Ministry of Education and Science of Ukraine
National Aerospace University
"Kharkiv Aviation Institute"

Department 202 «Theoretical Mechanics, Engineering and Robotic Systems»

***APPROVED***
Leader of the Project Group
_____ A.S. Kulik
«01» 09 2020

# WORKING PROGRAM OF COMPULSORY ACADEMIC DISCIPLINE

## "Engineering Mechanics (Technical mechanics)"
(name of academic discipline)

**Field of study:** 17 «Electronics and Telecommunication»

**Speciality:** 173 «Avionics»

**Educational programs:** System of Autonomous Navigation and Adaptive Control of Aircrafts

**Full of study: full-time**

**Level of Qualification**: 1-st (bachelor degree)

Kharkiv 2020

The developed study program of compulsory discipline «Engineering Mechanics (Technical mechanics)» is for English-speaking students of training direction 173 – Avionics

«24» August , 2020, 16 p.

Developer: Povhorodnii V.O., Associated Professor of Department202 «Theoretical Mechanics, Engineering and Robotic Systems», PhD _____

The program has been examined at the meeting of Department 202 «Theoretical Mechanics, Engineering and Robotic Systems»
Record of proceeding: № 1 from «29» 08 2020

Head of Department, DSc, Associated Professor _____ Baranov O.O._____

## 1. Description of the discipline

<table>
<tr><td rowspan="2">Characteristics</td><td rowspan="2">Branch of science, specialization, academic degree</td><td>Description of the discipline</td></tr>
<tr><td>full-time tuition</td></tr>
<tr><td>Credits – 5</td><td>Branch of science<br>17<br>«Avionics»<br>(cipher and name)</td><td>Rated</td></tr>
<tr><td>Modules – 2</td><td rowspan="4">Field of education: 6.051101 «Aircraft and Rocket Construction and Design»</td><td>Academic year:</td></tr>
<tr><td>Semantic modules – 2</td><td>second</td></tr>
<tr><td>Individual research task - 86</td><td>Semester</td></tr>
<tr><td>Total number of academic hours – 150</td><td>3-rd</td></tr>
<tr><td rowspan="11">Number of academic hours for full-time tuition:<br>auditorium – 64,<br>independent work and individual task – 86</td><td rowspan="11">Academic degree:<br>bachelor</td><td>Lectures, a.h.</td></tr>
<tr><td>32</td></tr>
<tr><td>Practices, seminars, a.h.</td></tr>
<tr><td>-</td></tr>
<tr><td>Laboratory activities, a.h.</td></tr>
<tr><td>32</td></tr>
<tr><td>Independent work, a.h.</td></tr>
<tr><td>86</td></tr>
<tr><td>Individual task, a.h.</td></tr>
<tr><td>-</td></tr>
<tr><td>Form of examination</td></tr>
<tr><td>examination</td></tr>
</table>

Note: relationship between classes' hours and student independent works' hours for full-time education is equal:

150/86=

## 2. Purpose and objectives of academic discipline

**Learning Aims –** forming of knowing and proficiency related to a theory and practice of contemporary automatic control systems analysis design.
**Learning Objectives** – relatively aircrafts and other vehicles' digital control systems, the acquiring of basic methods of mathematical describing the dynamic processes that run in discrete-time systems, providing for an analysis and synthesis of these systems in accordance with requirements given.

In accordance with the educational and professional program requirements, students should obtain the following **competencies**:

GC1. Ability of abstract and subject thinking while analyzing and designing the digital systems.

GC 2,5. Applying the acquired knowledge into practice. Ability to master and develop subject knowledge, and understand methods for mathematical introducing discrete system features.

GC 3. Handling a technical foreign language.

PCS2. Aptitude to choose a method to solve a particular task in assessment of a discrete system stability and a tool to obtain the given performance characteristics.

PCS 3. Executing verbal, graphic and mathematical description of discrete signals, elements and systems in time and frequency domains.

PCS 7. Ability to evaluate the stability, controllability, and observability of the linear digital ACS using algebraic and frequency approaches.

**Program learning outcomes:**

PLO1. Grounded choice of elements and dedicated element characteristics to perceive the specified digital control specifications.

