**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

**ON-BOARD ENERGY**
(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)

**2026**

## 1. THE GOAL OF MASTERING THE DISCIPLINE

The course "On-Board Energy" is part of the Master's program "Space mission and system design" in the 01.04.02 "Applied Mathematics and Informatics" program and is studied in the third semester of the second year. The course is offered by the department of the partner university. It consists of six sections and 20 topics and focuses on the fundamental principles of aerospace propulsion devices as systems, with their functional requirements, engineering, and environmental limitations, along with requirements and limitations that constrain design choices. Both air-breathing and rocket engines are covered, at a level that enables rational integration of the propulsion system into an overall vehicle design.

The goal of this course is to develop fundamental knowledge and skills in applying problem-solving methods necessary for professional work and to improve students' overall literacy in the discipline of On-Board Energy. Students will learn to list and explain the characteristics and performance of aerospace propulsion systems, model newly conceived rocket or air-breathing propulsion systems and estimate their performance and behavior, and develop preliminary designs of rocket or air-breathing propulsion systems to meet specified requirements.

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

Mastering the "On-Board Energy" discipline 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-2 | Capable of improving and implementing new mathematical methods for solving applied problems | GPC-2.1 Uses the results of applied mathematics to master and adapt new methods for solving problems in the area of professional interests;<br>GPC-2.2 Implements and improves new methods for solving applied problems in the field of professional activity;<br>GPC-2.3 Conducts a qualitative and quantitative analysis of the obtained solution in order to construct an optimal option. |
| GPC-3 | Able to develop mathematical models and analyze them when solving problems in the field of professional activity | GPC-3.1 Develops mathematical models in the field of applied mathematics and computer science;<br>GPC-3.2 Analyzes mathematical models for solving applied problems of professional activity;<br>GPC-3.3 Develops and analyzes new mathematical models for solving applied problems of professional activity in the field of applied mathematics and computer science. |
| PC-3 | Capable of participating in scientific research and development of design solutions in the field of ballistics, dynamics and flight control of spacecraft | PC-3.1 Knows the basic mathematical methods and modern tools in the field of ballistic design of space complexes and systems;<br>PC-3.2 Possesses basic knowledge of standards, norms and rules for developing design solutions in the field of ballistics, dynamics and flight control of spacecraft;<br>PC-3.3 Able to apply mathematical methods and modern information technologies in conducting scientific research and developing design solutions in the field of ballistics, dynamics and flight control of spacecraft. |
| PC-5 | Capable of analyzing, including in English, methods for studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories | PC-5.1 Knows proven and applied methods, including those from English-language sources, for studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories;<br>PC-5.2 Able to develop and modernize methods for studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories;<br>PC-5.3 Has mastered methods and approaches to studying ballistic |

| Cipher | Competence | Indicators of Competency Achievement (within this discipline) |
|---|---|---|
| | | and dynamic characteristics when modeling spacecraft flight trajectories. |

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

On-board Energy Discipline 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 "On-board Energy".

*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-2 | Capable of improving and implementing new mathematical methods for solving applied problems | Aerospace Systems;<br>Structures & Materials Modeling; | Pre-Graduation Internship in Industry;<br>Technological Training;<br>Dynamics and Control of Space Systems; |
| GPC-3 | Able to develop mathematical models and analyze them when solving problems in the field of professional activity | Programming;<br>Aerospace Systems;<br>Structures & Materials Modeling;<br>Project "Drone Systems Engineering. Part 1"; | Dynamics and Control of Space Systems;<br>Pre-Graduation Internship in Industry;<br>Technological Training; |
| PC-3 | Capable of participating in scientific research and development of design solutions in the field of ballistics, dynamics and flight control of spacecraft | Practical Training in Receiving Remote Sensing Data from Satellites and its Interpretation (online from RUDN Mission Control Center) / Research;<br>Aerospace Systems;<br>Structures & Materials Modeling;<br>Project "Drone Systems Engineering. Part 1";<br>*Applied Mechanics and Engineering***;<br>*Systems Engineering***; | Pre-Graduation Internship in Industry;<br>Technological Training;<br>Dynamics and Control of Space Systems; |
| PC-5 | Capable of analyzing, including in English, methods for studying ballistic and dynamic characteristics when modeling spacecraft flight trajectories | Practical Training in Receiving Remote Sensing Data from Satellites and its Interpretation (online from RUDN Mission Control Center) / Research;<br>English Language;<br>Aerospace Systems;<br>Structures & Materials Modeling;<br>*Applied Mechanics and Engineering***;<br>*Systems Engineering***;<br>Russian as a Foreign Language;<br>Advanced Methods of Remote Sensing and Geoinformation Sys- | Pre-Graduation Internship in Industry;<br>Technological Training;<br>Dynamics and Control of Space Systems; |

| Cipher | Name of competence | Previous courses/modules, practical training* | Subsequent disciplines/modules, practices* |
|---|---|---|---|
| | | tems; | |

