**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

**INFORMATION TECHNOLOGY IN MATHEMATICAL MODELLING**
(name of discipline/module)

**Recommended for the field of study/specialty:**

**27.04.04 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):**

**Artificial Intelligence, Machine Learning, and Space Science**
(name (profile/specialization) of the educational institution of higher education)

**2026**

## 1. THE GOAL OF MASTERING THE DISCIPLINE

The course "Information Technology in Mathematical Modelling" is part of the Master's program "Artificial Intelligence, Machine Learning, and Space Sciences" in the 27.04.04 "Control in Technical Systems" program and is studied in the first semester of the first year. The course is offered by the Department of Mechanics and Control Processes. It consists of 6 sections and 27 topics and focuses on the fundamental principles of modeling physical processes and phenomena, computational methods used in solving physics problems and processing experimental data, methods for optimally implementing experiments on a computer, and estimating the error in the results of calculations. Students also explore the main methods for solving typical problems and their application in professional activities.

The purpose of mastering this course is to develop fundamental knowledge and skills in applying problem-solving methods necessary for professional activity, practical skills in programming basic mathematical algorithms used in modeling physical phenomena, and to improve the overall level of digital literacy among students.

## 2. REQUIREMENTS FOR THE RESULTS OF MASTERING THE DISCIPLINE

Mastering the course "Information Technologies in Mathematical Modeling" 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) |
|---|---|---|
| UC-7 | Able to search for relevant sources of information and data, perceive, analyze, memorize, and transmit information using digital tools, as well as algorithms when working with data obtained from various sources in order to effectively use the information obtained to solve problems; evaluate information, its reliability, and draw logical conclusions based on incoming information and data | UC-7.1 Searches for the necessary sources of information and data, perceives, analyzes, remembers and transmits information using digital means, as well as with the help of algorithms when working with data obtained from various sources in order to effectively use the information received to solve problems;<br>UC-7.2 Conducts an assessment of information, its reliability, builds logical conclusions based on incoming information and data;<br>UC-7.3 Has a command of modern digital technologies, methods of searching, processing, analyzing, storing and presenting information (in the field of management in technical systems) in the context of the digital economy and modern corporate information culture.; |
| GPC-1 | Able to analyze and identify the natural scientific essence of control problems in technical systems based on provisions, laws and methods in the field of natural sciences and mathematics | GPC-1.1 Knows the basic laws, provisions and methods in the field of natural sciences and mathematics;<br>GPC-1.2 Able to identify the natural scientific essence of control problems in technical systems guided by the laws and methods of natural sciences and mathematics;<br>GPC-1.3 Proficient in tools for analyzing control problems in technical systems. |
| GPC-2 | Able to formulate control problems in technical systems and justify methods for solving them | GPC-2.1 Knows the basic methods of solving control problems in technical systems;<br>GPC-2.2 Able to justify methods for solving control problems in technical systems;<br>GPC-2.3 Proficient in methods of setting control problems in technical systems. |
| PC-2 | Able to apply modern theoretical and experimental methods for developing mathematical models of objects and processes under study in the field of aerospace systems management | PC-2.1 Knows modern theoretical and experimental methods used to develop mathematical models of studied objects and processes of professional activity;<br>PC-2.2 Able to determine the effectiveness of the methods used to develop mathematical models of the objects and processes under study; |

| Cipher | Competence | Indicators of Competency Achievement (within this discipline) |
|---|---|---|
| | | PC-2.3 Has mastered modern theoretical and experimental methods for developing mathematical models of objects and processes of professional activity in the field of study. |

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

Discipline "Information technologies in mathematical modeling" 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 "Information Technologies in Mathematical Modeling".