PLO3. Execution of verbal, graphic and mathematical models for discrete signals, elements and systems description in time and frequency domains.

PLO4. Applying up-to-date sensors database while engineering transducers associated with control systems and instruments of aircrafts.

PLO8. Solving actual problems of digitally controlled objects positioning and stabilization with the use of computer simulation and semi–native modeling.

**Interdisciplinary links:**

Prerequisites for studying this discipline: Higher math, Fundamentals of algorithmization, Fundamentals of system simulation, Theory of automatic control;

Discipline outcomes for using by adjacent courses: Control system designing, Bachelor's thesis.

### The objectives and the object of the study

The **object** of study is the laws of mechanics that allow to exactly determine the parameters that characterize the motion or equilibrium of solid, liquid and gaseous bodies, as well as systems of objects.
The **subject** of study - mechanical motions of bodies and mechanical interactions between bodies, as well as interactions of the bodies with the fields of forces.

The **purpose** of education - learning the rules and laws of theoretical mechanics to use in ensuing study of special subjects and solving practical problems.

As a result of "Engineering Mechanics (TM)" studding student **must know**:

- basic laws of mechanics, limits their use;
- methods of equivalent transformation of systems of forces;
- conditions of equilibrium of system of forces.
- general geometric properties of mechanical motion of particles, bodies and mechanical system;
- mathematical modeling of complex mechanical systems dynamics in generalized coordinates;

**must be able to**:

- competently apply the laws of mechanics for problems solution;
- clearly understand the ranges of mechanical laws applicability;
- develop a mathematical model of the mechanical system physical state (motion, rest);
- to analyze the results of mathematical calculations.

A student **must have an idea** about:

- the linear and nonlinear vibrations of mechanical systems;
- kinematics and dynamics of nonholonomic systems;
- the stability of equilibrium and motion of mechanical systems.

Learning aims is study of the main provisions? Theoretical foudations for the development of modern control systems; modern principles, schemes and methods of constructions of control systems, their characteristics.

## 3. Course content

### TERM 3

### Module№ 1 Statics.

**Topics**

**1.** Introducing. Two principal problems of statics. Main conception of statics: rigid body, force, system of forces, resultant of a force system, balanced force system. Axioms of statics. Main conceptions of vector algebra used in statics. Classification of forces: internal and external forces, concentrated and distributed forces, applied forces and reactions. Constraints and their reactions. Procedure of forming of free body diagram.

**2.** The resultant of concurrent force system. Methods of resultant determination: analytical, graphical. Equilibrium equation of concurrent force system. Vector and axial moment of force. Couples of forces and their features. Couple theorems.

**3.** General force system. Translation of a force to a parallel position. Total vector and total moment about a center of a general force system. Main theorem of statics (theorem about general force system reduction). Total moment dependence on a position of a reduction center. General force system equations of equilibrium. Special force system equations of equilibrium. Procedure of solving of problem about single constrained body equilibrium. System of bodies. Problem about system of constrained bodies equilibrium, procedure of solving.

**4**. Parallel force system resultant. Varignon's theorem. Mass centre of a rigid body, system of bodies. Methods of mass enter position determination

## Module 2. Kinematics. Dynamics.

**Topics**

**5.** Space and time in classical mechanics. Reference systems. Main problems of kinematics of a particle. Different methods of a particle motion representation: vector, coordinate and in terms of path (natural). Velocity and acceleration: vector and coordinate methods. Velocity and acceleration in terms of path variables. Normal and tangential accelerations. Cases when normal and tangential accelerations equal zero. Analytical researching of motion and researching with help of velocity hodograph.

**6.** Main problems of a rigid body kinematics. Translation of a rigid body, features of the motion. Rotation of a rigid body about fixed axis, the motion description. Angular velocity and angular acceleration of body. Velocity and acceleration of a point of rotating body.

**7.** Plane motion of rigid body. Equations of motion. Chasles' theorem. Velocity of a body's point. Instantaneous center of zero velocity (ICZV). Methods of ICZV finding. ICZV as pole. Plane motion of rigid body. Acceleration of point on a body.

