ENTRANCE EXAMINATION PROGRAM

FOR PHYSTECH SCHOOL OF AEROSPACE TECHNOLOGY
MECHANICAL ENGINEERING
COMPETITIVE GROUP

FOR APPLICANTS ENTERING PHD PROGRAMS

The entrance examination is conducted in the form of an interview. The interview consists of two parts:

- interview on the content of the final qualifying work written by the applicant at the end of the specialist's or master's degree - in accordance with Part I of this Program;

- interview on general theoretical questions of the chosen specialty- in accordance with Part II of this Program.

PART I

Questions on the final qualifying work of the applicant

(Master or specialist's degree)

1. Main provisions.
2. Novelty.
3. Relevance.

Specialty 2.5.14.
Strength and thermal regimes of aircrafts

PART II

1. Fundamentals of theoretical aerodynamics

1.1. Effects of force on moving bodies. Basic concepts, definitions, hypotheses. The movement of aircraft in a continuous medium, effects of force. The main parameters of the gas characterizing its state. Gas compressibility. Viscosity. Continuity hypothesis. The main vector of aerodynamic forces, moments, the concept of the center of pressure. General expression for aerodynamic force (dimensions and similarity theory), aerodynamic coefficients of forces and moments. similarity criteria. M and Re numbers. Frictional stress. Turbulence hypotheses. General characteristics of aerodynamic coefficients.

1.2. Basic Equations for the Conservation of Aerodynamics. Methods for studying gas motion. Lagrange and Euler methods. The concept of the streamline and the trajectory of motion. Movement of a liquid particle. Potential and vortex flows. Helmholtz theorem. Basic equations of aerodynamics. Investigated system of physical bodies. Liquid (gas) models. Continuity equations for the gas component i (for a mixture). Integral and differential forms of writing. Navier-Stokes equation. Differential equations of motion for an inviscid fluid (Euler equations). Energy equations for finite and infinitesimal volumes. Specific energy along the streamline for an inviscid fluid under adiabatic flow conditions. A generalized form of writing the aerogasdynamics conservation equations. Equation of state of perfect and real gas. Integrals of the equation of motion. System basic equations. Initial and boundary conditions. Modern numerical methods for solving the Euler, Navier-Stokes equations and their asymptotic models.

1.3. One-dimensional isentropic steady gas flow. Distribution of small perturbations in a gaseous medium. Relationship between gas flow rate and cross-sectional area. Gas parameters in isentropic flow. Relative velocities (M, λ , Cr) and their relationship. Critical values of parameters. Effect of compressibility on stagnation pressure. Gas dynamic functions.

1.4. Shock wave theory. The nature of shock waves. Schemes for calculating flow parameters at the shock wave. Theory of a direct shock wave. System of basic equations for the case of constant heat capacities. Calculation of gas parameters after the shock wave. Processes of shock and isentropic compression. Entropy change at the shock wave. Deceleration parameters behind a direct shock wave. Theory of an oblique shock wave (constant heat capacities). System of basic equations. The angle of inclination of the shock front. Velocity, pressure, density, temperature behind the shock wave. Shock polar. System of equations and algorithm for calculating flow parameters behind the shock, taking into account physical and chemical transformations. Influence of physicochemical transformations in gas on flow parameters behind shock wave. Reflection of shock waves from solid and free boundaries. Interaction of shock waves. Interaction of shock waves with a rarefaction wave.

1.5. Methods of characteristics and linearization. Basic kinematic equation of aerodynamics and methods for its solution. Method of characteristics. Cauchy problem. Characteristics in the planes of flow and velocity hodograph. Characteristic properties. Solution of the equations of characteristics in the plane of the velocity hodograph. Typical problems solved by the method of characteristics. Numerical and graphic solution of problems. Supersonic flow around fractures of surfaces (Prandtl-Meyer expansion fan).

1.6. Small perturbation theory. Linearization of the basic equations of ideal gas dynamics. Solutions of linearized equations of gas dynamics.

