on theoretical knowledge;
GPC-11	Able to understand the principles of operation of modern information technologies and use them to solve professional problems	GPC-11.1 Knows digital methods and technologies used in professional activities; GPC-11.2 Able to apply digital methods and technologies in professional activities to study and model objects of professional activity, analyze data, and present information; GPC-11.3 Confidently uses digital methods and technologies in professional activities (in the field of management in technical systems) for: studying and modeling objects of professional activity, data analysis, presentation of information;
GPC-2	Able to formulate objectives for professional activity based on knowledge of specialized sections of mathematical and natural science disciplines (modules)	GPC-2.1 Has a command of mathematical methods, programming fundamentals and specialized programming systems for implementing algorithms for solving applied problems; GPC-2.2 Able to select and adapt mathematical methods and software to solve practical problems; GPC-2.3 Possesses skills in developing and implementing algorithms for solving applied problems in the field of professional activity;
GPC-3	Able to use fundamental knowledge to solve basic control problems in technical systems in order to improve in professional activities	GPC-3.1 Knows the theoretical foundations and principles of mathematical modeling; GPC-3.2 Able to develop and use methods of mathematical modeling, information technologies to solve problems of applied mathematics; GPC-3.3 Possesses practical skills in solving problems of applied mathematics, methods of mathematical modeling, information technologies and the basics of their use in professional activities, skills of professional thinking and an arsenal of methods and approaches necessary for the adequate use of methods of modern mathematics in theoretical and applied problems;
GPC-6	Capable of developing and using algorithms and programs, mod-	GPC-6.1 Knows the basic algorithms and programs, modern information technologies, methods and means of control, diag-

Cipher	Competence	Indicators of Competency Achievement (within this discipline)
	ern information technologies, methods and means of control, diagnostics and management, suitable for practical application in the field of his professional activity	nostics and management, suitable for practical application in the field of his professional activity; GPC-6.2 Able to apply algorithms and programs, modern information technologies, methods and means of control, diagnostics and management, suitable for practical application in the field of his professional activity; GPC-6.3 Confidently uses algorithms and programs, modern information technologies, methods and means of control, diagnostics and management, suitable for practical application in the field of his professional activity;
PC-1	Capable of collecting, processing and interpreting modern scientific research data necessary to draw conclusions on relevant scientific research, including Earth remote sensing data	PC-1.1 Knows modern methods of collecting, processing and interpreting data from modern scientific research necessary for drawing conclusions on relevant scientific research; PC-1.2 Able to apply modern methods and tools for processing and interpreting scientific research data; PC-1.3 Possesses the basic skills of collecting, processing and interpreting data from modern scientific research, necessary for drawing conclusions on relevant scientific research;
PC-2	Capable of participating in the development of schematic documentation for the flight control system of launch vehicles and spacecraft, and in the preparation of publications based on the results of research and development	PC-2.1 Knows the basic approaches to the development of mathematical models of units, functional modules and devices for flight control systems of launch vehicles and spacecraft; PC-2.2 Able to compile analytical reviews and scientific and technical reports based on the results of research and development; PC-2.3 Has skills in designing functional units and blocks of flight control systems for launch vehicles and spacecraft;
PC-4	Able to formulate, analyze and solve engineering problems in the field of ballistics, motion mechanics and spacecraft motion control based on professional knowledge	PC-4.1 Knows the basic concepts and basic algorithms for solving problems in the field of ballistics, motion mechanics and motion control based on automated and automatic systems; PC-4.2 Able to solve engineering problems of an analytical nature in the field of ballistics, motion mechanics and spacecraft motion control based on professional knowledge; PC-4.3 Possesses skills in using mathematical methods for processing information obtained as a result of experimental studies, basic methods for analyzing the mechanics of motion and controlling the motion of spacecraft based on standard methods and software packages;

3. PLACE OF THE DISCIPLINE IN THE STRUCTURE OF THE EDUCATIONAL EDUCATIONAL INSTITUTION

Discipline "Space Flight Mechanics" refers to the mandatory part of block 1 "Disciplines (modules)" of the educational program of higher education.

As part of the higher education program, students also master other disciplines and/or practices that contribute to the achievement of the planned results of mastering the discipline "Space Flight Mechanics".

