ENTRANCE EXAMINATION PROGRAM

FOR PHYSTECH SCHOOL OF AEROSPACE TECHNOLOGY
COMPUTER SCIENCE AND INFORMATION TECHNOLOGY
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 1.2.2.
Mathematical Modeling, Numerical Methods and Program Complexes

PART II

1. Mathematical foundations

1.1. Fundamentals of the theory of limits. Implicit function theorem. Taylor’s formula. Basic theorems of integral calculus (change of variables, method of integration by parts, integration of rational functions). Numerical series (convergence criteria for constant and alternating series). Function series. Power series. Fourier series (calculation of coefficients).

1.2. Matrices and determinants of the nth order. Vector coordinates in basis. Transformation of coordinates of vectors when changing the basis of space. Operations on matrices. Matrix rank theorem. General solution of a system of linear equations. Homogeneous systems (space of solutions, fundamental systems of solutions). Eigenvectors and eigenvalues of a matrix.

1.3. Formulas for changing coordinates when moving from one Cartesian coordinate system to another. Calculation of scalar products, lengths of segments, angles. Curves and surfaces of the 1st and 2nd order.

1.4. Existence and uniqueness theorems for the solution of the Cauchy problem for a differential equation and a normal system. Linear equation of the nth order. Construction of a general solution of a linear equation. Inhomogeneous linear systems. Linear systems of differential equations with constant coefficients.
1.5. Basic equations of mathematical physics: heat equation, Laplace and Poisson's equations, wave equation. Radiation transfer equation in an absorbing, radiating and scattering medium. Correct statement of boundary value problems.
1.6. Solution of the homogeneous heat equation on a straight line.
1.7. General ideas about ill-posed problems. Fredholm equations of the 1st and 2nd kind. Regularization methods (Obukhova A.M., Tikhonov A.N., statistical regularization).
1.8. Fourier method for limited areas.

2. General questions of computational mathematics

2.1. Numerical solution of systems of linear algebraic equations. Conditioning. Direct solution methods (types of the Gauss method, sweep method). Iterative methods (method of simple iteration, the idea of Chebyshev acceleration of iterative methods, etc.).
2.2. Solving systems of nonlinear algebraic equations. The secant method, Newton's method. Theorem on the convergence of Newton's method. Method of simple iterations, convergence analysis.
2.3. Numerical differentiation: basic methods of approximation of 1st and 2nd derivatives. Approximation error, rounding error. The optimal step of numerical differentiation. Method of undetermined coefficients.
2.4. Numerical integration: Newton-Cotes quadrature formulas, Gaussian quadrature formulas. Estimation of the integration error. Runge's rule. Richardson extrapolation.
2.5. Methods for searching for extrema of functions of several variables. Gradient, coordinate and random descent.
2.6. Numerical solution of the Cauchy problem for ODE systems. The simplest difference schemes and their implementation. Runge-Kutta methods, basic construction, implementation algorithm, stability. Convergence theorems. Solution algorithm, approximation, convergence.
2.7. Boundary Value Problems for ODE Systems. Reduction of a linear boundary value problem to Cauchy problems. Nonlinear boundary value problems for ODE systems. Shooting method, Newton's method.

3. Methods for solving partial differential equations

3.1. Numerical methods for solving equations of hyperbolic type. Characteristic form of equations. Correct statement of boundary conditions. Schemes for the simplest transport equation: approximation, stability, convergence, monotonicity.
3.2. Numerical methods for solving equations of parabolic type. Explicit and implicit schemes. Sweep method. Spectral stability. Two-dimensional heat conduction equation. The problem of solving equations on the upper layer. Method of alternating directions in two-dimensional and three-dimensional problems.
3.3. "Cross" difference scheme for the Poisson's equation. Difference approximation of the Poisson's equations. Method of simple iterations, error, discrepancy. Spectral analysis of the convergence of simple iterations.
3.4. One-dimensional nonlinear partial differential equations, their difference approximation and implementation of the corresponding schemes. Schemes with nonlinearity on the upper and lower layers, their implementation (Newton's and sweep methods).
3.5. Spectral signature of stability and practice of its application. The principle of frozen coefficients. Courant-Friedrichs-Lewy stability condition. Stability with respect to initial data and boundary conditions.