1.7. Vortex and potential motion of an ideal incompressible medium. Vortex motions in an ideal continuous medium. The concept of speed circulation. Stokes' theorem. Kelvin's theorem. Helmholtz theorem. Determination of the field of velocities from a given field of vortices. Generalization of the Biot-Savart field. Velocities induced by a vortex (a segment of a vortex cord, a vortex ring). Interaction of a vortex with a moving medium. Plane potential motion of an ideal incompressible medium.

1.8. Potential flow method. Complex potential and complex velocity. Connection of the plane and hydrodynamic problems with the theory of functions of a complex variable. The simplest flat potential flows (rectilinear steady flow, flow inside a right angle, source and sink, dipole, vortex). Non-circulating and circulating flow around a round cylinder. The Euler-D'Alembert paradox. Forces and moments acting on a regular cylinder. Zhukovsky-Chaplygin method.

1.9. Boundary layer. Differential equation of a laminar boundary layer. Laminar boundary layer on a flat plate in an incompressible flow and at high velocities. Laminar boundary layer under pressure gradient. Weak and strong interactions. Accounting for 2^{nd} order effects. Approximate methods for calculating the laminar boundary layer. Transition of a laminar boundary layer into a turbulent one. Turbulent boundary layer. Equations of the averaged turbulent boundary layer. Reynolds stress. Detachment of the laminar and turbulent layer. Methods of experimental study of transition and detachment.

1.10. Aerodynamics of hypersonic speeds and rarefied gas. General properties of hypersonic flows. Hypersonic theory of small perturbations. Hypersonic theory of Newton-Busemann.

Influence of physicochemical processes on supersonic and hypersonic flows around blunt bodies. The concept of equilibrium, non-equilibrium and frozen flows. Characteristic features of weakly rarefied gas flows. Free molecular flow around bodies. Knudsen number. Models of the interaction of a free molecular flow with an aircraft.

2. Aerodynamics of aircraft

2.1. Aerodynamics of a wing. Profile and wing of finite span in an incompressible fluid flow. Thin airfoil theory. Aerodynamic characteristics of profiles. A wing of finite span in an incompressible fluid flow. Theory of a vortex carrier thread. The theory of the bearing surface. Calculation of aerodynamic characteristics at high angles of attack. Features of the distribution of the load on the wings of different shapes in plan. Theoretical and experimental studies of thin wings of small aspect ratio at high angles of attack, taking into account flow separation.

2.2. Profile and wing in a subsonic compressible gas flow. Linear theory of the wing. Relationship between the aerodynamic characteristics of a wing in compressible and incompressible flows.

2.3. Profile and wing at transonic speed. Critical Mach number. Similarity laws for transonic flows. Aerodynamic characteristics of profiles and wings at transonic speeds.

2.4. Profile and wing in supersonic flow. Thin plate in supersonic flow. Linear theory of thin airfoil and finite span wings in supersonic flow. Singularity method. Thin profile in hypersonic flow. Aerodynamic characteristics of wings at supersonic speed.

2.5. Aerodynamic characteristics of wings and empennage with deflected control surfaces. Aerodynamic characteristics of wings with mechanization. Influence of the shape of the wing on the efficiency of mechanization. Aerodynamic characteristics of the empennage with deflected rudders. Hinge moments of steering surfaces.

2.6. Aircraft body aerodynamics. Aircraft body at subsonic and supersonic speeds. Aerodynamic characteristics of hulls at subsonic speed. Flow around at transonic speed. Critical Mach number. Aerodynamic characteristics of hulls at transonic speed. Cone in supersonic flow. A blunt cone in a supersonic flow. Pointed object in supersonic flow. A blunt object of revolution in a supersonic flow. Aerodynamic characteristics of hulls and engine nacelles with air intakes. Hypersonic flow around blunt objects. Influence of real gas properties on aerodynamic characteristics of objects at hypersonic speed.

2.7. Aerodynamic interference. The nature of aerodynamic interference. The lift force of the hull and wing combination. Effect of bank angle on interference between hull and wing. Cross combination. Interference between wing and tail. Controls. Aerodynamic calculation of rudders.