Table 3.1. List of components of the educational program of higher education that contribute to the achievement of the planned results of mastering the discipline

Cipher	Name of competence	Previous courses/modules, practical training*	Subsequent disciplines/modules, practices*
GPC-6	Capable of developing and using algorithms and programs, modern information technologies, methods and	Computer Science and Programming; Introduction to Computing Science;	Undergraduate Training;

Cipher	Name of competence	Previous courses/modules, practical training*	Subsequent disciplines/modules, practices*
	means of control, diagnostics and management, suitable for practical application in the field of his professional activity		
GPC-1	Able to analyze the tasks of professional activity based on provisions, laws and methods in the field of natural sciences and mathematics	Mathematical analysis; Algebra and Geometry; Physics;	Technological Training; Undergraduate Training;
GPC-2	Able to formulate objectives for professional activity based on knowledge of specialized sections of mathematical and natural science disciplines (modules)	Mathematical analysis; Algebra and Geometry;	Technological Training; Undergraduate Training;
GPC-3	Able to use fundamental knowledge to solve basic control problems in technical systems in order to improve in professional activities	Algebra and Geometry; Mathematical analysis;	Technological Training; Undergraduate Training;
GPC-11	Able to understand the principles of operation of modern information technologies and use them to solve professional problems		Undergraduate Training; Technological Training;
PC-1	Capable of collecting, processing and interpreting modern scientific research data necessary to draw conclusions on relevant scientific research, including Earth remote sensing data	Computer Science and Programming; Introduction to Computing Science;	Technological Training; Undergraduate Training;
PC-2	Capable of participating in the development of schematic documentation for the flight control system of launch vehicles and spacecraft, and in the preparation of publications based on the results of research and development		Undergraduate Training;
PC-4	Able to formulate, analyze and solve engineering problems in the field of ballistics, motion mechanics and spacecraft motion control based on professional knowledge		Technological Training; Undergraduate Training;

* - filled in accordance with the competency matrix and the SUP EP HE

** - elective courses/practices

4. SCOPE OF THE DISCIPLINE AND TYPES OF EDUCATIONAL WORK

The total workload of the “Space Flight Mechanics” course is 24 credits.

Table 4.1. Types of educational work by periods of mastering the educational program of higher education for full-time education.

Type of academic work	TOTAL,academic hours		Semester(s)				
			3	4	5	6	7
<i>Contact work, academic hours</i>	411		36	51	108	108	108
Lectures (LC)	160		18	34	36	36	36
Laboratory work (LW)	125		0	17	36	36	36
Practical/seminar classes (SC)	126		18	0	36	36	36
<i>Independent work of students, academic hours</i>	363		36	57	108	45	117
<i>Control (exam/test with assessment), academic hours</i>	90		0	0	36	27	27
Total complexity of the discipline	academic hours	864	72	108	252	180	252
	credit	24	2	3	7	5	7

The total workload of the “Space Flight Mechanics” course is 24 credits.

Table 4.2. Types of educational work by periods of mastering the educational program of higher education for full-time education.

Type of academic work	TOTAL,academic hours		Semester(s)				
			3	4	5	6	7
<i>Contact work, academic hours</i>	411		36	51	108	108	108
Lectures (LC)	160		18	34	36	36	36
Laboratory work (LW)	125		0	17	36	36	36
Practical/seminar classes (SC)	126		18	0	36	36	36
<i>Independent work of students, academic hours</i>	363		36	57	108	45	117
<i>Control (exam/test with assessment), academic hours</i>	90		0	0	36	27	27
Total complexity of the discipline	academic hours	864	72	108	252	180	252
	credit	24	2	3	7	5	7

The total workload of the “Space Flight Mechanics” course is 24 credits.

Table 4.3. Types of educational work by periods of mastering the educational program of higher education for full-time education.

Type of academic work	TOTAL,academic hours		Semester(s)				
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Contact work, academic hours	411		36	51	108	108	108
Lectures (LC)	160		18	34	36	36	36
Laboratory work (LW)	125		0	17	36	36	36
Practical/seminar classes (SC)	126		18	0	36	36	36
Independent work of students, academic hours	363		36	57	108	45	117
Control (exam/test with assessment), academic hours	90		0	0	36	27	27
Total complexity of the discipline	academic hours	864	72	108	252	180	252
	credit	24	2	3	7	5	7

