INVESTIGATION OF WORKING PROCESSES IN A FLOWING CHANNEL OF RAMJET ENGINE

by

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The technique and results of experimental-theoretical study of gas-dynamics, heat transfer and the structure of gas-flow in the flowing channel of a ramjet engine in Mach number range M = (5-7) are presented. The temperature distribution along the flowing channel of a ramjet engine was experimentally obtained. The temperature along the wall of the flowing channel of the axisymmetric model was measured using the developed thermo-probe. Distributions of Mach number and temperature along the symmetry axis of the flowing channel of the model are obtained numerically. Comparison of the numerical and experimentally obtained values of the Mach number showed their qualitative agreement.

Key words: *gas dynamics, heat transfer, supersonic flow, experimental research, mathematical modeling*

Introduction

At present, in the practice of rocketry, the development of cruise missiles with hypersonic flight speeds is intensively developing [1-8]. Using of ramjet engines on solid propellants is one of the most promising directions for solving the problem of increasing the speed of flight of flying apparatus in the atmosphere [2, 3]. In ramjet engines with an open-flow scheme, combustion of the solid-propellant element takes place in a high-speed gas-flow [3]. The propellant combustion parameters are determined by the structure and thermogasdynamic parameters of the gas flowing. Due to the burnout of the solid-propellant element, the geometric characteristics of the flowing channel change. Thus, the change of geometric characteristics of the flowing channel, the structure and parameters of the over flowing stream are interrelated processes. Reciprocal influence of these processes must be taken into account when designing ramjet engines of the specific open-flow scheme. In this connection, modeling the structure and determination of parameters of the gas-flow in the flowing channel of the ramjet engine is one of the main stages of a development of methods for calculating of the intra-ballistic characteristics of ramjet engines (thrust, specific impulse, propellant burning rate, intra-chamber pressure, *etc*.). In view of the complexity of the geometry of flowing channel and the change in its geometric characteristics during the operation of the engine under conditions of trans- and supersonic velocities of the gas-flow, the mathematical models under

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development require verification by comparison with experimental data. Since the testing of real motors is associated with high materialcosts, it is expedient to conduct preliminary studies on model engine installations for obtaining objective experimental information.

In this paper, the results of an experimental-theoretical study of the structure and basic parameters of the air flow in plane and axisymmetric models of a ramjet engine in Mach number range, M = (5-7) are presented.

Technique of experimental-theoretical study of the structure and basic parameters of a supersonic gas-flow

The experimental study was carried out on a pulsed aerodynamic installation with heating the gas [9-11] in the open air at atmospheric pressure. To create a supersonic flow in the range of M = (5-7) in an aerodynamic installation, steel axisymmetric profiled nozzles were used [10]. The experiments were performed for a flat, fig. 1(a), and axisymmetric, fig. 1(b), of models ramjet engine. In the tests, the pressure and temperature of the gas (air) in the prechamber and in the flowing channel of the models were measured. On plane models, the flow structure was visualized in the flowing channel.

During the experiments, the temperature in the prechamber was measured with a special temperature sensor. The measurement of the gas temperature in the flowing channel of the plane model was carried out by a thermocouple method.

A thermo-probe was manufactured for measure the temperature along the wall of the flowing channel of an axisymmetric model. The view of the axisymmetric model with the installed thermo-probe is shown in fig. 1(a).

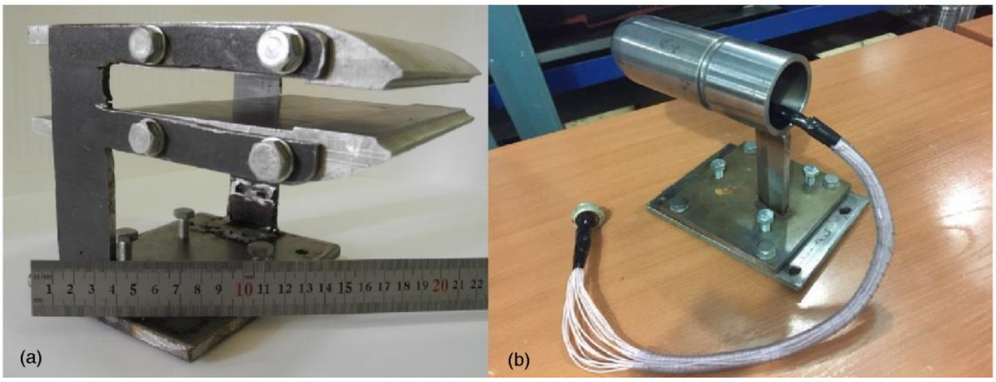
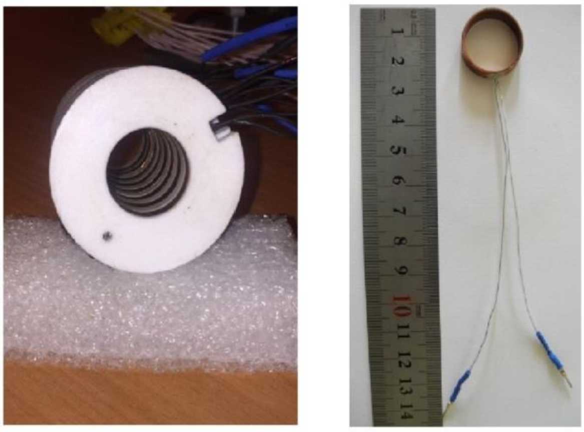


