29th Congress of the International Council of the Aeronautical Sciences
St. Petersburg, Russia; September 7-12, 2014

HEAT FLUX LEVEL DETERMINATION IN MODEL COMBUSTION CHAMBER OF HIGH-SPEED RAMJET ENGINE

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Keywords: *high-speed ramjet engine, heat flux determination, thermal state of high-speed ramjet engine*

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Abstract

The various methods of convective heat flux level estimation in a model combustion chamber of high-speed ramjet engine are considered in this paper. Combustion chamber heat flux distribution was obtained by three methods. Conclusions about the possibility of the simplified methods application for assessing heat fluxes in the combustion chambers of high-speed ramjet engines were made.

1 Introduction

In the flow path of high-speed ramjet engine a large variety of complex gas-dynamic phenomena combines (interaction of shocks, the growth of the boundary layer, the complex mechanism of combustion, etc.). The modern level of computer technology allows modeling of processes and by solving the energy equation of the boundary layer to obtain the level of convective heat fluxes. Defining the convective heat flux in the wall, one can predict the thermal state and develop cooling system design flow path.

2. Calculated model

To conduct computational studies geometry of high-speed ram jet in two-dimensional formulation was selected. To determine the parameters of air flow at the inlet to the combustion chamber proper (shocks focus on cowling) three-shock intake was selected. This allows to determine accurately the displacement thickness of the boundary layer, which in turn makes it possible to ascertain the flow behavior in the combustion chamber and the transmission of disturbances. Fuel is supplied through four struts installed at the combustion chamber inlet. Calculated geometry is shown in Fig. 1.

There are boundary conditions:

M_∞=6; p_∞=1880 Pa; T_∞=224 K; M_{H2}=1; p_{H2}= 150 kPa; T_{H2}= 225 K; T_w =1000 K.

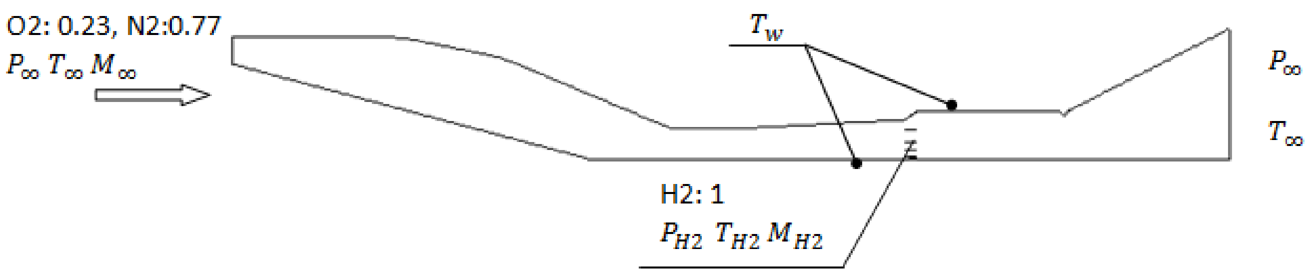

Fig.1. Calculated scheme of flow path and boundary condition

3. Heat flux level determination

It was decided to define wall heat fluxes by three methods. The first approach involves the solution of unsteady gas dynamics equations. RANS equations are considered, supplemented by SST turbulence model, while gas is considered as a multicomponent mixture where the reactions proceed by a multistep kinetic mechanism of hydrogen oxidation in air (Dimitrov mechanism). As known, the solution of such a system of equations is extremely demanding of computing resources, which does not allow widespread use of this method for assessing the level of heat fluxes for all variety of boundary conditions and configurations.

Reducing the number of components of the reaction mixture allows to reduce the computation time. In the second method of this work numerical simulation of flow in the flow path of the combustion chamber was carried out on the basis of the gas dynamics equations, which were solved for a smaller number of reacting components. The number of components of the gas mixture corresponds to the equilibrium composition of the reacted mixture. Rate constants of chemical reactions not calculated but equilibrium constants are calculated.

The essence of the third method involves the use of a modified one-dimensional Ievlev method allowing to determine the level of heat fluxes using the transport properties of the medium and the gas-dynamic functions. Ievlev method was also applied to the present configuration of the model combustion chamber of high-speed ramjet engine with the same boundary conditions as the two aforementioned methods.