2.8. Aerodynamic characteristics of the aircraft. Lift, drag. Polars of the first and second kind. Moments of pitch and yaw. Roll moment. Aerodynamic characteristics of an aircraft with takeoff and landing mechanization. The influence of the earth.

2.9. Aerodynamic characteristics of helicopter’s rotors and propellers. Main rotor in vertical takeoff and descent mode. Vortex ring mode. Self-rotation. Rotor in oblique flow modes. Traction force, propulsion force, power. Flying movement of the blades. Blowing the helicopter body with a main rotor. Ways to create control moments. The perfect propeller. Similarity criterion. Screw charts. The relationship between tractive force and power. Flight and relative efficiency of a real propeller. Vortex theory of the propeller. Coaxial screws.

3. Aircraft heat transfer processes

3.1. Friction and heat transfer. Laminar heat transfer at high speeds and temperatures. Similarity laws in heat transfer problems. Integral characteristics of the boundary layer. Heat transfer at low velocities in the boundary layer of an incompressible fluid. Heat transfer coefficients at high speeds. Relationship between friction and heat transfer. The transition from laminar to turbulent flow. Turbulent heat transfer at high speeds and temperatures. Approximate theories of turbulent motion. Approximate methods for calculating heat transfer in a turbulent boundary layer.

3.2. Heat transfer during chemical reactions in the boundary layer. Differential equations of diffusion for a laminar boundary layer in a mixture of reacting gases. Energy equation. Chemically equilibrium boundary layer. Chemically nonequilibrium flow on the catalytic wall. Calculation of heat transfer in the reacting gas.
3.3. Heat transfer on the surface of aircraft in three-dimensional flow. Flow in a three-dimensional boundary layer. Differential equation of a three-dimensional boundary layer. Attachment-lines. Calculation of heat transfer in three-dimensional laminar flow in the boundary layer. Combined effect of injection and roughness on heat transfer. Flow in open areas. Boundary layers in an inhomogeneous external flow.
3.4. Heat transfer in a rarefied gas. Theory of heat transfer in a rarefied gas. Regimes of thermal and dynamic processes. Heat transfer in the free molecular and transition regions of the flow.
3.5. Methods of experimental study of heat transfer.
3.6. Heat transfer in structural elements of aircraft. Basic concepts and equations of the theory of thermal conductivity. Boundary conditions in thermal conductivity problems. Methods for solving thermal conductivity problems. Analytical methods. Numerical solution of the problem of thermal conductivity. Modeling of temperature fields. Transfer of radiant heat to aircraft and inside structural elements. Basic definitions and equations of heat transfer by radiation. Methods for solving radiation transfer equations. Heat transfer by radiation inside an absorbing, radiating and scattering medium. Temperature fields in thin-walled aircraft. Heating and cooling of a body with the same temperature in volume. Aerodynamic heating of the skin. Uneven temperature distribution over the surface of a thin-walled structure. Temperature fields in reinforced structures.
3.7. Thermal protection of aircraft. Methods of thermal protection. Types of heat-shielding materials. Heat transfer inside heat-shielding coatings. Thermal resistance of the thermal insulation layer. Non-stationary thermal conductivity in multilayer structures. Approximate methods for calculating the heating of thin-walled structures with thermal insulation. Aerothermochemical destruction of thermal insulation. Methods of experimental study of heat-shielding coatings and materials used in aircraft under conditions of intense thermal exposure. Methods and features of thermal testing of aircraft structures.

4. Aerophysical experiment. Wind tunnels and benches

4.1. Principles of simulation of flow conditions around aircraft in terrestrial laboratories. Similarity parameters Re, M, Pr, St, etc.
4.2. Wind tunnels. Types of wind tunnels at low subsonic speeds. Characteristics of the flow around aircraft models in subsonic wind tunnels. Influence of wall induction on aerodynamic characteristics. Ways to reduce induction. Using the theory of potential flows to calculate the elements of subsonic tubes and wall induction.
4.3. Transonic wind tunnels and their types. Ways to reproduce natural numbers Re of the flight in the wind tunnel.
4.4. Supersonic wind tunnels. Wave launch. The main elements of supersonic wind tunnels. The problem of condensation of moisture and air in the wind tunnel.
4.5. Hypersonic wind tunnels. Types of hypersonic tubes. Impact and impulse wind tunnels.

