particular, a Branch Reference on the determination of thermal loads on construction elements by the methods of inverse problems of heat conduction was developed and published at the Moscow Aviation Institute. The methods for the solution of conjugate and uncorrected inverse problems developed by the Moscow Aviation Institute, the Institute of Heat and Mass Exchange, Academy of Sciences of the Belorussian SSR, Moscow State University, the Khar'kov Aviation Institute, and a number of others have been put into practice in the work of a number of scientific-research and design—construction organizations. Automated complexes for the treatment of the data of thermal experiments are being created. All these studies and projects are in the stage of quite intensive growth and development.

The addresses and reports discussed at the Second All-Union Seminar and approved for publication by the Organizational Committee of the seminar are presented in this issue of "Inzhenerno-Fizicheskii Zhurnal" (Journal of Engineering Physics).

SOME PROBLEMS IN THERMAL DESIGN FOR AIRCRAFT AND THEIR EXPERIMENTAL TREATMENT

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The status and some methodological problems of thermal studies, thermal design, and the treatment of experimental results from thermal tests are discussed.

In recent years, inverse heat-transfer problems have become one of the basic modalities for investigation of heat transfer and for simulation of the thermal regimes in many technical systems. A characteristic feature of modern methods for the solution of inverse problems is the orientation toward machine technology. "Manual" methods are used only in the simplest cases and do not change this general trend. Thus one can talk of machine methods for the solution of inverse heat-transfer problems and of machine methods for machine simulation based on the concept of the inverse problem.

The analysis and interpretation of the results of thermal experiments continue to be the main field for application of the inverse heat-transfer problem. It was in precisely this field that the greatest advances of theoretical and applied nature were achieved from the viewpoint of the effectiveness of the methods and the breadth of their practical application. This field of application for the methods of the inverse heat-transfer problem includes the determination of boundary conditions, the reconstruction of temperature fields, the determination of contact thermal resistances, and the determination of heat- and mass-transfer coefficients. In planning practical applications, corresponding methods are used for experimental studies of nonsteady heat transfer, for constructing low-inertia thermal-flux sensors, for identifying heat- and mass-transfer processes in heat-resistant materials and coatings, for determining and controlling optimal heating and cooling conditions for materials used in various technical processes, etc.

A methodology is also beginning to be developed for the solution of inverse problems of identification and correction of thermal models of complex technical systems, for example, in the thermovacuum testing of spacecraft.

The production of results of acceptable accuracy often requires considerable complexity in a thermal model of a process or technical system under investigation and the development of more complex and refined methods for the solution of the inverse heat-transfer problem. All this leads to an increase in the consumption of machine time. If one considers that the analysis of an actual or simulated thermal experiment always passes through several stages with a multiplicity of repeated calculations and different refinements, the occasional interaction of an investigator with a computer entails not only a significant increase in the total time for data analysis, but also a sometimes undesirable reduction in the number of possible variations of the analysis with loss of accuracy and information content in the results. Thus a need has arisen in many thermal experiments for automation of all information analysis starting with the collection, systematization, and editing of primary statistical and determinant analysis before solution of the inverse

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problem and the production of final results. The automated nature of the analysis of data from thermal experiments imposes rigid requirements on the algorithms and programs for the solution of the inverse heat-transfer problem. These are primarily related to accuracy, speed, assurance of the principle of program modularity, and the possibility of complete elimination of the operator from the process of analysis.

Automated methods for the solution of inverse problems are of great importance at various stages in the development and refinement of mathematical models involved in thermal designs for aircraft. In the construction of mathematical models, it is necessary to ensure a definite degree of adequacy of the test thermal object with respect to satisfaction of the requirements for model simplicity and convenience in working with the model. Since the functioning of objects in thermal design is characterized by the occurrence of complex, interrelated, and sometimes even insufficiently understood physicochemical processes, the competence of a model is usually checked during the course of specially formulated experiments. In this way, not only are the characteristics and parameters of thermal models checked, but their structure is also modified so that design results of satisfactory accuracy are obtained. The choice and refinement of thermal models for design objects must be based to a considerable extent on the inverse heat-transfer problem. The reason for this is that the determination, based on classical methods, of the development of models of dynamic processes used in the analysis of equation systems proves to be unfruitful for thermal models in many cases. This is associated with the difficulties of realizing input effects of special form, with nonlinearities in the differential equations describing heat-transfer processes, and with the variability of the coefficients. The study of objects in thermal design and of the conditions under which they operate is based on a mathematical description corresponding to the space state of a dynamic system. Such an approach is fruitful in thermal-design practice. It permits extensive and complete use of the capabilities of modern computing technology and the determination of a model with arbitrary variation of the input functions. This approach is based on the use of the inverse heat-transfer problem.