* - 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 “On-board energy” discipline is 5 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** |
| *Contact work, academic hours* | *72* | | *72* |
| Lectures (LC) | 36 | | 36 |
| Laboratory work (LW) | 0 | | 0 |
| Practical/seminar classes (SC) | 36 | | 36 |
| *Independent work of students, academic hours* | *72* | | *72* |
| *Control (exam/test with assessment), academic hours* | *36* | | *36* |
| **Total complexity of the discipline** | **academic hours** | ***180*** | *180* |
| | **credit** | ***5*** | *5* |

## 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 | Modeling of thermal rocket engines | 1.1 | Nozzle flow | Basic principles of gas flow through rocket nozzles. Expansion and acceleration of exhaust gases. Relationship between pressure, temperature, and velocity along the nozzle. Choked flow conditions at the nozzle throat. | LC, SC |
| | | 1.2 | Mass flow control | Factors affecting mass flow rate in rocket engines: throat area, chamber pressure, gas properties. Methods for regulating mass flow. Impact of mass flow variations on thrust and engine performance. | LC, SC |
| | | 1.3 | Modeling of rocket nozzles | Mathematical and computational models for predicting nozzle performance. Key parameters: thrust coefficient, characteristic velocity, specific impulse. Simplifying assumptions in nozzle modeling: one-dimensional flow, steady-state conditions, ideal gas behavior. | LC, SC |
| | | 1.4 | Effects of nozzle area ratio | Definition of nozzle area ratio as exit area divided by throat area. Influence of area ratio on exhaust velocity and thrust. Optimum expansion versus over-expansion and under-expansion. Consequences of flow separation in over-expanded nozzles. | LC, SC |
| Section 2 | Types of nozzles | 2.1 | Connection of flow to nozzle shape | Convergent nozzles for subsonic flow conditions. Convergent-divergent nozzles for supersonic flow. Influence of nozzle contour on flow uniformity and losses. Bell-shaped nozzles versus conical nozzles. Aerospike nozzles and altitude-compensating designs. Trade-offs between efficiency, weight, and manufacturing complexity. | LC, SC |
| Section 3 | Solid propellant gas generators | 3.1 | Stability | Combustion stability in solid propellant gas generators. Stable versus unstable burning. Causes of combustion instability: pressure oscillations, acoustic coupling, propellant composition variations. Methods for damping instabilities: baffles, inhibitors, resonant rod designs. | LC, SC |
| | | 3.2 | Grain designs | Definition of grain as the solid propellant charge. Grain configurations: single perforation, multi-perforation, star-shaped, finocyl, wagon wheel. Influence of grain geometry on burning surface area and thrust profile. Neutral, progressive, and regressive burning characteristics. Grain structural integrity and stress analysis. | LC, SC |