4.6. Basic physicochemical processes in high-temperature air. Problems of relaxation phenomena in the flow around models and in flows in nozzles. High-temperature installations: electric arc gas heaters, plasma torches, MHD - gas accelerators.

5. Metrological bases of measurements

5.1. Measurements as a way of obtaining information about the surrounding world. The role of D.I. Mendeleev in the development of Russian metrology.

5.2. The structure of the information-measuring channel and the characteristics of the main elements.
5.3. Additive Model of signal and interference.
5.4. Converting the measured physical quantity into an electrical signal, sensors.
5.5. Physical phenomena underlying the transformation of measured physical quantities by sensors.
5.6. Signal conversion in the measuring channel. Spectral characteristics of signals. Spectra of random signals, channel noise band.

6. Technique and methods of aerophysical measurements

6.1. Measurement errors. Random measurement errors, sources, quantification. Random errors of indirect measurements. Dynamic measurement errors.
6.2. The structure of the measuring channel and the characteristics of the elements.
6.3. Inverting amplifier of electrical signals. Non-inverting amplifier of electrical signals. Differential amplifier of electrical signals. Digital integrator.
6.4. First order low-pass filter. Second order low-pass filter. First order digital filter.
6.5. Discretization of continuous signals in time. Discrete signal spectrum. Restoration of a discrete signal, a condition for the accuracy of restoration. Kotelnikov’s theorem. Correctness of discrete signal recovery. Discretization and restoration of a sinusoidal signal.
6.6. Measurement of pulsating pressure, basic requirements for the characteristics of sensors. Dynamic characteristics of sensors for measuring pulsating pressure. Frequency and phase distortions that occur when measuring pulsating pressure with sensors. Influence of the air channel on the frequency characteristics of sensors for measuring pulsating pressure.

7. Measurement of total and distributed aerodynamic loads

7.1. Coordinate axes. Aerodynamic coefficients.
7.2. Elastic elements of strain gauges for measuring longitudinal, lateral, normal aerodynamic forces and moments of pitch, roll and yaw.
7.3. Six-component intra-model scales, the effect of temperature and methods for reducing temperature error.
7.4. Dynamic characteristics of scales.
7.5. Development of multi-point instruments for determining the distribution of pressure in models.
7.6. Miniature intra-model pressure sensors, device, principle of operation and main characteristics.
7.7. Sensors for measuring pressure pulsations.
7.8. Drainless panoramic method for determining pressure distribution. Luminescence of dyes, characteristics of a luminescent pressure transducer. Principles of excitation and registration of luminescence.

8. Temperature and heat flux measurement

8.1. Contact and non-contact methods of temperature measurement. Measuring the temperature of gas flows, the inertia of temperature receivers.
8.2. Optical methods for measuring the temperature of gas flows and the surface temperature of models.
8.3. Normal mode method. Calorimetric heat flow sensors. Microcalorimeters with anisotropic heat-insulating sleeve. Heat sensitive coatings.
8.4. Measurement of heat flux in short-term hypersonic installations.

9. Automatic control theory

9.1. Solution for differential equations of linear systems state. Transition matrix and matrix transition function.
9.2. Controllability of linear systems with constant parameters. Canonical form of controllability. Stabilization. Matrix transfer function and frequency response of the system.

9.3. Connection of impulse transition function, transfer function and frequency response of the system. Zeros and poles of matrix transfer functions.
9.4. Stability of automatic systems. Algebraic stability criteria. Stability boundary.
9.5. Routh-Hurwitz criterion. Mikhailov and Nyquist criterion.
9.6. Optimal restoration of the linear systems state. Optimal observers.
9.7. Stochastic approach to the observation problem. Integral quadratic form as a measure of the universal observer.
9.8. Differential equation for the matrix of variances of the recovery error. Structure and established properties of the optimal observer.
9.9. Deterministic problem of linear optimal control. Statement of the optimization problem. Integral quadratic optimality criterion.
9.10. Differential Equation for the optimal gain matrix. Stochastic problems of linear optimal control.
9.11. Synthesis of a stochastic linear optimal controller. Structure of the optimal controller.

