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ФИО: Ястребов Олег Александрович
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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

MODELING AND VALIDATION

(name of discipline/module)

Recommended for the field of study/specialty:

01.04.02 APPLIED MATHEMATICS AND INFORMATICS

(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):

SPACE MISSION AND SYSTEM DESIGN

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

1. THE GOAL OF MASTERING THE DISCIPLINE

The course "Modeling and Validation" is part of the Master's program "Space mission and system design" in the major 01.04.02 "Applied Mathematics and Informatics" and is studied in the first semester of the first year. The course is offered by the department of the partner university. It consists of three sections and 13 topics and focuses on the fundamental principles of deterministic systems, system identification, and stochastic systems; analysis of the main methods for solving typical problems; and familiarization with their application in professional activities.

The goal of mastering the discipline is the formation of fundamental knowledge and skills in applying problem solving methods necessary for professional activities, increasing the general level of literacy of students in the discipline Modeling and Validation.

2. REQUIREMENTS FOR THE RESULTS OF MASTERING THE DISCIPLINE

Mastering the discipline "Modeling and Validation" 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; UC-7.2 Conducts an assessment of information, its reliability, builds logical conclusions based on incoming information and data.;
PC-1	Able to formulate goals and objectives of scientific research in the field of applied mathematics and computer science, computer technology and modern programming technologies, and select methods and means for solving problems	PC-1.1 Possesses fundamental knowledge obtained in the field of mathematical and (or) natural sciences, programming and information technology; PC-1.2 Able to find, formulate and solve standard problems in his own research activities in the field of applied mathematics and computer science, computer technology and modern programming technologies; PC-1.3 Has practical experience in research activities in the field of applied mathematics and computer science, computer engineering and modern programming technologies.;
PC-2	Able to apply modern theoretical and experimental methods for developing mathematical models of objects and processes under study related to professional activities in the field of training and participate in their implementation in the form of software products	PC-2.1 Knows modern theoretical and experimental methods for developing mathematical models, innovative design tools and elements of architectural solutions for information systems; PC-2.2 Able to develop and implement algorithms for mathematical models based on languages and packages of applied modeling programs; PC-2.3 Has practical experience in developing options for implementing information systems using innovative tools.

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

Discipline "Modeling and Validation" refers to the part formed by the participants of educational relations 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 "Modeling and Validation".

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		Advanced Methods of Remote Sensing and Geoinformation Systems; Web Application Development and Security; Practical Training and Research in Dynamics and Control of Space Systems (online from RUDN Mission Control Center) / Research work; Technological Training; Pre-Graduation Internship in Industry;
PC-1	Able to formulate goals and objectives of scientific research in the field of applied mathematics and computer science, computer technology and modern programming technologies, and select methods and means for solving problems		Pre-Graduation Internship in Industry; Practical Training in Receiving Remote Sensing Data from Satellites and its Interpretation (online from RUDN Mission Control Center) / Research; Practical Training and Research in Dynamics and Control of Space Systems (online from RUDN Mission Control Center) / Research work; Technological Training; Advanced Methods of Remote Sensing and Geoinformation Systems; System Design; Dynamics and Control of Space Systems;
PC-2	Able to apply modern theoretical and experimental methods for developing mathematical models of objects and processes under study related to professional activities in the field of training and participate in their implementation in the form of software products		Advanced Methods of Remote Sensing and Geoinformation Systems; System Design; Project "Drone Systems Engineering. Part 1"; Pre-Graduation Internship in Industry; Practical Training in Receiving Remote Sensing Data from Satellites and its Interpretation (online from RUDN Mission Control Center) / Research;

Cipher	Name of competence	Previous courses/modules, practical training*	Subsequent disciplines/modules, practices*
			Practical Training and Research in Dynamics and Control of Space Systems (online from RUDN Mission Control Center) / Research work; Technological 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 “Modeling and Validation” course is 4 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)
			1
<i>Contact work, academic hours</i>	20		20
Lectures (LC)	10		10
Laboratory work (LW)	10		10
Practical/seminar classes (SC)	0		0
<i>Independent work of students, academic hours</i>	88		88
<i>Control (exam/test with assessment), academic hours</i>	36		36
Total complexity of the discipline	academic hours	144	144
	credit	4	4