*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* |
|---|---|---|---|
| UC-7 | Able to search for relevant sources of information and data, perceive, analyze, memorize, and transmit information using digital tools, as well as algorithms when working with data obtained from various sources in order to effectively use the information obtained to solve problems; evaluate information, its reliability, and draw logical conclusions based on incoming information and data | | *Artificial Neural Networks (Reinforcement Learning)***; *Artificial Neural Networks (Reinforcement Learning)***; Web application development and security; Research work / Scientific research work; Undergraduate Training; |
| GPC-1 | Able to analyze and identify the natural scientific essence of control problems in technical systems based on provisions, laws and methods in the field of natural sciences and mathematics | | *Undergraduate Training; Geoinformation Systems and Applications; Advanced Methods of Space Flight Mechanics; Advanced Methods of Earth Remote Sensing;* |
| GPC-2 | Able to formulate control problems in technical systems and justify methods for solving them | | *Dynamics and Control of Space Systems; Undergraduate Training;* |
| PC-2 | Able to apply modern theoretical and experimental methods for developing mathematical models of objects and processes under study in the field of aerospace systems management | | *Research work / Scientific research work; Undergraduate Training; Dynamics and Control of Space Systems; Artificial Neural Networks (Deep Learning)**; Artificial Neural Networks (Deep Learning)**; Advanced Methods of Space Flight Mechanics;* |

| Cipher | Name of competence | Previous courses/modules, practical training* | Subsequent disciplines/modules, practices* |
| --- | --- | --- | --- |
| | | | *Artificial Neural Networks (Reinforcement Learning)**; Geoinformation Systems and Applications;* |

* - 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 discipline “Information technologies in mathematical modeling” is 3 credit units.

*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) |
|---|---|---|---|
| | | | **1** |
| *Contact work, academic hours* | *34* | | *34* |
| Lectures (LC) | 17 | | 17 |
| Laboratory work (LW) | 0 | | 0 |
| Practical/seminar classes (SC) | 17 | | 17 |
| *Independent work of students, academic hours* | *47* | | *47* |
| *Control (exam/test with assessment), academic hours* | *27* | | *27* |
| **Total complexity of the discipline** | **academic hours** | ***108*** | *108* |
| | **credit** | ***3*** | *3* |

## 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 | Interpolation and approximation. | 1.1 | Basic concepts of the theory of approximate calculations | Approximate computation theory is a branch of mathematics that studies methods for finding approximate solutions to problems in the absence of exact analytical solutions. Calculation error: absolute and relative error. Sources of error: initial data, method, rounding. Bit depth and machine precision in computer calculations. | LC, SC |
| | | 1.2 | Methods of approximate solution of computational problems | Direct methods yield an exact solution in a finite number of steps without rounding. Iterative methods construct a sequence of approximations converging to the exact solution. The choice of method depends on the problem size, required accuracy, and computational resources. Robustness of a method is defined as the negligible impact of input data errors on the result. | LC, SC |
| | | 1.3 | Gaussian Method. Matrix inversion using Gaussian method. Sweep method | The Gauss method as a direct method for solving systems of linear algebraic equations with successive elimination of unknowns. The forward approach of the Gauss method for reducing a matrix to triangular form. The backward approach for successive determination of unknowns. Matrix inversion using the Gauss method by simultaneously solving several systems with the identity matrix on the right-hand side. The sweep method as a specialized method for solving systems with a tridiagonal matrix, arising in finite-difference approximation of boundary value problems. | LC, SC |
| Section 2 | Solving equations | 2.1 | Iterative methods for solving nonlinear equations. Newton's method | A nonlinear equation as a problem of finding the root of a function of one variable. Iterative methods involving constructing a sequence of approximations converging to the root. Newton's method as a tangent method using the derivative of the function to accelerate convergence. Geometric interpretation: constructing a tangent to the graph of a function and finding its intersection with the x-axis. Quadratic rate of convergence of Newton's method near the root. | LC, SC |
| | | 2.2 | The method of simple iteration and contraction mappings. Interpolation and approximation by polynomials | The simple iteration method is the reduction of an equation to the form $x = \varphi(x)$ followed by repeated application of the function $\varphi$. Convergence condition: the function $\varphi$ must be a contraction mapping in the neighborhood of the root. Interpolation is the exact | LC, SC |