4. Results

Numerical simulation results of the first two methods are shown in Figure 2, 3, 4. Some differences in the structure of the flow and temperature distribution and concentrations of H_2O can be noticed.

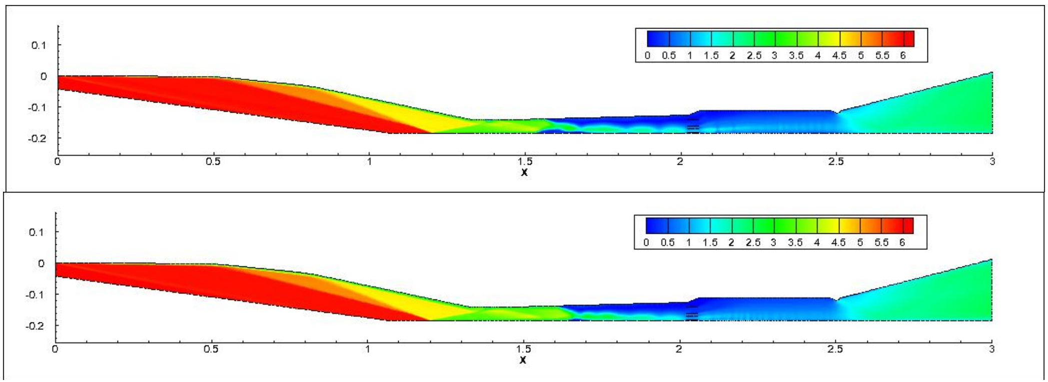

Fig.2. Mach number distribution on the path of high-speed ramjet engine (top - detailed chemical kinetics, bottom - equilibrium approximation)

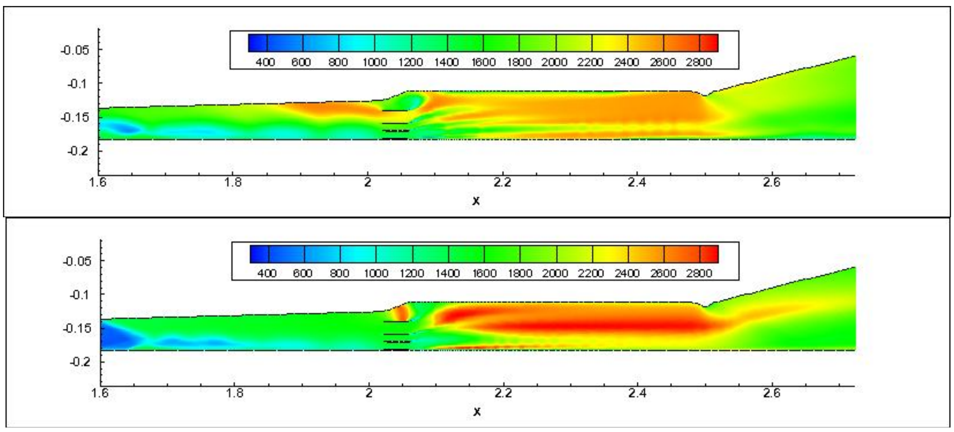

Fig.3. Static temperature distribution along a path of high-speed ramjet engine (top - detailed chemical kinetics, bottom - equilibrium approximation)