5. CONTENT OF THE DISCIPLINE

Table 5.1. Content of the discipline (module) by types of academic work

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
Section 1	Introduction	1.1	Spaceflight mechanics in the structure of scientific and technical knowledge. Structure of the discipline. Application areas of spaceflight mechanics methods.	Definition of spaceflight mechanics as a branch of ballistics and celestial mechanics that studies the motion of spacecraft. Characteristics of the discipline's structure: center-of-mass dynamics, dynamics relative to the center-of-mass, ballistics, and astrodynamics. Description of the application areas of spaceflight mechanics methods: orbital insertion, motion prediction, orbital maneuvers, interplanetary transfers, attitude control, and space mission planning.	OK
		1.2	Dynamics of bodies of variable mass. Law of universal gravitation. Fundamental laws of mechanics.	Definition of a variable-mass body as an object whose mass changes over time due to the separation or addition of particles. Characterization of the Meshchersky equation for describing the motion of variable-mass bodies. Formulation of Newton's law of universal gravitation: the force of gravitational attraction is proportional to the product of the masses and inversely proportional to the square of the distance. Description of the fundamental laws of mechanics: the first law of inertia, the second law on the proportionality of force and acceleration, and the third law on the equality of action and reaction.	LC, SC
		1.3	Spherical trigonometry	Definition of spherical trigonometry as a branch of geometry that studies the relationships between the sides and angles of spherical triangles. Characterization of key formulas: the formula for the sides of a right-angled spherical triangle, the law of sines, and the law of cosines for a side and an angle. Description of the application of spherical trigonometry in spaceflight mechanics for calculating celestial coordinates, orientation angles, and spacecraft flight paths.	LC, LW
Section 2	Undisturbed motion of a spacecraft	2.1	Basic Concepts and Definitions. Equations of Motion in a Gravitational Field	Definition of unperturbed motion as the motion of a spacecraft under the influence of only the gravitational field of the central body. Description of key concepts: attracting center, radius vector, gravitational parameter, orbital plane. Characterization of the equations of motion in a gravitational field in vector form and in projections onto the coordinate axes. Derivation of the acceleration equation as the second derivative of the radius vector.	LC, SC

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
		2.2	Integrals of the equations of unperturbed motion	Definition of integrals of motion as quantities that remain constant over time. Characterization of three basic integrals: the energy integral of specific mechanical energy, the area integral of the angular momentum vector, and the Laplace integral of the eccentricity vector. Description of the physical meaning of each integral: constancy of energy determines the type of orbit, constancy of angular momentum ensures motion in a fixed plane.	LC, LW
		2.3	Trajectory equation. Types of orbits. Geometric characteristics of orbits.	Derivation of the trajectory equation in polar coordinates. Characteristics of orbital types depending on eccentricity: circle at zero eccentricity, ellipse at eccentricity from zero to one, parabola at eccentricity equal to one, hyperbola at eccentricity greater than one. Description of orbital geometric characteristics: focus, semi-major and semiminor axes, focal parameter, periapsis and apoapsis, and true anomaly.	LC, LW
		2.4	Kinematic parameters of movement	Definition of kinematic parameters as quantities characterizing the position and velocity of a spacecraft in space. Description of the radial and transverse components of velocity. Characteristics of the dependence of velocity on radius in an elliptical orbit. Formula for velocity at periapsis and apoapsis. Relationship of circular velocity and first cosmic velocity with the gravitational parameter and radius. Definition of parabolic velocity as second cosmic velocity.	LC, LW
		2.5	Kepler's equation	Definition of Kepler's equation as the fundamental equation of unperturbed elliptical motion. Statement of the equation: the mean anomaly is equal to the eccentric anomaly minus the product of the eccentricity and the sine of the eccentric anomaly. Description of the quantities: the mean anomaly increases uniformly over time, the eccentric anomaly is an auxiliary geometric parameter. Characteristics of methods for solving Kepler's equation: the method of successive approximations and the iterative method.	LC, SC
		2.6	Determination of Keplerian orbital elements from initial conditions of motion	Definition of Keplerian elements as a set of six parameters that uniquely define an orbit. Description of the elements: semi-major axis, eccentricity, inclination, longitude of the ascending node, argument of periapsis, and true anomaly at the initial instant. Characterization of the algorithm for determining the elements based on the initial radius vector and velocity vector. Calculation of the specific energy and angular momentum, followed by the semi-	LC, LW