| Section number | Name of the discipline section | Topic Title | | Topic Contents | Type of academic work* |
|---|---|---|---|---|---|
| | | | | passage of a function through given points. Approximation is an approximate description of data by a simpler function. Polynomial interpolation and approximation are the choice of a polynomial of the appropriate degree. | |
| | | 2.3 | Statements of simple interpolation problems. Lagrange interpolation polynomial | Interpolation as the recovery of a function from its values at discrete nodes. Problem statement: for given argument-value pairs, find a polynomial of minimum degree passing through all points. The Lagrange interpolation polynomial is explicitly expressed as a sum of basis polynomials, each equal to one at its node and zero at all others. Application of the Lagrange polynomial to non-equidistant interpolation nodes. | LC, SC |
| | | 2.4 | Newton's interpolation polynomial for unequal intervals | The Newton polynomial as an alternative form of interpolation polynomial, convenient for sequentially adding nodes. Divided differences as an analog of derivatives for discrete data. Constructing a Newton polynomial using divided differences of first, second, and higher orders. The advantage of the Newton form over the Lagrange form when increasing the number of nodes without recalculating all coefficients. | LC, SC |
| | | 2.5 | Finite differences and Newton interpolation polynomials for equidistant nodes | Finite differences as differences between adjacent function values with uniform argument spacing. First-order, second-order, and so on differences. Newton interpolation polynomials for equally spaced nodes using finite differences. Newton's first interpolation formula for forward interpolation is at the beginning of the table. Newton's second interpolation formula for backward interpolation is at the end of the table. | LC, SC |
| Section 3 | Solving systems of equations | 3.1 | Elements of numerical integration | Numerical integration as an approximate calculation of a definite integral based on the values of the integrand at individual points. Quadrature formulas as approximations of the integral by a weighted sum of the function values at the nodes. The need for numerical integration when an antiderivative is missing in elementary functions or when the function is specified in a table. The error of quadrature formulas and its dependence on the integration step. | LC, SC |
| | | 3.2 | Newton-Cotes quadrature formulas and their special cases | Newton-Cotes quadrature formulas as a family of integration methods with uniformly spaced nodes. Replacing the integrand with an interpolation polynomial and integrating it exactly. Special cases: | LC, SC |

| Section number | Name of the discipline section | Topic Title | | Topic Contents | Type of academi c work* |
|---|---|---|---|---|---|
| | | | | the rectangle formula using one node, the trapezoidal formula with two nodes, and Simpson's formula with three nodes. The order of accuracy of each formula is expressed as the degree of the exactly integrable polynomial. | |
| | | 3.3 | The quadrature formula of a trapezoid. The geometric meaning of a trapezoid. | The trapezoidal formula as an approximation of the integral by the area of the trapezoid formed by the segment connecting the function values at the endpoints of the interval. Geometric meaning: replacing the curvilinear trapezoid under the function graph with a regular trapezoid. Compound trapezoidal formula with division of the integration interval into many smaller segments. The error in the trapezoidal formula is proportional to the square of the step. | LC, SC |
| | | 3.4 | Simpson's quadrature formula | Simpson's formula as an integration method using a parabolic approximation of the integrand on each three-point interval. Geometric interpretation: replacing a curve segment with a parabolic arc. Composite Simpson's formula with a partition of the interval into an even number of segments. The error in Simpson's formula is proportional to the fourth power of the step, making it more accurate than the trapezoidal rule for smooth functions. | LC, SC |
| Section 4 | Solving differential equations | 4.1 | Elements of numerical solution of differential equations. | Numerical solution of differential equations as an approximate solution of a function based on its derivatives at discrete points. Reduction of a continuous problem to a finite system of algebraic equations. Classification of methods: single-step and multi-step, explicit and implicit. The Cauchy problem as finding a solution under given initial conditions. | LC, SC |
| | | 4.2 | Difference approximation of differential operators. First-order accuracy method | Difference approximation as a replacement of derivatives with finite-difference relations. Approximation of the first derivative using forward, backward, and central differences. Euler's method as the simplest one-step, first-order accurate method for solving the Cauchy problem. The formula for Euler's method is: the value at the next point is equal to the value at the current point plus the product of the step and the derivative. The error of Euler's method is proportional to the first power of the step. | LC, SC |
| | | 4.3 | Methods for solving ordinary differential equations. Second-order methods | Second-order methods with error proportional to the square of the step. A modified Euler method with derivative calculation at mid-step. Heun's method as a two-stage predictor-corrector method. Improved accuracy compared to Euler's method with a slight in- | LC, SC |