The inverse heat-transfer problem belongs to the improperly formulated problems. The property specified requires thorough investigation and justification of the method chosen for solution depending on the type of inverse problem, and on the characteristics of its use in thermal simulation and in specific experimental studies. It is also necessary to organize a careful correlation of the methods for solution of the inverse problem with the methods for primary analysis of experimental information.

A subject for detailed study at the Moscow Aviation Institute at the present time is precisely such a comprehensive analysis of the areas for applicability of various methods for solution of the inverse heat-transfer problem together with optimal design of experimental studies and measurements.

The selection of parameters for a heat-resistant system is of great importance in thermal design for a number of aircraft. The complexity of the physicochemical phenomena occurring during the operation of such craft in responsible for the need to carry out an extensive program of experimental studies both on specially constructed test stands and installations on the ground and by the performance of actual or simulated flight experiments. The purpose of such studies can be, for example, an evaluation of the accuracy of existing methods for the calculation of heat transfer, the determination of the area of applicability of one method or another, a study of the performance of heat-resistant materials, etc.

A modern thermal experiment, and even more one in flight, is exceptionally expensive and complex so that its performance demands thorough preparation and primarily scientifically sound, efficient planning. Planning provides a clear logical scheme for performance of the experiment, increases the efficiency and accuracy of the results, and makes possible the saving of time and materials in the performance of the experiment.

The problems in experimental design include a means for selection of a heat-transfer model or of a mechanism for breakdown of a heat-resistant material, a means for setting up the measured parameters, for optimal arrangement in space and time of the measuring equipment, and for selecting a method for analyzing the results. They also influence the selection of the design for the experimental installation and model.

A large portion of the problems which arise in the planning of a thermal experiment can obviously be related to the problems in planning experiments for the determination of a mechanism for a process, i.e., for seeking mathematical models describing a process under investigation. Less attention than is deserved is being devoted to this field of the mathematical theory of experimental design of experiments at the present time; this particularly concerns the practical application of the methods for planning such experiments.

Thus the problem of obtaining the greatest amount of information about a heat-transfer process under study with minimum consumption of material and time is a pressing one at the present time. Mathematical methods for planning experiments, in contrast with existing methods, make it possible to reduce the number of tests, to reduce experimental error, to obtain a mathematical model possessing certain optimal properties, and to evaluate the basic effects of interactions.

It is practically impossible to consider all the numerous and interrelated processes occurring under actual conditions. It is difficult to evaluate the correctness of the choice of computing scheme and the reliability of the results.

Numerical simulation on a computer is an important and presently intensively developing trend in the study of complex processes in heat and mass transfer. A machine experiment acquires special importance in those cases where a sufficiently complete experimental study of a phenomenon is difficult.

One such problem is nonsteady heat transfer during the interaction between a solid and a gas flow. A mathematical model of the process sufficiently close to the actual physical picture can be constructed on the basis of a coupled heat-transfer problem where simultaneous solution of the nonsteady-state equations of the gaseous boundary layer and of heat transfer in the solid is considered. Boundary conditions of the fourth kind are assigned at the interface between the solid and gaseous regions. Such a formulation of the problem makes it possible to consider the mutual thermal effect of gas and solid and to evaluate the dependence of the parameters for nonsteady heat transfer on the geometric and thermophysical characteristics of the solid. In addition, coupled problems provide an opportunity to establish general relationships in nonsteady heat transfer, including the effect of a whole series of controlling parameters, the experimental determination which requires numerous and expensive experiments. All this is evidence that the study of coupled problems may be an extremely timely trend in the theory of heat and mass transfer.