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				major axis, eccentricity, and orbital orientation.	
		2.7	Determination of kinematic parameters of motion based on Keplerian orbital elements	Description of the inverse problem: calculating the position and velocity of a spacecraft at an arbitrary time using known Keplerian elements. Characteristic of the sequence of actions: solving the Kepler equation to find the eccentric anomaly, calculating the true anomaly and radius, calculating coordinates in the orbital plane, transforming to a heliocentric or geocentric coordinate system using rotation matrices. Calculating the velocity vector.	LC, LW
		2.8	Spacecraft flight path	Definition of a flight path as the projection of a spacecraft's orbit onto the surface of a rotating central body. Description of the effect of the Earth's daily rotation on the westward shift of the path with each orbit. Characterization of the orbital concept: path latitude and longitude, ascending and descending nodes. Description of the target path and landing corridor. Calculation of path repeatability for circular orbits.	LC, LW
		2.9	Determination of Keplerian orbital elements from two positions of the spacecraft	Formulation of the Gauss problem: determining the orbit given two positions of the radius vector and the time interval between them. Description of the Lambert method: the relationship of the flight time to the semi-major axis and chord of the trajectory. Characteristics of the iterative solution of the Lambert transcendental equation. Determining the ambiguity of the solution for elliptical orbits.	LC, SC
Section 3	Disturbed motion of the center of mass of a spacecraft	3.1	General characteristics of disturbances and basic methods for studying disturbed motion	Definition of disturbed motion as motion deviating from an undisturbed Keplerian trajectory under the influence of additional forces. Characteristics of the main disturbing forces: gravitational field non-centrality, atmospheric drag, gravitational attraction of other celestial bodies, radiation pressure, and relativistic effects. Description of the two main methods for studying disturbed motion: the osculating element method and the numerical integration method.	LC, SC
		3.2	Osculating Elements Method	Definition of osculating elements as instantaneous Keplerian elements that the spacecraft would have if the perturbations ceased at a given moment. Characterization of Lagrange differential equations for the change in osculating elements under the action of perturbing forces. Description of the right-hand sides of the equations as derivatives of the perturbing function with respect to or-	LC, LW

Section number	Name of the discipline section	Topic Title	Topic Contents	Type of academic work*
			bital elements. Advantages of the method: clarity and the possibility of analytical averaging.	
		3.3 Analysis of perturbed motion in near-circular orbits	Definition of a near-circular orbit as an orbit with eccentricity close to zero. Description of methods for linearizing the equations of perturbed motion for small eccentricities. Characterization of secular perturbations of the elements: slow drift of the longitude of the ascending node and the argument of periapsis under the influence of the Earth's oblateness. Description of short-period perturbations with an orbital period. Analysis of the evolution of the orbital shape and orientation.	LC, LW
		3.4 The influence of the non-centrality of the Earth's gravitational field	Description of the Earth's gravitational field using a spherical-function expansion of the geopotential. Characteristic of the fundamental disturbance from the second zonal harmonic J_2 , caused by the Earth's oblateness at the poles. Description of the effects: precession of the nodal line, rotation of the orbital plane around the Earth's axis, rotation of the apsidal line, and rotation of the orbit in its plane. Calculation of the diurnal nodal shift for sun-synchronous orbits.	LC, LW
		3.5 The influence of the Earth's atmosphere	Characterization of atmospheric drag as a dissipative force directed against the velocity vector. Description of the dependence of drag on atmospheric density, spacecraft velocity, and ballistic coefficient. The main effects of drag are: reduction of the semimajor axis, reduction of orbital altitude, reduction of eccentricity, circularization of the elliptical orbit, and reduction of the spacecraft's lifetime in low orbits.	LC, SC
		3.6 The influence of gravity of celestial bodies	Definition of perturbing acceleration as the difference between the accelerations due to the gravitational pull of a third body and the acceleration of the central body itself. Characterization of the influence of the Moon and the Sun as the main sources of gravitational perturbations for Earth satellites. Description of effects for high-orbit spacecraft: secular changes in eccentricity and inclination, resonance phenomena. Characterization of the sphere of action of gravity and the three-body problem.	LC, LW
		3.7 The influence of light pressure	Definition of radiation pressure as the force caused by the transfer of momentum from solar photons to the surface of a spacecraft. Characterization of the dependence of the force on surface area,	LC, LW