| Section number | Name of the discipline section | Topic Title | | Topic Contents | Type of academic work* |
|---|---|---|---|---|---|
| | | | | crease in computational costs. | |
| | | 4.4 | Methods for solving ordinary differential equations. Fourth-order methods | The classical fourth-order Runge-Kutta method is the most common method for solving the Cauchy problem. Four coefficients are calculated at each step: at the beginning of the step, twice in the middle, and at the end. The resulting formula is a weighted sum of the coefficients with weights of one-sixth, one-third, one-third, and one-sixth. The error of the method is proportional to the fourth power of the step. This represents a tradeoff between computational costs and high accuracy. | LC, SC |
| Section 5 | Information models in physics | 5.1 | Boundary Value Problems. Variational-Difference Schemes for Boundary Value Problems | Boundary value problems as problems for differential equations with conditions at the boundaries of the computational domain. Distinction from the Cauchy problem: the conditions are specified not at a single point, but at the edges of an interval. Variational-difference schemes as a method for constructing discrete models based on minimizing the energy functional. Reduction of a boundary value problem to a system of linear algebraic equations with a tridiagonal matrix. | LC, SC |
| | | 5.2 | Grid approximation. Euler's method for a system of equations | Grid approximation as a replacement of a continuous domain with a discrete set of grid nodes. Uniform and non-uniform grids depending on the nature of the solution. Euler's method for a system of first-order ordinary differential equations. Coordinate-wise application of Euler's method to each equation in the system. Application to modeling the dynamics of physical systems. | LC, SC |
| | | 5.3 | Error and stability of Euler's method. Elements of numerical differentiation | The local error of the Euler method at a single step is proportional to the square of the step. The global error, accumulating over all steps, is proportional to the first power of the step. The stability of the Euler method as a limitation on the step size when solving stiff systems of differential equations. Elements of numerical differentiation as the calculation of derivatives from tabular data. The sensitivity of numerical differentiation to errors in the initial data. | LC, SC |
| | | 5.4 | Formula for numerical differentiation for unequal nodes | Numerical differentiation for arbitrary node placement without uniform spacing. Using interpolation polynomials to obtain derivative formulas. Formulas for the first derivative using divided differences. Formulas for the second derivative. Error increases with node clustering due to the Runge effect. | LC, SC |
| | | 5.5 | Total error in numerical differentiation. Least | The total error of numerical differentiation is the sum of the | LC, SC |

| Section number | Name of the discipline section | Topic Title | | Topic Contents | Type of academic work* |
|---|---|---|---|---|---|
| | | | squares method | method error and the input data error. A tradeoff in step size selection: decreasing the step size reduces the method error but increases the impact of roundoff errors in the data. The least-squares method is used to approximate noisy data with a smooth function followed by analytical differentiation. Data smoothing is used to reduce the impact of random errors before differentiation. | |
| | | 5.6 | Elements of Operations Research Theory | Operations research theory as a scientific discipline concerned with optimal decision-making in complex systems. Key areas: linear, nonlinear, and dynamic programming, game theory, and queuing theory. A mathematical model of an operation as a set of controlled variables, an objective function, and constraints. Application of operations research theory to problems of management, planning, and resource allocation. | LC, SC |
| Section 6 | The concept of computer modeling | 6.1 | Mathematical programming. Elements of linear programming | Mathematical programming as a branch of optimization that studies methods for finding the extremum of a function under constraints. Linear programming as a special case with a linear objective function and linear constraints. The feasible solution domain is considered a convex polyhedron in the space of variables. Applied linear programming problems: production plan optimization, transportation problems, and mixture problems. | LC, SC |
| | | 6.2 | Canonical linear programming problem | Canonical form of a linear programming problem: maximization or minimization of a linear objective function subject to equality constraints and non-negativity of variables. Reduction of an arbitrary problem to canonical form by adding additional variables for inequalities. Basic and free variables in canonical form. A feasible basic solution as a corner point of a feasible polyhedron. | LC, SC |
| | | 6.3 | The geometric meaning of a system of linear inequalities. The geometric meaning of a two-dimensional linear programming problem. | A system of linear inequalities as the intersection of half-planes in two-dimensional space. A feasible polyhedron as a convex region bounded by straight lines. The level lines of the objective function as a family of parallel lines. A geometric solution to a two-dimensional problem: moving the level line toward the optimum until it touches a corner point of the polyhedron. The optimum is always reached at one of the vertices of the polyhedron. | LC, SC |
| | | 6.4 | The Idea of the Simplex Method. Simplex Tables. Geometric Characteristics in Linear Programming Problems and Methods. | The simplex method as an algorithm for sequentially searching through the corner points of a feasible polyhedron to improve the objective function. An initial feasible basis solution. Selecting the | LC, SC |