10. Random process

10.1. Definition of a random process (function), laws and moments of its distribution.
10.2. Types of random processes: discrete, continuous-valued, stationary, normal, Markov’s.

10.3. Addition, differentiation, integration of random processes. Ergodicity of random processes. Spectral density.
10.4. Transformation of random processes by linear and nonlinear dynamical systems. Method of correlation matrix and statistical linearization.

11. General theory of measurement

11.1. Point methods for estimating distribution parameters (maximum likelihood method, method of moments, least square method).
11.2. Confidence estimation of normal linear regression parameters.
11.3. The concept of statistical hypothesis. General method for constructing goodness of fit criterion.
11.4. General linear hypothesis of normal regression. Optimal estimates of measured scalar quantities with a known distribution law.
11.5. The concept of digital methods for analyzing time series (filtering, smoothing, estimating the covariance function and spectrum density function).
11.6. Statement of the problem of planning an experiment to estimate the parameters of the regression model.

12. Flight research

12.1. The role of flight research in the creation of aircrafts. Advanced flight research on the formation of the basic concepts for the creation of advanced aircraft.
12.2. Research on the problems of aerodynamics, stability, controllability, maneuverability, etc. Flying laboratories, analogue aircraft, flying models.
Information support of the flight experiment.
12.3. Measuring tools. The necessary composition of the measured parameters and the characteristics of information-measuring systems for various kinds of flight research.
12.4. The main types of primary information sensors. Static and dynamic characteristics of sensors and their influence on the methodology of the experiment.
12.5. Systems for collecting and transmitting information. Radio engineering and optical means of external trajectory measurements.
12.6. The use of satellite technologies and flying aircraft measuring systems in the global systems of external trajectory measurements

12.7. New information technologies: databases, knowledge bases, information-reference and expert systems. Global Information Networks
12.8. Ensuring the safety of the flight experiment. Technical means and methods for improving flight safety: signaling devices and indicators of dangerous modes; choice of restrictions on motion parameters; sequence of modes. Special instructions to the crew.

Reference

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Specialty 2.5.12.
Aerodynamics and heat transfer processes of aircraft

PART II

1. **Fundamentals of theoretical aerodynamics**

1.1. *Effects of force on moving bodies*. *Basic concepts, definitions, hypotheses*. The movement of aircraft in a continuous medium, effects of force. The main parameters of the gas characterizing its state. Gas compressibility. Viscosity. Continuity hypothesis. The main vector of aerodynamic forces, moments, the concept of the center of pressure. General expression for aerodynamic force (dimensions and similarity theory), aerodynamic coefficients of forces and moments. similarity criteria. M and Re numbers. Frictional stress. Turbulence hypotheses. General characteristics of aerodynamic coefficients.

1.2. *Basic Equations for the Conservation of Aerodynamics*. Methods for studying gas motion. Lagrange and Euler methods. The concept of the streamline and the trajectory of motion. Movement of a liquid particle. Potential and vortex flows. Helmholtz theorem. Basic equations of aerodynamics. Investigated system of physical bodies. Liquid (gas) models. Continuity equations for the gas component i (for a mixture). Integral and differential forms of writing. Navier-Stokes equation. Differential equations of motion for an inviscid fluid (Euler equations). Energy equations for finite and infinitesimal volumes. Specific energy along the streamline for an inviscid fluid under adiabatic flow conditions. A generalized form of writing the aerogasdynamics conservation equations. Equation of state of perfect and real gas. Integrals of the equation of motion. System basic equations. Initial and boundary conditions. Modern numerical methods for solving the Euler, Navier-Stokes equations and their asymptotic models.