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				reflectivity, and solar radiation intensity. Description of the effects for large-area sail-type spacecraft and for geostationary satellites. Effect on orbit: periodic perturbations and long-term drift.	
Section 4	Dynamics of spacecraft motion relative to the center of mass	4.1	Moments of forces acting on a spacecraft	Definition of torque as a vector quantity characterizing the rotational effect of force. Description of the main sources of torque: gravitational torque due to the unevenness of the gravitational field, aerodynamic torque from interaction with the atmosphere, luminous torque from solar radiation pressure, internal torques from engine operation and the movement of moving parts.	LC, SC
		4.2	Differential equations of rotational motion of a spacecraft	Formulation of the fundamental equation of rotational dynamics: the moment of inertia multiplied by the angular acceleration is equal to the sum of the moments of external forces. Description of the use of the inertia tensor to characterize the distribution of mass relative to a coordinate system. Characterization of the Euler equations in projections onto the principal central axes of inertia. Description of the problem of controlling the angular position of an apparatus.	LC, LW
		4.3	Poisson's kinematic relations. Energy integral	Definition of Poisson's kinematic equations relating angular velocity to the time derivatives of direction cosines. Description of the relationship between angular velocity and kinematic parameters: Euler angles and quaternions. Characteristic of the advantage of using quaternions for numerical modeling of rotational motion: the absence of singularities. Definition of the energy integral.	LC, LW
		4.4	Energy integral. Relative equilibrium of a spacecraft. Stability of equilibrium.	Definition of relative equilibrium as a state in which a spacecraft maintains a constant orientation relative to the orbital coordinate system. Description of equilibrium positions under the action of gravitational torque: stable orientation of an elongated spacecraft along the local vertical. Characterization of the Lyapunov equilibrium stability criteria. Stability conditions for a dumbbell satellite model.	LC, LW
		4.5	Oscillation limits. Non-inversion conditions	Definition of oscillation limits as the maximum angles of deviation of the apparatus's axis from the equilibrium position under initial disturbances. Description of the phase portrait of rotational motion in coordinates of deviation angle and angular velocity. Characterization of the non-inversion condition as a limitation on the initial kinetic energy at which the apparatus performs librational	LC, LW

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				oscillations without a full rotation.	
		4.6	Methods of orientation and stabilization of spacecraft	Definition of attitude control as imparting a desired angular position to a spacecraft. Characterization of stabilization methods: passive stabilization (gravitational, magnetic, aerodynamic); active stabilization using flywheels, gyrodynes, and low-thrust jet engines. Description of three-axis orientation and spin stabilization. Comparison of energy consumption and accuracy of various methods.	LC, LW
Section 5	Orbital maneuvers in the central gravitational field	5.1	Basic principles of the theory of maneuvers	Definition of an orbital maneuver as a targeted change in the orbital parameters of a spacecraft using a propulsion system. Characterization of an impulse maneuver as an instantaneous change in the velocity vector at the point of impulse application. Description of the maneuver optimization problem to minimize the characteristic velocity of the total impulse. Determination of gravitational losses and engine efficiency.	LC, SC
		5.2	Transition maneuvers	Description of the simplest maneuver for transferring from one circular orbit to another coplanar circular orbit. Characteristic of the Hohmann-Zehnder elliptical transfer ellipse: minimum characteristic velocity loss at the optimal ratio of orbital radii. Calculation of two impulses: boost at periapsis and braking at apoapsis. Description of bi-elliptical transfers for large ratios of orbital radii.	LC, LW
		5.3	Meeting in coplanar orbits	Definition of the rendezvous task as the alignment of a spacecraft with a target object at a given point in space at a given time. Characterization of the phase angle and calculation of the dwell time between orbits. Description of the conic section method for flight planning with a given time. Optimization of impulses for rendezvous with the space station.	LC, LW
		5.4	Encounter in non-coplanar orbits	Description of the rendezvous task for spacecraft moving in different planes. Characterization of the need to change orbital inclination as the most energy-intensive maneuver. Calculation of the impulse for rotating the orbital plane at the nodal line. Optimal combination of maneuvers: changing inclination together with orbital shape adjustment. Use of a transfer through the ascending or descending node.	LC, SC
		5.5	Numerical methods for optimization and improving the accuracy of maneuver param-	A description of the need for numerical methods to account for disturbances and non-impulsive engine operation. A description of	LC, LW

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
			eters	the methods of variational calculus and Pontryagin's maximum principle for finding an optimal control program. The use of successive approximation and gradient methods. Improving maneuver accuracy through trajectory correction based on navigational measurements.	
		5.6	Maneuvering with an engine having limited constant thrust	Definition of a finite-thrust maneuver as a realistic scenario for propulsion system operation over a finite time interval. Description of differences from an impulsive maneuver: control losses, gravitational losses, and the need to account for changes in vehicle mass. Characteristics of spiral transfers between circular orbits. Optimization of the thrust vector direction to minimize flight time or fuel consumption.	LC, LW
Section 6	Coordinate systems	6.1	Celestial coordinate system. Heliocentric coordinate system	Definition of the celestial coordinate system as an inertial system with its origin at the center of the Sun or the barycenter of the Solar System. Description of the fundamental plane of the ecliptic, the plane of the Earth's orbit, and the direction to the vernal equinox. Characteristics of the heliocentric ecliptic coordinate system for describing the motion of planets and interplanetary spacecraft.	LC, LW
		6.2	Geocentric coordinate systems. Linked coordinate systems	Definition of a geocentric inertial coordinate system with the origin at the center of the Earth and axes oriented toward the fixed stars. Description of the terrestrial equatorial coordinate system associated with the rotating Earth. Characteristics of an orbital coordinate system: the X-axis is along the radius vector, the Z-axis is along the normal to the orbital plane, and the Y-axis complements the right-hand triad. Definition of a coherent coordinate system rigidly attached to the body of the spacecraft.	LC, SC
		6.3	Transition between coordinate systems	Description of the transition between coordinate systems using rotation matrices around the coordinate axes. Characterization of rotation matrices by an angle around the X, Y, and Z axes. Sequential transition from an inertial system to a geocentric system, then to an orbital system, and then to a constrained system using Euler angles. Accounting for the Earth's rotation when transitioning from inertial coordinates to geographic coordinates.	LC, LW
Section 7	Time scales	7.1	Solar, stellar and atomic time	Definition of true solar time as the time determined by the apparent motion of the Sun. Description of mean solar time as a uniform scale averaging the irregularities of true solar motion. Character-	LC, SC