4. Additional questions of computational mathematics

4.1. Stiff systems of ordinary differential equations (ODE). Numerical methods of solution. A – stable, A(α) – stable methods, asymptotic stability.

4.2. Explicit and implicit Runge-Kutta methods, basic construction, implementation algorithm, stability. Analysis in the space of undetermined coefficients. Stability function of Runge-Kutta methods.

4.3. Linear multistep circuits (Adams). Circuits for extended systems (Obreshkov's circuits). Approximation, stability, convergence, analysis in the space of undetermined coefficients.

4.4. Examples of methods for solving equations of hyperbolic type. Hybrid circuit. Riemann invariants on the example of the system of equations of acoustics. Comparison of methods in the space of undetermined coefficients.

4.5. Solutions of the Poisson's equations by finite difference methods. Method of simple iterations, error, discrepancy. Choice of the optimal iterative parameter. Chebyshev acceleration method, stability analysis, stable renumbering of iteration parameters. The concept of variational methods for solving systems of linear algebraic equations.

4.6. The method of variable directions for solving the Poisson's equation. Spectral analysis of convergence. Choice of the optimal iterative parameter. Estimation of the number of iterations. Method of alternating directions with a series of parameters.

4.7. Methods for searching for extrema of functions of several variables. Gradient, coordinate and random descent. Representation of methods for solving nonconvex problems.

4.8. Setting ill-posed problems. Examples. Qualitative description of the approach to their solution. The role of a priori information. Examples - the integral equation of the 1st kind, the inverse problem of heat conduction.

5. Parallel computing

5.1. Multiprocessor and distributed systems. Costs and benefits in the implementation of parallel and vector computing.

5.2. MPI message-passing model. PVM data transfer model. Two Paradigms of Parallel Programming: Data Parallelism and Task Parallelism.

5.3. Three parts of a parallel program (parallel, serial, data exchange). Synchronization of processes, uniformity of processor loading. Review of software tools for parallelization.

5.4. Classes of problems that can be efficiently vectorized and parallelized. Processing one-dimensional and two-dimensional arrays. Scientific tasks. Calculations at the nodes of grids and lattices.

6. Object oriented programming

6.1. The content of the object-oriented model. The concepts of abstraction, encapsulation, polymorphism, typing and their implementation in programming languages.

6.2. Encapsulation. Modification and optimization of programs using encapsulation.

6.3. Inheritance. Code reuse. Polymorphism as a means of ensuring the extensibility of programs. The concept of an interface.

6.4. The concept of properties and events in object technologies. Aggregation. Persistence of objects.

6.5. Class diagrams. Concepts and principles of object-oriented design.

6.6. CASE - tools and their use for automating the design of programs.

7. Computer simulation

7.1. Problems of numerical modeling in continuum mechanics. Areas of scientific and industrial application.

7.2. Modeling cycle from problem setting to post-processing.

7.3. Classification and structure of modern software systems. Criteria for evaluating opportunities. Problem-oriented testing. Register of Russian software.
7.4. Constructed and adapted geometric model. Geometric preprocessing. Types of computational grids. Requirements for the computational grid in terms of ensuring the accuracy of the solution.
7.5. Calculation model. Use of similarity criteria and symmetry properties. Modeling of stationary and non-stationary processes. Typical classes of problems.
7.6. Organization of calculation in multiprocessor systems. Scalability.

References

Mathematical Foundations

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8. Тихонов А.Н., Арсенин В.Я. Методы решения некорректных задач. М.: Наука. 1979 г. –288 с.

General questions of computational mathematics

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