Figure 1. General view of plane (a) and axisymmetric (b) models

The thermo-probe represents a set of fluoroplastic rings of the equal diameter. The Cu rings with a chromel-copel thermocouple were attached to the inner surface of each ring. Photographs of the thermos-probe fully assembled and a Cu ring with a thermocouple are given in fig. 2.

For monitoring during the tests, the temperature near the back wall of the working chamber was measured with help of an additional temperature sensor. The view of placed in the working part of the aerodynamic installation the axisymmetric model in complex with temperature sensors is shown in fig. 3.

When mathematical modeling, the flow of a continuous medium (air) was described by the Navier-Stokes averaged equations system for turbulent flow of a viscous compressible



(a) (b)

Figure 2. Thermo-probe fully assembled (a) and Cu ring with thermocouple (b)

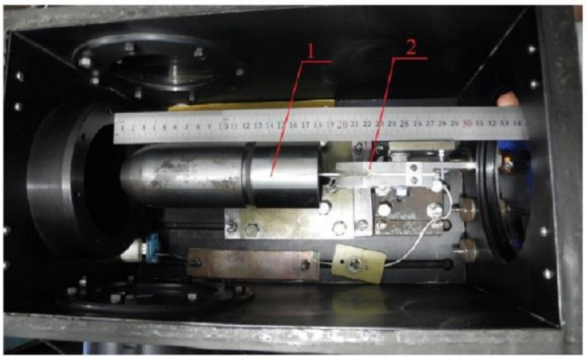


Figure 3. Axisymmetric model in complex with temperature sensors; *1 – axisymmetric model, 2 – temperature sensor*

gas. As a model of turbulence, the SST-model (Menter's model of shear stresses) was used, based on the vortex viscosity hypothesis. Flow characteristics were obtained using the ANSYS FLUENT software package. The numerical implementation of the solution was carried out on an unstructured grid with different resolution.

The results of the experimental-theoretical study

Series of experiments were carried out for each Mach number in the range M = (5-7). The values of the basic characteristics of the gas-flow were measured for flowing around of a plane and axisymmetric models of a ramjet engine. The results of visualization of the flow structure in the flow channel of the plane model have made it possible to reveal the features of the flow, fig. 4(a). The fields of Mach numbers in the external flowing stream and in the flowing channel of the plane model, obtained by calculation, are given in fig. 4(b).

The temperature measurement data for the flowing around an axisymmetric model are given in fig. 5. The data given were obtained in one of the experience in a series of ten experiments. These are follow conditions for conducting a series of experiments: M = 6, the heater temperature is 673 K, the duration of the aerodynamic installation is five seconds. In

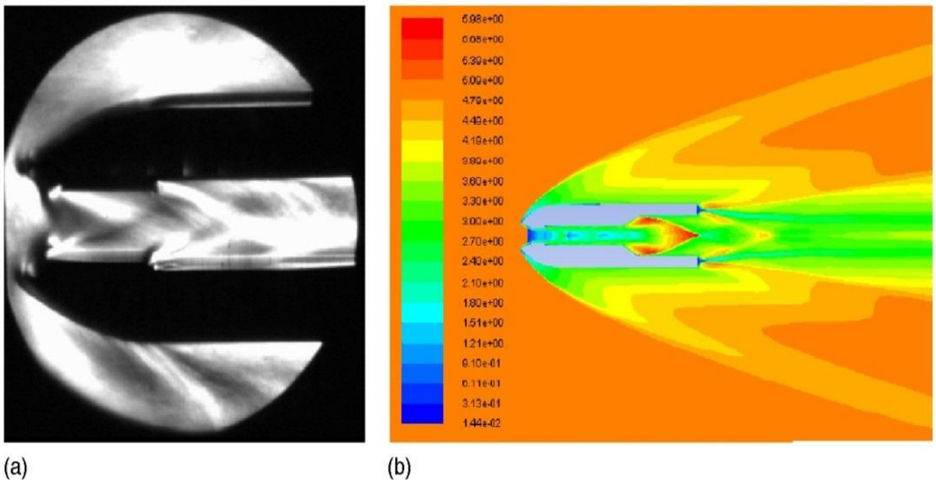


Figure 4. The video-frame of the flow structure (a), and the fields of Mach numbers (b) in the external flowing stream and in the flowing channel of the plane model, M = 5
(*for colour image see journal web site*)