**8.** Spherical motion of a rigid body (rotation about a fixed point). Instantaneous axis of rotation. Angular velocity and angular acceleration of the body. Velocity of a point on the body. Acceleration of a point on the body. Motion of a free body. Velocity and acceleration of a free body point.

**9.** Relative motion of a particle. General relationship between time derivatives of a vector for different references, the relationship between velocities of a particle for different references, acceleration of a particle for different references. Cases when Coriolis acceleration equals zero.

**10**. Dynamics of a Particle. Axioms of dynamics. The two main problems of dynamics. Solution of direct and inverse problems of particle dynamics.

**11.** Motion of a particle with respect to the noninertial frame of reference. Free and constrained particles equations of motion in noninertial frame of reference. Forces of inertia their features. Classical mechanics relativity principle. The relative resting conditions.

**12.** Particles system. Parameters of a particle system: mass, center of mass, Mass moment of inertia about an axis (axial), about a pole (polar), Parallel-axes theorem. The simplest bodies axial moments.

**13.** Linear momentum of a particle. Total linear momentum of the particle system. Force-momentum principle. Principle of linear momentum conservation. Principle of system mass-center motion. Differential equations of translational motion of particles system.

## 4. Course arrangement

Calculation-graphic work.

Problem 1. Single constrained body equilibrium 8

| Names of Modules and Topics | Number of hours | | | | |
|---|---|---|---|---|---|
| | full-time tuition | | | | |
| | total<br>namely | | | | |
| 1 | total | lec | pr | lab | s.l. |
| **TERM 3** | | | | | |
| **Thematic module 1** | | | | | |
| **TOPIC 1.** Introducing. Two principal problems of statics Main conception of statics: rigid body, force, system of forces, resultant of a force system, balanced force system. Axioms of statics. Main conceptions of vector algebra used in statics. | 12 | 2 | - | 2 | 8 |
| **TOPIC 2.** The resultant of concurrent force system. Methods of resultant determination: analytical, graphical. Equilibrium equation of concurrent force system. Vector and axial moment of force. Couples of forces and their features. Couple theorems. | 14 | 4 | - | 4 | 6 |

| | | | | | |
|---|---|---|---|---|---|
| **TOPIC 3.** General force system. Translation of a force to a parallel position. Total vector and total moment about a center of a general force system. Main theorem of statics (theorem about general force system reduction). Total moment dependence on a position of a reduction center. General force system equations of equilibrium. Special force system equations of equilibrium. | 22 | 4 | - | 4 | 14 |
| **TOPIC 4.** Classification of forces: internal and external forces, concentrated and distributed forces, applied forces and reactions. Constraints and their reactions. Procedure of forming of free body diagram (FBD). Procedure of solving of problem about single constrained body equilibrium. System of bodies. Problem about system of constrained bodies equilibrium, procedure of solving. | 21 | 4 | - | 4 | 13 |
| **TOPIC 5.** Parallel force system resultant. Varignon's theorem. Mass centre of a rigid body, system of bodies. Methods of mass enter position determination | 6 | 2 | - | 2 | 2 |
| **Totally for module 1** | **75** | **16** | **-** | **16** | **43** |
| **Thematic module 2** | | | | | |
| **TOPIC 6.** Particle kinematics.<br>Space and time in classical mechanics. Reference systems. Main problems of kinematics of a particle. Different methods of a particle motion representation: vector, coordinate and in terms of path (natural). Velocity and acceleration: vector and coordinate methods. Velocity and acceleration in terms of path variables. Normal and tangential accelerations. Cases when normal and tangential accelerations equal zero. Analytical researching of motion and researching with help of velocity hodograph. | 15 | 4 | - | 4 | 7 |
| **TOPIC 7.** Main problems of a rigid body kinematics. Translation of a rigid body, features of the motion. Rotation of a rigid body about fixed axis, the motion description. Angular velocity and angular acceleration of body. Velocity and acceleration of a point of rotating body. | 14 | 4 | - | 4 | 6 |
| **TOPIC 8.** Plane motion of rigid body. Equations of motion. Chasles' theorem. Velocity of a body's point. Instantaneous center of zero velocity (ICZV). Methods of ICZV finding. ICZV as pole. Plane motion of rigid body. Acceleration of point on a body. | 10 | 2 | - | 2 | 6 |
| **TOPIC 9.** Spherical motion of a rigid body (rotation about a fixed point). Instantaneous axis of rotation. Angular velocity and angular acceleration of the body. Velocity of a point on the body. Acceleration of a point on the body. Motion of a free body. Velocity and acceleration of a free body point. | 10 | 2 | - | 2 | 6 |
| **TOPIC 10.** Compound motion of a particle. General relationship between time derivatives of a vector for different references, the relationship between velocities of a particle for different references, acceleration of a particle for different references. Cases when Coriolis acceleration equals zero. Compound motion of a body. | 10 | 2 | - | 2 | 6 |
| **TOPIC 11.** Dynamics of a Particle. Axioms of | **8** | **1** | **-** | **1** | **6** |