1.3. *One-dimensional isentropic steady gas flow*. Distribution of small perturbations in a gaseous medium. Relationship between gas flow rate and cross-sectional area. Gas parameters in isentropic flow. Relative velocities (M, λ , Cr) and their relationship. Critical values of parameters. Effect of compressibility on stagnation pressure. Gas dynamic functions.

1.4.*Shock wave theory*. The nature of shock waves. Schemes for calculating flow parameters at the shock wave. Theory of a direct shock wave. System of basic equations for the case of constant heat capacities. Calculation of gas parameters after the shock wave. Processes of shock and isentropic compression. Entropy change at the shock wave. Deceleration parameters behind a direct shock wave. Theory of an oblique shock wave (constant heat capacities). System of basic equations. The angle of inclination of the shock front. Velocity, pressure, density, temperature behind the shock wave. Shock polar. System of equations and algorithm for calculating flow parameters behind the shock, taking into account physical and chemical transformations. Influence of physicochemical transformations in gas on flow parameters behind shock wave. Reflection of shock waves from solid and free boundaries. Interaction of shock waves. Interaction of shock waves with a rarefaction wave.

1.5.*Methods of characteristics and linearization*. Basic kinematic equation of aerodynamics and methods for its solution. Method of characteristics. Cauchy problem. Characteristics in the planes of flow and velocity hodograph. Characteristic properties. Solution of the equations of characteristics in the plane of the velocity hodograph. Typical problems solved by the method of characteristics. Numerical and graphic solution of problems. Supersonic flow around fractures of surfaces (Prandtl-Meyer expansion fan).

Small perturbation theory. Linearization of the basic equations of ideal gas dynamics. Solutions of linearized equations of gas dynamics.

1.6.*Vortex and potential motion of an ideal incompressible medium*. Vortex motions in an ideal continuous medium. The concept of speed circulation. Stokes' theorem. Kelvin's theorem. Helmholtz theorem. Determination of the field of velocities from a given field of vortices. Generalization of the Biot-Savart field. Velocities induced by a vortex (a segment of a vortex cord, a vortex ring). Interaction of a vortex with a moving medium. Plane potential motion of an ideal incompressible medium.

Potential flow method. Complex potential and complex velocity. Connection of the plane and hydrodynamic problems with the theory of functions of a complex variable. The simplest flat potential flows (rectilinear steady flow, flow inside a right angle, source and sink, dipole, vortex). Non-circulating and circulating flow around a round cylinder. The Euler-D'Alembert paradox. Forces and moments acting on a regular cylinder. Zhukovsky-Chaplygin method.

1.7.*Boundary layer*. Differential equation of a laminar boundary layer. Laminar boundary layer on a flat plate in an incompressible flow and at high velocities. Laminar boundary layer under pressure gradient. Weak and strong interactions. Accounting for 2nd order effects. Approximate methods for calculating the laminar boundary layer. Transition of a laminar boundary layer into a turbulent one. Turbulent boundary layer. Equations of the averaged turbulent boundary layer. Reynolds stress. Detachment of the laminar and turbulent layer. Methods of experimental study of transition and detachment.

1.8.*Aerodynamics of hypersonic speeds and rarefied gas*. General properties of hypersonic flows. Hypersonic theory of small perturbations. Hypersonic theory of Newton-Busemann. Influence of physicochemical processes on supersonic and hypersonic flows around blunt bodies. The concept of equilibrium, non-equilibrium and frozen flows. Characteristic features of weakly rarefied gas flows. Free molecular flow around bodies. Knudsen number. Models of the interaction of a free molecular flow with an aircraft.

2. Aerodynamics of aircraft

2.1.*Aerodynamics of a wing*. Profile and wing of finite span in an incompressible fluid flow. Thin airfoil theory. Aerodynamic characteristics of profiles. A wing of finite span in an incompressible fluid flow. Theory of a vortex carrier thread. The theory of the bearing surface. Calculation of aerodynamic characteristics at high angles of attack. Features of the distribution of the load on the wings of different shapes in plan. Theoretical and experimental studies of thin wings of small aspect ratio at high angles of attack, taking into account flow separation.