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				ization of stellar time as the time measured by the Earth's rotation relative to the fixed stars. Definition of atomic time as the most uniform scale, based on the frequency of electromagnetic radiation from cesium atoms.	
		7.2	Dynamic and coordinated time	Definition of dynamic time as an argument in the equations of motion of celestial bodies in gravitational fields. Characterization of terrestrial dynamic time and barycentric dynamic time for problems in spaceflight mechanics. Description of Coordinated Universal Time as a compromise scale aligning atomic time with the Earth's rotation. Characterization of leap seconds.	LC, LW
		7.3	Transition between time scales	Description of the transition between stellar and solar time using a conversion factor. Formula for the relationship between mean solar time and stellar time at a given moment. Conversion from Coordinated Universal Time to atomic time, taking into account the accumulated difference. Use of time difference tables for converting observation times.	LC, SC
Section 8	Methods for predicting spacecraft motion	8.1	Forms of representation of the Earth's gravitational field	Description of the Earth's gravitational field through expansion of the gravitational potential in a series of spherical harmonics. Characterization of zonal, tesseral, and sectorial harmonics. Representation as Stokes coefficients and normalized coefficients. Use of geopotential models EGM96, EGM2008, and others for acceleration calculations.	LC, SC
		8.2	Mathematical modeling of disturbing forces	Description of the atmospheric drag model: density dependence on altitude in a standard atmosphere, accounting for the ballistic coefficient and drag coefficient. Modeling of the gravitational pull of the Moon and Sun through point masses. Modeling of radiation pressure taking into account shadowing by the Earth and reflected albedo. Characteristics of simplified and high-precision models for various tasks.	LC, SC
		8.3	Analytical methods for traffic forecasting	Definition of analytical methods as methods for deriving formulas for orbital elements as functions of time. Characterization of the averaging method for secular and long-period perturbations from short-period ones. Description of the Brauer and Kozai theory of satellite motion. Advantages of analytical methods: speed and clarity; disadvantages: limited accuracy for low orbits.	LC, LW
		8.4	Representation of the right-hand sides of the	Description of the transition from equations of motion in Cartesian	LC, LW

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
			equations of motion as functions of orbital elements	coordinates to equations for Keplerian elements. Expression of disturbing accelerations through derivatives of the disturbing function with respect to the elements. Characteristics of the Lagrange and Gauss equations. Description of the application features for small eccentricities and inclinations.	
		8.5	Numerical methods for motion prediction	Definition of numerical methods as methods for directly integrating differential equations of motion. Characteristics of single-step methods: the fourth-order Runge-Kutta method, the Runge-Kutta-Felberg method with automatic step selection. Description of the multi-step Adams-Bashforth-Multon methods. Characteristics of the high-accuracy requirement for long-term forecasting.	LC, LW
		8.6	Methods of the theory of special perturbations in problems of spacecraft dynamics	Definition of special perturbations as methods using numerical integration for a specific initial state. Characteristic of the Encke method: integration of deviations from a reference unperturbed orbit. Cowell's method: direct integration of the full equations of motion. Comparison of the effectiveness of the methods depending on the magnitude of the perturbations and the required accuracy.	LC, LW
Section 9	Determination of spacecraft motion parameters based on trajectory measurements	9.1	Characteristics and classification of measurements. Transformation of measurement information.	Description of the classification of trajectory measurements by the type of measured value: range, radial velocity, angular coordinates. Characteristics of ground-based and airborne measuring instruments. Conversion of measurement information: conversion from measured values to coordinates and velocity. Accounting for systematic and random measurement errors.	LC, SC
		9.2	Lambert's problem	Formulation of the Lambert problem: determining an orbit from two positions and the transfer time between them. Description of the Lambert equation, which relates the transfer time to the semi-major axis and the sum of the distances to the attracting center. Characteristics of iterative solution methods. Application of the Lambert problem to ballistic design of interplanetary flights and rendezvous.	LC, LW
		9.3	Least squares method	Definition of the least-squares method as a method for statistically processing redundant measurements to find the most probable motion parameters. Description of minimizing the sum of squared residuals between measured and calculated values. Characteristics of the linear and nonlinear least-squares method. Application to improving orbital parameters based on trajectory measurement	LC, LW

