INVERSE AND CONJUGATE PROBLEMS OF HEAT EXCHANGE*

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The Twenty-Fifth Congress of the Communist Party of the Soviet Union devoted much attention to the problems of increasing the efficiency and quality of public production, including the efficiency and quality of scientific research and technological solutions. In this sense the development and introduction of methods of scientific research and of methods of modeling and designing technological systems that are scientifically sound and effective in practical use must be considered as a definite contribution to the solution of this problem.

In the creation of new technological models whose functioning is accompanied by the occurrence of intense thermal processes, a major role is assigned to thermal design, the modeling of thermal regimes, and thermal experiment. For example, the design and experimental development of systems for the heat shielding and thermal regulation of flying descent vehicles, interplanetary spaceships, probe craft, artificial satellites of the earth and planets, and reusable space-transport systems are closely connected with the solution of a whole complex of problems of a heat- and mass-exchange character.

The rational selection of the design parameters of such systems and even the very appearance of many designed objects are determined by the thermal conditions of the interaction with the surrounding medium. In many cases of practical importance the processes of heat and mass exchange have a very complex and transient nature. In the various stages of the design, from the development of the proposals to the technical design and experimental development, ever more complicated calculating models and methods, more fully allowing for individual thermal phenomena and processes, are used.

Experimental thermal studies, bench work, and full-scale tests usually consist of unique individual events, the accomplishment of which is accompanied by great economic expenditures.

It is natural that the correct statement of the problems of thermal design and modeling of thermal regimes and the choice of efficient methods of treatment and analysis of the results of thermal experiments have exceptionally great importance under these conditions. And on this plane inverse problems of heat exchange, being the means of identification of thermal models and of the interpretation of experimental results, serve as the foundation for the solution of these problems.

Conjugate problems of heat and mass exchange have permitted a fresh look at processes of heat and mass exchange and have made possible the theoretical investigation of transient thermal phenomena. A number of new relationships have been established with their help. Inverse problems, in their application to the study of transient processes, serve the same purpose, but on the plane of experimental research now.

The advent of sufficiently powerful electronic calculating machines, particularly third-generation computers, makes it possible to approach the analysis, modeling, and synthesis of technical systems in a fundamentally new and considerably more well-founded manner. The next stage in this trend is the creation of specialized computing complexes, such as a system for automated design, including thermal design, and a system for the automated treatment of the data of thermal experiments. This stage is also subject to the overall goal of increasing the efficiency and quality of scientific research and technological solutions.

The First All-Union Seminar on Inverse Problems of Heat Exchange and the Treatment of Results of Thermal Experiments met in February of 1974. In the time since then a whole series of important projects have been carried out on the creation of efficient new methods of modeling based on the use of inverse problems, and their practical introduction in various fields of science and technology has been accomplished. In

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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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