| | | | | | |
|---|---|---|---|---|---|
| dynamics. The two main problems of dynamics. Solution of direct and inverse problems of particle dynamics. | | | | | |
| **TOPIC 12.** Motion of a particle with respect to the noninertial frame of reference. Free and constrained particles equations of motion in noninertial frame of reference. Forces of inertia their features. Classical mechanics relativity principle. The relative resting conditions. Particles system. Parameters of a particle system: mass, center of mass, Mass moment of inertia about an axis (axial), about a pole (polar), Parallel-axes theorem. The simplest bodies' axial moments. | **8** | **1** | **-** | **1** | **6** |
| **Totally for modulei 2** | **75** | **16** | **-** | **16** | **43** |
| **Totally for term** | **150** | **32** | **-** | **32** | **86** |
| | | | | | |

## 5. Laboratory works

| № | Name | Hours |
|---|---|---|
| Term 3 | | |
| 1 | Topics 1 and 2. Force. Force resolution onto components, composition of forces. Algebraic moment of force about a center | 2 |
| 2 | Topic 3. Equilibrium of a body (2D). Reaction of constraints. FBD | 4 |
| 3 | Topic 3. Equilibrium of a system of bodies (2D). | 2 |
| 4 | Topic 3. General force system. Total vector and total moment about choosing center of reduction | 4 |
| 6 | Topic 6. Particle kinematics | 2 |
| 7 | Topic 7. Rigid body in translation. Rigid body rotation about fixed axis | 4 |
| 8 | Topic 8. Plane motion of a rigid body | 2 |
| 9 | Topic 9. Spherical motion of a rigid body | 2 |
| 10 | Topic 10. Particle compound motion | 2 |
| 11 | Topic 11. Axioms of dynamics particle dynamics in inertial frame of reference . | 2 |
| 12 | Topic 12. Particle dynamics in noninertial frame of reference . | 2 |
| 13 | Topic 13. Force-linear momentum principle | 2 |
| 14 | Topic 14. Moment-angular momentum principle in inertial frame of reference. | 2 |

## 6. Independent work

| № | Name | Hours |
|---|---|---|
| Term 3 | | |
| 1. | **TOPIC 1.** Two main problems of statics Axioms of statics.. | 2 |
| 2. | **TOPIC 2.** The resultant of concurrent force system. Equilibrium equation of concurrent force system. Vector and axial moment of force. Couples. | 2 |
| 3. | **TOPIC 3.** General force system. Total vector and total moment about a center of a general force system. Main theorem of statics. General force system equations of equilibrium. Special force system equations of equilibrium. | 2 |
| 4. | **TOPIC 4.** Classification of forces: Constraints and their reactions. FBD. Main conceptions of vector algebra used in statics. Method of section. | 2 |
| 5. | **TOPIC 5.** Parallel force system resultant. Varignon's theorem. Mass centre of a rigid body, system of bodies. Methods of mass enter position determination | 2 |
| 6. | **TOPIC 6.** Particle kinematics. | 4 |

| | | |
|---|---|---|
| 7. | **TOPIC 7.** Translation of a rigid body features of the motion. Rotation of a rigid body about fixed axis. | 2 |
| 8. | **TOPIC 8.** Plane motion of rigid body. | 6 |
| 9. | **TOPIC 9.** Spherical motion of rigid body. | 2 |
| 10. | **TOPIC 10.** Particle compound motion**.** | 3 |
| 11. | **TOPIC 11.** Axioms of dynamics Particle dynamics in inertial frame of reference . | 2 |
| 12. | **TOPIC 12.** Particle dynamics in noninertial frame of reference . | 2 |
| 13. | **TOPIC 13.** .Mass-geometrical characteristics of a particle system. | 2 |
| 14. | **TOPIC 14.** Force-Linear momentum principle | 2 |