Profile and wing in a subsonic compressible gas flow. Linear theory of the wing. Relationship between the aerodynamic characteristics of a wing in compressible and incompressible flows.

Profile and wing at transonic speed. Critical Mach number. Similarity laws for transonic flows. Aerodynamic characteristics of profiles and wings at transonic speeds.

Profile and wing in supersonic flow. Thin plate in supersonic flow. Linear theory of thin airfoil and finite span wings in supersonic flow. Singularity method. Thin profile in hypersonic flow. Aerodynamic characteristics of wings at supersonic speed.

Aerodynamic characteristics of wings and empennage with deflected control surfaces. Aerodynamic characteristics of wings with mechanization. Influence of the shape of the wing on the efficiency of mechanization. Aerodynamic characteristics of the empennage with deflected rudders. Hinge moments of steering surfaces.

2.2. *Aircraft body aerodynamics*. Aircraft body at subsonic and supersonic speeds. Aerodynamic characteristics of hulls at subsonic speed. Flow around at transonic speed. Critical Mach number. Aerodynamic characteristics of hulls at transonic speed. Cone in supersonic flow. A blunt cone in a supersonic flow. Pointed object in supersonic flow. A blunt object of revolution in a supersonic flow. Aerodynamic characteristics of hulls and engine nacelles with air intakes. Hypersonic flow around blunt objects. Influence of real gas properties on aerodynamic characteristics of objects at hypersonic speed.

2.3. *Aerodynamic interference*. The nature of aerodynamic interference. The lift force of the hull and wing combination. Effect of bank angle on interference between hull and wing. Cross combination. Interference between wing and tail. Controls. Aerodynamic calculation of rudders.

Aerodynamic characteristics of the aircraft. Lift, drag. Polars of the first and second kind. Moments of pitch and yaw. Roll moment. Aerodynamic characteristics of an aircraft with takeoff and landing mechanization. The influence of the earth.

2.4. *Aerodynamic characteristics of helicopter's rotors and propellers*. Main rotor in vertical takeoff and descent mode. Vortex ring mode. Self-rotation. Rotor in oblique flow modes. Traction force, propulsion force, power. Flying movement of the blades. Blowing the helicopter body with a main rotor. Ways to create control moments. The perfect propeller. Similarity criterion. Screw charts. The relationship between tractive force and power. Flight and relative efficiency of a real propeller. Vortex theory of the propeller. Coaxial screws.

3. Aircraft heat transfer processes

3.1. *Friction and heat transfer*. Laminar heat transfer at high speeds and temperatures. Similarity laws in heat transfer problems. Integral characteristics of the boundary layer. Heat transfer at low velocities in the boundary layer of an incompressible fluid. Heat transfer coefficients at high speeds. Relationship between friction and heat transfer. The transition from laminar to turbulent flow. Turbulent heat transfer at high speeds and temperatures. Approximate theories of turbulent motion. Approximate methods for calculating heat transfer in a turbulent boundary layer.

Heat transfer during chemical reactions in the boundary layer. Differential equations of diffusion for a laminar boundary layer in a mixture of reacting gases. Energy equation. Chemically equilibrium boundary layer. Chemically nonequilibrium flow on the catalytic wall. Calculation of heat transfer in the reacting gas.

Heat transfer on the surface of aircraft in three-dimensional flow. Flow in a three-dimensional boundary layer. Differential equation of a three-dimensional boundary layer. Attachment-lines. Calculation of heat transfer in three-dimensional laminar flow in the boundary layer. Combined effect of injection and roughness on heat transfer. Flow in open areas. Boundary layers in an inhomogeneous external flow.

Heat transfer in a rarefied gas. Theory of heat transfer in a rarefied gas. Regimes of thermal and dynamic processes. Heat transfer in the free molecular and transition regions of the flow. Methods of experimental study of heat transfer.