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				data.	
		9.4	Kalman filters	Definition of the Kalman filter as a recursive algorithm for optimally estimating the state of a dynamic system from noisy measurements. Description of the two filter stages: prediction and correction. Characterization of the error covariance matrix and Kalman gain. Application of Kalman filters for real-time spacecraft navigation during rendezvous and landing.	LC, LW
Section 10	Dynamics of launching a spacecraft into near-Earth orbit	10.1	Launch coordinate systems. Determining the optimal launch time	Description of launch coordinate systems: geocentric launch system, topocentric system with the origin at the launch point. Characterization of the effect of Earth's rotation on the initial launch velocity of the spacecraft. Determining the optimal launch time for insertion into a given orbit: taking into account the position of the orbital plane and the need to hit the launch window. Calculating the launch azimuth.	LC, SC
		10.2	Rocket engines. Forces and moments acting on the launch vehicle	Characteristics of rocket engines as reactive engines. Description of engine thrust as the reactive force of exhaust gases. List of forces acting on a launch vehicle: engine thrust, gravity, aerodynamic lift, and drag. Description of control moments from rotation of combustion chambers, gas rudders, and lattice rudders.	LC, LW
		10.3	Mathematical modeling of launch vehicle motion	Description of the system of differential equations for the launch vehicle's center of mass in the launch coordinate system. Equation for mass change and fuel consumption per second. Simulation of the atmospheric portion of the flight, taking into account changes in air density and dynamic pressure. Flight program description: gravity turn, stage shutdown, insertion into reference orbit.	LC, LW
Section 11	Dynamics of the spacecraft's descent to Earth	11.1	General Descent Scheme. Descent Trajectory Requirements	Description of the general descent scheme: propulsion braking for deorbit, atmospheric entry, aerodynamic braking, parachuting, or soft landing. Descent trajectory requirements: crew and equipment overload limits, thermal protection heat flux limits, and landing accuracy specifications. Description of ballistic and gliding descents.	LC, LW
		11.2	Mathematical modeling of the motion of a descent vehicle in the atmosphere	Description of the equations of motion for a descent vehicle in the atmosphere, taking into account gravity, aerodynamic forces, and control effects. Characterization of aerodynamic coefficients: drag coefficient and lift coefficient. Modeling of heat fluxes depending on speed and altitude. Calculation of the trajectory up to the mo-	LC, SC

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				ment of parachute deployment.	
Section 12	Interplanetary flights	12.1	Methods for calculating sections of interplanetary trajectories	Description of methods for calculating interplanetary trajectories as a sequence of heliocentric sections and sections within the planetary spheres of influence. Characteristics of the conic section method: partitioning the trajectory into Keplerian arcs. Description of the method for stitching conic sections using hyperbolic velocities of entry and exit from the planetary spheres of influence. Accounting for gravity assist maneuvers in the planetary fields.	SC
		12.2	Interplanetary spacecraft flight patterns. Launch windows.	Characteristics of direct flights from Earth to the target planet. Description of gravity assist maneuvers at intermediate planets to increase energy or change the orbital plane. Definition of the launch window as the time interval during which the flight requires a minimum characteristic velocity. Calculation of the heliocentric angular positions of the planets at the time of launch.	LC, LW
		12.3	Mathematical modeling of interplanetary spacecraft motion	Description of the equations of motion for an interplanetary spacecraft in a heliocentric coordinate system, taking into account the gravitational pull of the Sun, planets, and disturbing forces. Characteristics of the calculation of maneuvers and stage ejections. Modeling of trajectory corrections during the flight. Description of the calculation of the planet's gravitational field during approach and transfer to the orbit of an artificial satellite.	LC, LW
		12.4	Optimization of interplanetary trajectories	Defining the interplanetary trajectory optimization problem as finding the minimum characteristic velocity consumption or minimum flight time. Characterizing global optimization methods: enumerating possible launch dates and flight durations. Describing the use of gravity assist maneuvers and impulses to reduce energy consumption. Characterizing numerical optimization methods: sequential quadratic programming, genetic algorithms.	LC, LW

* - to be completed only for FULL-TIME education: LC – lectures; LW – laboratory work; SC – practical/seminar classes.