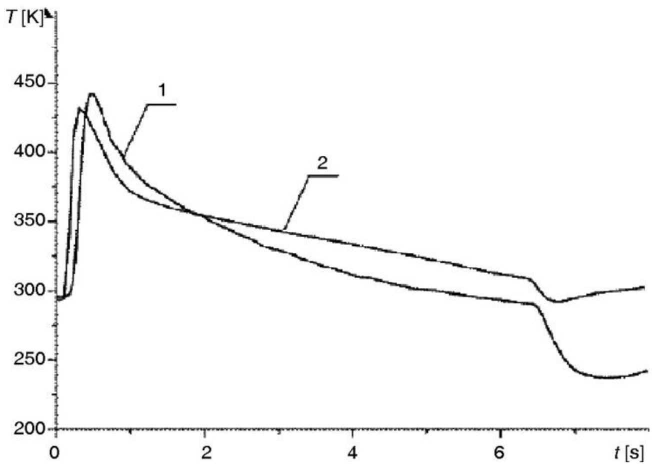


Figure 5. Measured dependences of the temperature from the time in the prechamber (1) and near the back wall of the working chamber (2)

fig. 5 the dependences of the temperature from the time in the prechamber (1) and near the back wall of the working chamber (2) are given.

In fig. 6, the measured dependences of the temperature from the time, obtained with a thermo-probe, fig. 6(a), and the averaged maximum values of wall temperature along the flowing channel, fig. 6(b), are shown. The x is the distance from the initial section of the model (see fig. 3) to the working junction of the thermocouple.

In fig. 7, computationally obtained distributions of Mach numbers, fig. 7(a), and temperature, fig. 7(b), along the symmetry axis of the flowing channel of the model are given when M = 5 of the ambient air-flow. When $x = 0.042$ m the Mach number value is obtained experimentally, the point in fig. 7(a). The comparison of the numerical and experimentally obtained Mach number values showed that the relative error is less than 10 %.

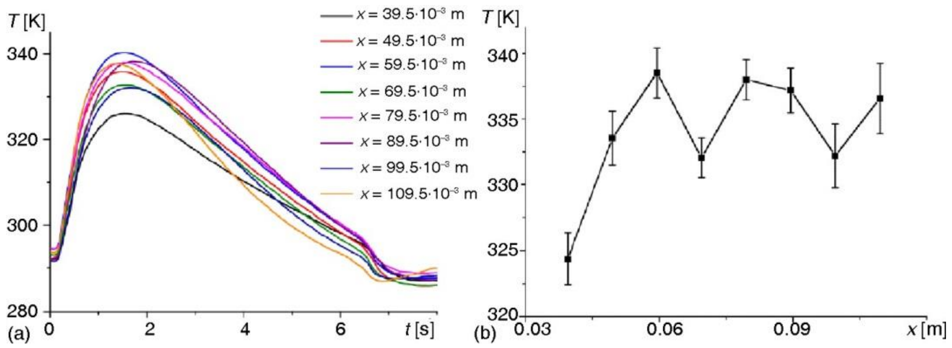


Figure 6. The measured dependencies of wall temperature from the time (a) and the averaged maximum values of wall temperature (b) along the flowing channel

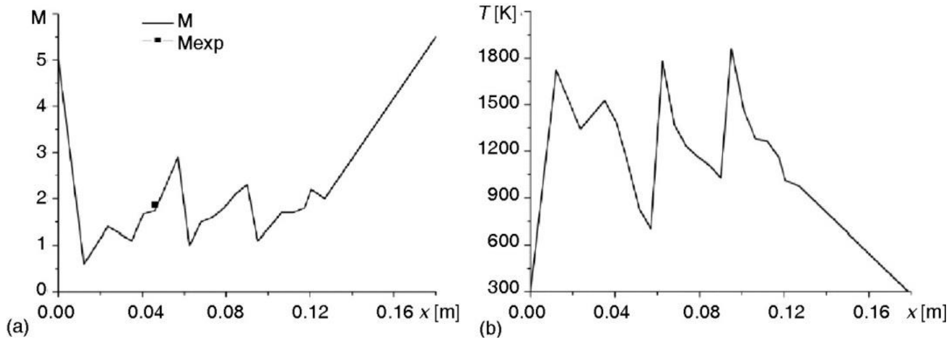


Figure 7. The Mach number values (a) and temperature (b) along the flowing channel symmetry axis of the axisymmetric model, M = 5

Conclusion

An experimental-calculating technique for study of gas dynamics, heat transfer and the structure of gas-flow in the flowing channel of a ramjet engine in Mach numbers range M = (5-7) is proposed. Technical means were developed to ensure the implementation of the proposed technique. The results of temperature measurements obtained on the basis of the proposed technique are adequate to the physics of the process under study. Comparison of the results of numerical calculations and experimental data showed their qualitative agreement.

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