## 7. Individual task

Term 3

| № | Name | Hours |
|---|---|---|
| 1 | Calculation-graphic work 1«System of two rigid bodies equilibrium (2D). Rigid body equilibrium (3D)».<br>Stages of work.<br>System of two rigid bodies equilibrium (2D)<br>– FBD for system of two rigid bodies forming;<br>– FBD for separated bodies forming;<br>– Forming of Equilibrium conditions for separated bodies;<br>– Solution of system of linear algebraic equations (equilibrium conditions equations);<br>– Checking up of the solution with help of Equilibrium conditions for system of two rigid bodies;<br>– Results analysis. | 25 |
| | Calculation-graphic work 1 «Plane motion of Rigid body. Particle compound motion».<br>Stages of work.<br>Plane motion of Rigid body<br>– Bodies character of motion analysis;<br>– Position of ICZV determination;<br>– Determination of Angular velocity of rigid body in plane motion;<br>– Determination of velocities of points of rigid body in plane motion;<br>– Choice of the method of determination of angular acceleration of rigid body in plane motion;<br>– Solution of vector equations about linear accelerations distribution for bodies in the problem.<br>– Position of ICZA determination, Checking up of the problem solution.<br>Compound motion of a particle<br>– Determination of character of bulk motion, type of relative motion of the particle;<br>– Determination of relative, bulk and absolute velocities, Graphical presentation of the velocities;<br>– Determination of relative, bulk, Coriolis' and absolute accelerations, Graphical presentation of the accelerations. | 26 |

## 8. Learning methods

Lectures, practices; individual consultations; homework instructor-led; self-study student with the aid of tutorials were published by chair; olympiad.

### Questions for independent work
### Term 3

1. Basic conceptions: rigid body, force, force system, rigid body equilibrium. Statics problems. Statics axioms.
2. Moment of force about a center: magnitude, direction.
3. Moment of force about an axis: magnitude, methods of calculation.
4. Couple. Couple vector moment: direction, magnitude. The features of couple.
5. Total vector and total moment of a force system. Methods of total vector and total moment determination. Statics invariants.
6. Reducing of the general force system. Total vector and total moment. Dependence of the total vector and total moment on the particular center of reduction selected.
7. Force system resultant. Varignon's theorem.
8. Special force systems. Conditions of equilibrium.
9. Free and constrained body. Constraints and their reactions. Common types of constraints and their reactions (2-D and 3-D). Construction of free body diagram.
10. Statically determinate and indeterminate rigid body. The crucial steps in solving equilibrium problem for single body.
11. Equilibrium of system of rigid bodies. External and internal forces, the features of internal forces. Method of section (method of isolating of connected system members).
12. Center of gravity and its coordinates. Ways of definition of center of gravity position.
13. The ways of particle motion representation. Trajectory, velocity and acceleration of a particle in terms of rectangular coordinates x,y,z.
14. The ways of particle motion representation. Velocity and acceleration of a particle in terms of path variables.
15. The ways of particle motion representation. Normal $W^n$ and tangent $W^\tau$ accelerations of a particle in terms of rectangular coordinates x,y,z.
16. Conditions of accelerated, decelerated or uniform motion of a particle. Researching of particle motion (type of motion determination) for different methods of particle motion representation.
17. The simplest types of rigid body motion: translation, rotation about fixed axis. The features of these motions.
18. Velocity of point in rigid body in plane motion with respect to any base point. Angular velocity of rigid body in plane motion. Angular velocity independence of particular base point selected.
19. Plane motion of rigid body. Ways of particle velocity determination: with respect to a base point (pole), according to the equiprojectivity principle.
20. Plane motion of rigid body. Instantaneous center of zero velocity: definition, ICZV existence condition, the ways of definition of ICZV position.
21. Plane motion of rigid body. Ways of particle acceleration determination: with respect to a base point (pole), with respect to instantaneous center of zero acceleration
22. A particle motion observed from a system which itself is in plane motion. Basic conceptions: absolute, relative and transport motion. Absolute velocity of a particle.
23. A particle motion observed from a system which itself is in plane motion. Basic conceptions: absolute, relative and transport motion. Absolute acceleration of a particle. Coriolis acceleration: magnitude, direction, conditions under which Coriolis acceleration is equal to zero.
24. Axioms of dynamics