In our studies, coupled problems were used in the analysis of nonsteady thermal interactions between a solid and a laminar flow of fluid or dissociated air around it. For example, in the latter case a five-component model of an air mixture was considered with the chemical reactions in the boundary layer included. It turned out that the parameters for nonsteady heat transfer in the solid—gas system were practically independent of the thermophysical and geometric characteristics of the solid,while in the solid—liquid system the difference between nonsteady heat-transfer parameters and the corresponding quasisteady parameters might be considerable.

It should also be noted that a numerical solution of coupled problems in heat and mass transfer is a complex problem in computational mathematics. The desired mathematical model is not always realized because of the limited capacities of modern computing technology. However, it is safe to say that coupled problems remain, and will remain, a powerful instrument in studies of the relationships in nonstationary heat and mass transfer.

To perform high-quality thermal experiments appropriate to the modern level of technical development, it is necessary to create a new system for the analysis of experimental information from the viewpoint of methodology. Such a system must possess a high degree of automation in all computational procedures. Automation not only makes it possible to perform the analysis operationally but also increases the accuracy of the final results.

Preliminary analysis of experimental data takes on great importance in automated analysis. The purpose of preliminary analysis is to put all experimental information into a form suitable for solution of subsequent problems, particularly inverse heat-transfer problems.

At the present time, statistical analysis has received widespread acceptance as preliminary (primary) analysis. On the basis of experience in the study of a broad class of random processes, the methods of mathematical statistics make it possible to perform sufficiently detailed analysis of experimental results and provide an opportunity to evaluate the quality of the experimental information obtained.

The results of the primary analysis also have a direct effect on the solution of the inverse heat-transfer problem.

The use of the results from statistical analysis also have a direct effect on the solution of the inverse heat-transfer problem.

The use of the results from statistical analysis in the determination of thermal boundary conditions makes it possible to increase the accuracy in obtaining desired values of thermal flux and surface temperature, and to expand the area of application of individual algorithms for the inverse heat-transfer problem.

Any experimental data carry, in addition to useful information, distortions of all kinds superimposed as the result of the operation of measuring equipment, of insufficiently modern technology in the preparation of detectors, etc. In addition, the processes under investigation may themselves possess some statistical variability. The methods of statistical analysis provide an opportunity to evaluate all the distortions superimposed on the experimental data obtained.

In studying thermal conductivity, one is forced to deal with nonsteady states fairly often, and the use of traditional statistical methods is rarely successful in practice because they all were developed for steady-state processes. In the analysis of nonsteady-state processes, it is necessary to consider a narrow range of random processes and to construct hypotheses.

The situation is often complicated by greatly limited experimental information such as a single realization of a random process under study. Preliminary studies showed that even under such significantly limited conditions, statistical analysis yields acceptable results.

As already stated, mathematical simulation of the thermal regime of an aircraft as one of the factors determining its appearance and parameters plays an important role in the design of aircraft and also in the development of other objects in new technology. As a rule, previously checked experimental and theoretical relationships and methods are used in mathematical simulation describing thermophysical processes. A mathematical thermal model set up for studying the thermal regime of an aircraft makes it possible to investigate its thermal regime under various external load conditions, to take account of the variability in the thermophysical characteristics of materials and coatings, and, in addition, to consider the ranges introduced in the design solution.

Various hypotheses and methods are used in the formulation of mathematical thermal models. Recently, methods based on the use of elements of the theory of graphs were introduced into the practice of mathematical simulation. These methods are distinguished by their newness and can be used successfully for automated design of aircraft and other objects in new technology.

In a number of cases, mathematical simulation makes it possible to study thermophysical processes, the physical simulation of which cannot be achieved successfully under surface conditions. Among such processes are thermogravitational convection of low-boiling fluids in the fuel tanks of aircraft under weak-field conditions and some others.

Mathematical simulation plays an important role in studies of coupled heat-transfer problems in design structures of complex configuration since, within the limitations of the thermal model of the structure, it makes it possible to consider the course of thermophysical processes, to investigate their interaction, to solve optimization problems for the thermal mode of the structure, etc.

It should be noted that optimization of the thermal mode of an aircraft is closely connected with the solution of the inverse heat-transfer problem in structures of complex form. Among such problems, for example, is the reconstruction of the temperature profile in interconnected elements of a structure under study from known values of the temperature in individual elements. Although these problems are complex even in the plan advanced, one can hope that their solution will be obtained in the immediate future.