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	Deterministic Systems	1.1	Difference and Differential Equations	Difference equations for discrete-time systems. Differential equations for continuous-time systems. Ordinary differential equations and partial differential equations. Initial conditions and boundary conditions. Order and linearity of equations. Applications to mechanical, electrical, and aerospace systems.	LC, LW
		1.2	Solution of Linear Difference and Differential Equations	Analytical methods for solving linear equations. Homogeneous and particular solutions. Characteristic equations and eigenvalues. Free response and forced response. Steady-state and transient behavior. Superposition principle for linear systems.	LC, LW
		1.3	Numerical Simulation Methods for ODEs	Need for numerical solutions when analytical methods are not feasible. Euler methods: forward Euler, backward Euler. Runge-Kutta methods. Multi-step methods. Stiffness and stability considerations. Choice of time step. Error analysis and convergence.	LC, LW
		1.4	Stability and Sensitivity Analysis	Stability definitions: asymptotic stability, marginal stability, instability. Linearization around equilibrium points. Eigenvalue criteria for stability of linear systems. Phase plane analysis for second-order systems. Sensitivity analysis: parametric sensitivity, initial condition sensitivity. Robustness to parameter variations and disturbances.	LC, LW
		1.5	Hybrid Dynamic Systems	Systems continuous combining dynamics and discrete events. Switching systems and piecewise smooth dynamics. Hysteresis and discontinuities. Reset maps and impact dynamics. Zeno phenomena. Applications: systems with relays, mechanical impacts, switching controllers, sampled-data systems.	LC, LW
Section 2	System Identification	2.1	Parameter Fitting	Definition of system identification as model building from measured data. Parameter estimation problem: selecting model parameters to fit experimental observations. Process of model structure selection, parameter estimation, and model validation. Goodness of fit criteria. Overfitting and underfitting. Bias-variance trade-off.	LC, LW
		2.2	Linear Regression	Relationship between input and output variables in multiple-input single-output systems. Model structure: linear combination of regressors. Ordinary least squares estimation. Assumptions for valid linear regression: independence, homoscedasticity, normality.	LC, LW

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				Confidence intervals for parameters. Regression diagnostics and residual analysis.	
		2.3	Least Squares Method	Principle of minimizing sum of squared errors between model predictions and measured data. Geometric interpretation. Derivation of normal equations. Solution using matrix operations. Weighted least squares. Recursive least squares for online estimation. Regularized least squares for ill-posed problems.	LC, LW
		2.4	Nonlinear Optimization Methods	Need for nonlinear optimization when model is not linear in parameters. Local versus global optimization. Gradient-based methods: steepest descent, Newton's method, Gauss-Newton, Levenberg-Marquardt. Derivative-free methods. Handling of constraints. Convergence criteria. Sensitivity to initial guesses. Application to nonlinear system identification.	LC, LW
Section 3	Stochastic Systems	3.1	Probability Distributions	Random variables and probability density functions. Discrete and continuous distributions. Important distributions: uniform, Gaussian or normal, exponential, Poisson, binomial. Cumulative distribution functions. Expectation, variance, covariance, correlation. Multivariate distributions. Joint and conditional distributions. Central limit theory.	LC, LW
		3.2	Generating Random Variables	Methods for generating random numbers with specified distributions. Pseudo-random number generators. Inverse transform sampling. Acceptance-rejection method. Box-Muller transform for Gaussian variables. Generating correlated random variables using Cholesky decomposition. Random number generation for simulation of stochastic systems.	LC, LW
		3.3	Monte Carlo Simulation	Using random sampling to approximate deterministic or stochastic quantities. Propagation of uncertainty through models. Estimation of expected values, variances, and quantities. Convergence rate and error estimation. Variance reduction techniques: antithetic variates, control variates, importance of sampling. Application to reliability analysis, risk assessment, performance evaluation.	LC, LW
		3.4	Markov Processes and Discrete Event Systems	Markov property: future depends only on present state. Discrete-time and continuous-time Markov chains. Transition probabilities and transition rates. State space and transition diagrams. Stationary distributions and steady-state analysis. Discrete event systems as state-driven simulations. Event scheduling and time advance mech-	LC, LW

Section number	Name of the discipline section	Topic Title		Topic Contents	Type of academic work*
				anisms. Applications to queuing systems, manufacturing systems, communication networks, and maintenance modeling.	

* - 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 (in the amount of ____ units), a board (screen) 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. Introduction to Dynamic Systems: Theory, Models, and Applications. DG Luenberger, 1979.
2. Numerical Analysis, R. L. Burden and J. D. Faires, 1993

Further reading:

1. Modeling and Simulation of Systems Using Matlab and Simulink., DK Chaturvedi, 2010
2. CATIA V5 Tutorials Mechanism Design & Animation Release 21 - By Jonathan M. Weaver, Nader G. Zamani, Published August 23, 2012

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
 - RUDN University Electronic Library System – RUDN University Electronic Library System <https://mega.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
 - EBS "Knowledge" <https://znanium.ru/>
2. Databases and search engines
 - Sage <https://journals.sagepub.com/>
 - Springer Nature Link <https://link.springer.com/>
 - Wiley Journal Database <https://onlinelibrary.wiley.com/>

- Scientometric database Lens.org <https://www.lens.org>

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

1. Lecture course on the subject "Modeling and Validation".

* - 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:

Associate Professor

Position, DEPARTMENT

Signature

Saltykova Olga
Alexandrovna

Surname I.O.

HEAD OF THE DEPARTMENT:

Position of the DEPARTMENT

Signature

Surname I.O.

HEAD OF THE EP HE:

Professor

Position, DEPARTMENT

Signature

Razumny Yuri Nikolaevich

Surname I.O.