| Section number | Name of the discipline section | Topic Title | | Topic Contents | Type of academic work* |
|---|---|---|---|---|---|
| Section 4 | Models for rocket engines | 4.1 | Flow of reacting gases | Thermodynamics of chemically reacting gas mixtures. Equilibrium and frozen flow assumptions. Influence of chemical reactions on gas properties: temperature, molecular weight, specific heat ratio. Combustion processes in rocket chambers: mixing, ignition, flame propagation. | LC, SC |
| | | 4.2 | Nozzle flow of reacting gases | Expansion of reacting gases through the nozzle. Effects of finite-rate chemical reactions during expansion. Shift from equilibrium to frozen composition at high expansion ratios. Impact of reacting flow on delivered specific impulse and exhaust plume characteristics. | LC, SC |
| Section 5 | Aircraft propulsion | 5.1 | Configuration and components | Overall layout of aircraft gas turbine engines. Major components: inlet, compressor, combustor, turbine, exhaust nozzle. Engine types: turbojet, turbofan, turboprop, turboshaft. Functions and interactions of each component. | LC, SC |
| | | 5.2 | Aircraft engine modeling | Thermodynamic cycle analysis of gas turbine engines. Steady-state performance modeling at different flight conditions: altitude, Mach number, throttle setting. Off-design performance prediction. Component maps and matching between compressor and turbine. | LC, SC |
| | | 5.3 | Turbojet engine | Principles of turbofan operation with bypass flow. Bypass ratio definition and classification: low bypass, high bypass, ultra-high bypass. Advantages of turbofans over turbojets: lower fuel consumption, reduced noise, higher thrust at subsonic speeds. Separate flow and mixed flow exhaust configurations. | LC, SC |
| | | 5.4 | Turbofan engines | Advanced turbofan concepts: geared turbofan, variable cycle engines. Fan and low-pressure compressor design. Thrust contribution from core and bypass streams. Trade-offs between specific thrust and propulsive efficiency. | LC, SC |
| | | 5.5 | Inlets or diffusers | Function of inlets: capture and decelerate incoming air. Subsonic inlets: pitot type, external compression. Supersonic inlets: internal compression, mixed compression. Diffuser design for pressure recovery and flow uniformity. Boundary layer control and inlet distortion effects. | LC, SC |
| | | 5.6 | Exhaust nozzles | Convergent nozzles for subsonic exhaust jets. Convergent-divergent nozzles for supersonic exhaust. Variable area nozzles for thrust vectoring and reverse thrust. Nozzle pressure ratio and its effect on thrust. Cooling methods for high temperature nozzle | LC, SC |

| Section number | Name of the discipline section | Topic Title | | Topic Contents | Type of academic work* |
|---|---|---|---|---|---|
| | | | | components. | |
| | | 5.7 | Compressors and fans | Axial flow compressors: blade rows, stage pressure ratio, multi-stage compression. Centrifugal compressors: impeller, diffuser, volume. Compressor maps: speed lines, surge line, operating line. Stall and surge phenomena: causes, detection, avoidance methods. | LC, SC |
| | | 5.8 | Turbines, stage characteristics, degree of reaction | Axial flow turbine design: nozzle guide vanes, rotor blades, energy extraction. Turbine stage characteristics: velocity triangles, work output, efficiency. Degree of reaction definition: proportion of static pressure drop occurring in the rotor blade row. High-reaction versus low-reaction stages. Cooling technologies for turbine blades. | LC, SC |
| | | 5.9 | Engine structures, centrifugal stresses, engine arrangements | Structural components: casings, shafts, bearing supports, mounting arrangements. Centrifugal stresses in rotating components: blades, discs, spacers. Stress analysis and material selection. Engine lay-outs: single spool, twin spool, triple spool arrangements. Advantages and disadvantages of each configuration. | LC, SC |
| Section 6 | Aircraft engine noise: principles, regulations | 6.1 | Jet noise | Sources of jet noise: turbulent mixing of exhaust gases with ambient air. Dependence on exhaust velocity and temperature. Noise characteristics: broadband shock-associated noise, turbulent mixing noise. Jet noise reduction techniques: chevrons, lobed mixers, high bypass ratio. | LC, SC |
| | | 6.2 | Turbomachinery noise | Fan noise: tone noise at blade passage frequency and harmonics, broadband noise. Compressor and turbine noise sources. Interaction noise between rotor-stator stages. Noise generation mechanisms: wake interaction, tip clearance vortices, boundary layer effects. Noise reduction methods: active noise control, acoustic liners, blade design optimization. International noise regulations. Measurement and certification procedures for aircraft noise. | 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. Kerrebrock, J. L. Aircraft Engines and Gas Turbines. 2nd ed. MIT Press, 1992. ISBN: 9780262111621.
2. Sutton, G. P., and O. Biblarz. Rocket Propulsion Elements. 7th ed.Wiley Interscience, 2000. ISBN: 9780471326427

*Further reading:*

1. Gas Turbine Theory: By Henry Cohen, GFC Rogers, HIH Saravanamuttoo, Publisher: Addison Wesley Longman
2. Spacecraft Systems Engineering, 3rd ed. : By Peter Fortescue, John Stark and Graham Swinerd, Publisher: John Wiley & Sons

*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 "On-board energy".

* - 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 | | Saltykova Olga Alexandrovna |
| *Position, DEPARTMENT* | *Signature* | *Surname I.O.* |

**HEAD OF THE DEPART-MENT:**

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| | | |
| *Position of the DEPARTMENT* | *Signature* | *Surname I.O.* |

**HEAD OF THE EP HE:**

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