| Section number | Name of the discipline section | Topic Title | | Topic Contents | Type of academic work* |
|---|---|---|---|---|---|
| | | | Mutually Dual Linear Programming Problems. | variable introduced into the basis based on the largest positive estimate. Selecting the variable derived from the basis based on the minimum simplex relation. Simplex tables as a form of computing organization. Geometric characteristics of linear programming problems: the dimension of the variable space, the number of constraints. Mutually dual linear programming problems: each original problem has a corresponding dual problem, and the optima of both problems coincide. | |
| | | 6.5 | Elements of Nonlinear Programming. The Method of Undefined Lagrange Multipliers | Nonlinear programming as optimization problems with a nonlinear objective function or nonlinear constraints. Solution complexity increases due to the possible presence of multiple local extrema. The method of undetermined Lagrange multipliers for solving problems with equality constraints. Constructing the Lagrange function as the sum of the objective function and the products of the multipliers and constraints. Equating the partial derivatives of the Lagrange function to zero to obtain the necessary extremum conditions. | LC, SC |

* - 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. | |
| 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. Ilyina V.A. Silaev P.K. Numerical methods for theoretical physicists (part 1,2) RHD, 2003, 2004.
2. Amosov A.A., Dubinsky Yu.A., Kopchenova N.V. Computational methods for engineers. "Moscow Energy Institute" 2003. − 595s
3. Malinetsky G.G. Mathematical foundations of synergetics. Chaos, structures, computational experiment. Edition 4. Series: Synergetics: from past to future. URSS Editorial 2005. - 312 p.
4. Gmurman V.E. Elements of approximate calculations. Higher School: 2005. − 93 p.

*Further reading:*

1. Fedorenko R.P. Introduction to Computational Physics. - M.: Publishing house Mosk. Phys.-Techn. Institute, 1994. − 528 p.
2. Heerman D.V. Methods of computer experiment in theoretical physics. - M.: Nauka, 1990. - 176 p.
3. Bursian E.V. Physics. 100 problems to solve on a computer. - St. Petersburg: MiM, 1997.
4. Tyurin Yu.N. Data analysis on a computer / Yu.N. Tyurin, A.A. Makarov. - M.: Finance and Statistics, 1995.

*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 "Information technologies in mathematical modeling".

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

**DEVELOPERS:**

| | | |
|---|---|---|
| Associate Professor | | Saltykova Olga Alexandrovna |
| *Position, DEPARTMENT* | *Signature* | *Surname I.O.* |
| Associate Professor | | Demidov Alexander Sergeevich |
| *Position, DEPARTMENT* | *Signature* | *Last name I.O.* |

**HEAD OF THE DEPARTMENT:**

| | | |
|---|---|---|
| Head of Department | | Razumny Yuri Nikolaevich |
| *Position of the DEPARTMENT* | *Signature* | *Surname I.O.* |

**HEAD OF THE EP HE:**

| | | |
|---|---|---|
| Professor | | Razumny Yuri Nikolaevich |
| *Position, DEPARTMENT* | *Signature* | *Surname I.O.* |