6. LOGISTIC AND TECHNICAL SUPPORT OF DISCIPLINE

Table 6.1. Material and technical support for the discipline

Audience type	Equipment of the auditorium	Specialized educational/laboratory equipment, software and materials for mastering the discipline (if necessary)
Lecture	A lecture hall equipped with specialized furniture, a whiteboard (screen), and multimedia presentation equipment.	
Computer class	A computer room for conducting classes, group and individual consultations, ongoing monitoring and midterm assessment, equipped with personal computers (14 in total), a board (screen) and technical means for multimedia presentations.	
Seminar	An auditorium for conducting seminar-type classes, group and individual consultations, ongoing monitoring and midterm assessment, equipped with a set of specialized furniture and technical means for multimedia presentations.	
For independent work	A classroom for independent student work (can be used for seminars and consultations), equipped with a set of specialized furniture and computers with access to the Electronic Information System.	

* - the classroom for independent work of students MUST be indicated!

7. EDUCATIONAL, METHODOLOGICAL AND INFORMATIONAL SUPPORT OF THE DISCIPLINE

Main literature:

1. Vlasov S.A., Kulvits A.V., Skripnikov A.N. Spacecraft flight theory: textbook. – St. Petersburg: A.F. Mozhasky Space Academy, 2018 – 412 p.
2. Averkiev N.F., Vlasov S.A., Bogachev S.A., Zhatkin A.T., Kulvits A.V. Ballistic principles of designing launch vehicles and satellite systems: textbook. – St. Petersburg: A.F. Mozhaisky Air Defense Academy, 2017. – 300 p.
3. Baranov A.A. Maneuvering of spacecraft in the vicinity of a circular orbit. – M.: Publishing house “Sputnik+”, 2016 – 512 p.
4. Bordovitsyna T.V., Avdyushev V.A. Theory of motion of artificial Earth satellites. Analytical and numerical methods: a tutorial. – Tomsk: Publishing house of Tomsk. University, 2007 – 178 p.
5. N.M. Ivanov, L.N. Lysenko. Ballistics and navigation of spacecraft. — M.: Publishing house of MSTU im. N. E. Bauman, 2016 - 524 p.

Further reading:

1. DA Vallado. Fundamentals of Astrodynamics and Applications. 4th ed. - USA, Hawthorne: Microcosm Press, 2013 - 1135 p. ISBN 13: 9781881883180. ISBN 10: 1881883183
2. O. Montenbruck, E. Gill. Satellite Orbits: Models, Methods and Applications. - Ger-

many, Berlin: Springer, 2000 - 371 p. ISBN 978-3-540-67280-7

3. Ts.V. Soloviev, E.V. Tarasov. Forecasting of interplanetary flights. - M: "Mashinostroenie", 1973 - 401 p.

4. M.B. Balk, V.G. Demin, A.L. Kunitsyn. Collection of problems in celestial mechanics and cosmodynamics. Moscow: Nauka, 1972 - 336 p.

Resources of the information and telecommunications network "Internet":

1. RUDN University Electronic Library System and third-party electronic library systems to which university students have access based on concluded agreements

- Electronic library system of RUDN - ELS RUDN

<http://lib.rudn.ru/MegaPro/Web>

- Electronic Library System "University Library Online" <http://www.biblioclub.ru>

- EBS Yurayt <http://www.biblio-online.ru>

- Electronic Library System "Student Consultant" www.studentlibrary.ru

- Electronic Library System "Troitsky Bridge"

2. Databases and search engines

- electronic fund of legal and regulatory documentation <http://docs.cntd.ru/>

- Yandex search engine <https://www.yandex.ru/>

- Google search engine <https://www.google.ru/>

- SCOPUS abstract database <http://www.elsevierscience.ru/products/scopus/>

Educational and methodological materials for independent work of students in mastering a discipline/module:*

1. Lecture course on the subject "Space Flight Mechanics".

* - all teaching and methodological materials for independent work of students are posted in accordance with the current procedure on the discipline page in TUIS!

DEVELOPER:

Senior Lecturer

Position, DEPARTMENT

Signature

Morozova Tatyana

Anatolyevna

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HEAD OF THE DEPARTMENT:

Head of Department

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