3.2.*Heat transfer in structural elements of aircraft*. Basic concepts and equations of the theory of thermal conductivity. Boundary conditions in thermal conductivity problems. Methods for solving thermal conductivity problems. Analytical methods. Numerical solution of the problem of thermal conductivity. Modeling of temperature fields. Transfer of radiant heat to aircraft and inside structural elements. Basic definitions and equations of heat transfer by radiation. Methods for solving radiation transfer equations. Heat transfer by radiation inside an absorbing, radiating and scattering medium. Temperature fields in thin-walled aircraft. Heating and cooling of a body with the same temperature in volume. Aerodynamic heating of the skin. Uneven temperature distribution over the surface of a thin-walled structure. Temperature fields in reinforced structures.

3.3.*Thermal protection of aircraft*. Methods of thermal protection. Types of heat-shielding materials. Heat transfer inside heat-shielding coatings. Thermal resistance of the thermal insulation layer. Non-stationary thermal conductivity in multilayer structures. Approximate methods for calculating the heating of thin-walled structures with thermal insulation. Aerothermochemical destruction of thermal insulation. Methods of experimental study of heat-shielding coatings and materials used in aircraft under conditions of intense thermal exposure. Methods and features of thermal testing of aircraft structures.

Reference

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Specialty 2.5.16.
Dynamics, ballistics, aircraft motion control

PART II

1. Theory of automatic regulation and control

1.1. Solution for differential equations of linear systems state. Transition matrix and matrix transition function.
1.2. Controllability of linear systems with constant parameters. Canonical form of controllability. Stabilization. Matrix transfer function and frequency response of the system.
1.3. Connection of impulse transition function, transfer function and frequency response of the system. Zeros and poles of matrix transfer functions.
1.4. Stability of automatic systems. Algebraic stability criteria. Stability boundary.
1.5. Routh-Hurwitz criterion. Mikhailov and Nyquist criterion.
1.6. Optimal restoration of the linear systems state. Optimal observers.
1.7. Stochastic approach to the observation problem. Integral quadratic form as a measure of the universal observer.
1.8. Differential equation for the matrix of variances of the recovery error. Structure and established properties of the optimal observer.
1.9. Deterministic problem of linear optimal control. Statement of the optimization problem. Integral quadratic optimality criterion.
1.10. Differential Equation for the optimal gain matrix. Stochastic problems of linear optimal control.
1.11. Synthesis of a stochastic linear optimal controller. Structure of the optimal controller.

2. Classical calculus of variations.

Statements of problems in the calculus of variations. General form of the first variation. The main lemma of the calculus of variations. Euler-Lagrange equations. Ostrogradsky equation. Problems with a movable right (left) end. Transversality condition. Erdmann-Weierstrass conditions. Unilateral variations. The field of extremals. Conjugate point. Jacobi condition and equation. Weierstrass function. Strong and weak extremes. Necessary and sufficient optimality conditions for the simplest problem of the calculus of variations. Legendre condition. Variational problems for a conditional extremum. Holonomic and nonholonomic constraints. Isoparametric problems.

3. Pontryagin’s maximum principle for problems of optimal control of dynamical systems

Mathematical formulation of problems of optimal control of a dynamical system. Problems of Lagrange, Mayer, Bolz. Classical approach to the definition of optimal programs. Hamiltonian. Necessary optimality conditions in this approach. Needle control variations. Pontryagin's maximum principle for solving problems with free right end and fixed time. Variations of the trajectory and the cone of end variations of the phase vector. Necessary optimal conditions in the maximum principle. Pontryagin's maximum principle in problems with fixed and non-fixed time and movable right end. Transversality conditions.

Continuity of the Hamiltonian. Legendre-Clebsch condition. The Pontryagin maximum principle for Lagrange, Mayer, Bolz problems with different types of control and trajectory conditions. Discrete maximum principle. Energy approach and singular perturbation method for optimal planning of aircraft trajectories in solving transport problems.

4. Methods for solving two-point boundary value problems.
Newton's method, sweep methods, Abramov, Krylov-Chernous’ko’s methods. The sweep method for a linear-quadratic optimal control problem. Riccati equation.

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