25. Free particle equation of motion in inertial frame of reference. Different forms.
26. The two problems of dynamics
27. Free particle equation of motion in noninertial frame of reference. Forces of inertia. The features of the forces of inertia, conditions of the inertia forces zeroing.

## 9. Testing

The course is divided into four modules:

1. Statics.
2. Kinematics.
3. Dynamics.

Term 3. Module 1 is passed during 10-th week (one attempt), module 2 is passed during 18-th week (one attempt).

Term 3. Module 2 is passed during 9-th week (one attempt), module 4 is passed during 15-th week (one attempt).

Before passing modulus, student must make all laboratory works, individual task and independent work of this modulus.
Defense of individual task is in writing and orally forms.

Deadline for submitting and defense of individual tasks:
individual task problem 1 – 9- *th* week of term 3,
individual task problem 2 – 15- *th* week of term 3,
individual task problem 3 – 18- *th* week of term 3,
After deadline time, students do not obtain points for individual tasks.

**Terms 3 and 4 – examinations.**

## 10. Points distribution between topics

**Term 3**

| Monitoring and independent work | | | | | | | | | | Exam |
|---|---|---|---|---|---|---|---|---|---|---|
| Thematic module 1 | | | | Thematic module 2 | | | | | Total | |
| T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | | |
| 8 | 9 | 28 | 5 | 8 | 8 | 15 | 4 | 15 | 100 | 100 |

**National scale and ECTS grade**

| Total score | ECTS scale | Mark on national scale (exam or grade test) |
|---|---|---|
| 90…100 | A | Excellent |
| 83…89 | B | Good |
| 75…82 | C | |
| 68…74 | D | Satisfactory |
| 60…67 | E | |
| 35…59 | FX | Unsatisfactory (exam repeating is possible) |
| 0…34 | F | Unsatisfactory (it is necessary to repeat the course) |

Student which passed all modules, can take total rating score and not pass final test. If student is not agree with total rating score, he can improve it passing final test.

Total rating score is converted into ECTS and National score using recommended grade scales.

## 11. Recommended literature for the course


1. F.P. Beer and E.R. Johnston, Vector Mechanics for Engineers – Statics. Dynamics, McGraw Hill Book Company, 2003.
2. J.L. Meriam and L.G. Kraige, Engineering Mechanics – Statics. Dynamics, John Wiley & Sons, 2002.
3. Theoretical mechanics. Statics: Textbook / V.A. Oikin, O.Y. Kladova, V.N. Pavlenko, Y.A. Stetsenko. — Kharkov: National Aerospace University 'Kharkov Aviation Institute', 2010. – 84 p.
4. Theoretical mechanics. Statics: Textbook / V. N. Pavlenko, I. V. Bunyaeva, S. S. Vorozhko et al. – Kharkov: National Aerospace University «Kharkov Aviation Institute», 2012. – 100 p.
5. Theoretical mechanics. Kinematics: Tutorial for self-education / V. N. Pavlenko, I. V. Bunyaeva, S. S. Vorozhko et al. – Kharkov: National Aerospace University named after N. Ye. Zhukovskiy «Kharkov Aviation Institute», 2012. – 96 p.
6. Theoretical mechanics. Dynamics: Textbook / V. N. Pavlenko, I. V. Bunyaeva, S. S. Ternovskaya et al. – Kharkov: National Aerospace University named after N. Ye. Zhukovskiy «Kharkov Aviation Institute», 2013. – 184 p.


## 12. Information sources

1. http://k202.khai.edu/ru/site/istoriya-kafedri.html
2. http://www.khai202.ho.ua/en/index.html.