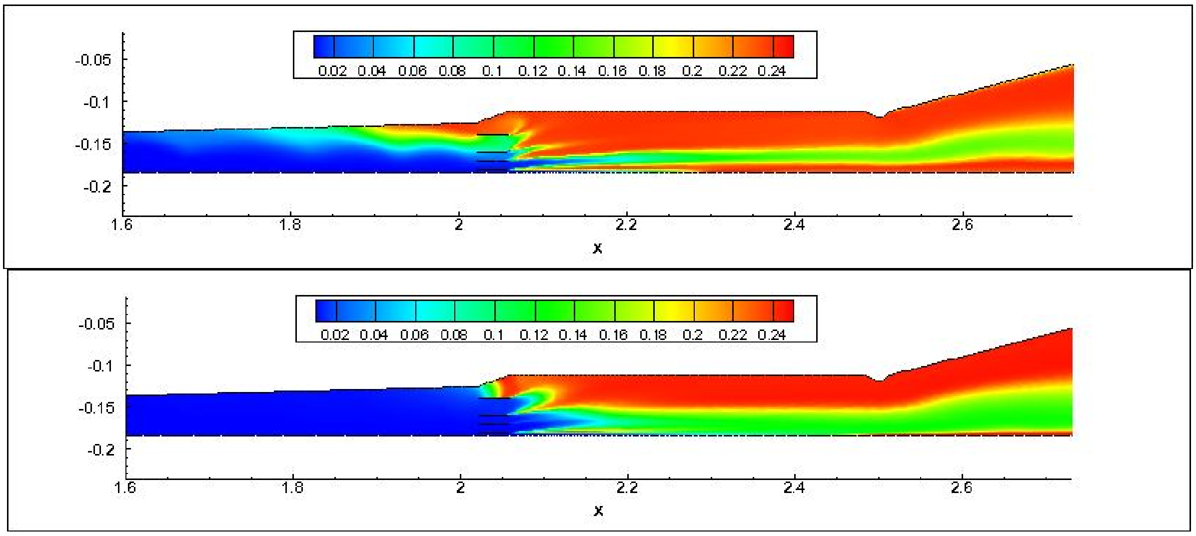

Fig.4. H_2O concentration distribution along a path of high-speed ramjet engine (top - detailed chemical kinetics, bottom - equilibrium approximation)

Figure 5 shows the distribution of the combustion efficiency. The combustion chamber was divided by sections, the mass flow rate of hydrogen (H2) was determined in each section, and the combustion efficiency was determined by the following formula:

$$\eta = 1 - \frac{\dot{M}^0_{H_2} - \dot{M}_{H_2}}{\dot{M}^0_{H_2}} \qquad (1),$$

where $\dot{M}^0_{H_2}$ - , the mass flow rate of hydrogen (H2) in fuel struts section,

$\dot{M}_{H_2}$ - the mass flow rate of hydrogen (H2) in particular section,

η - combustion efficiency.

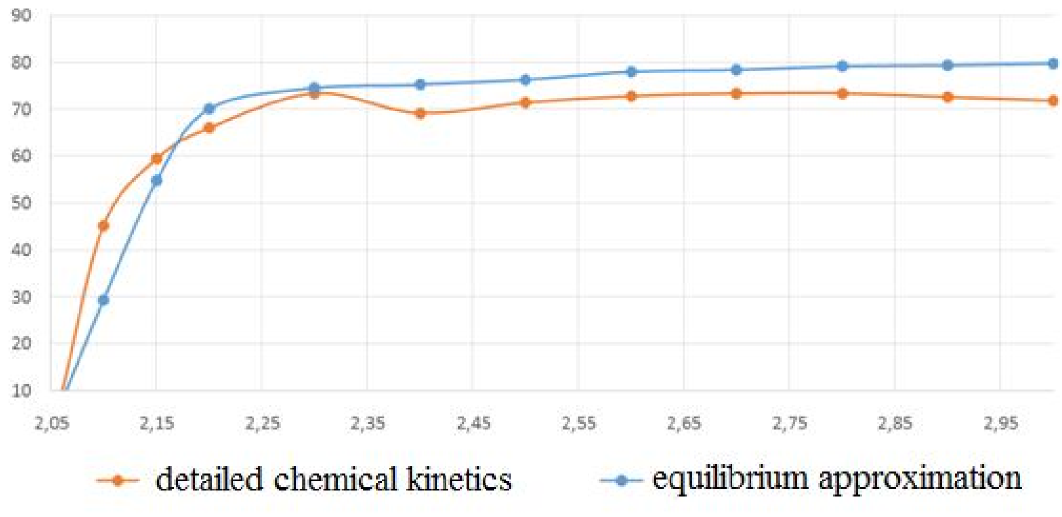

Fig.5. Combustion efficiency distribution along a path of high-speed ramjet engine

Figures 6, 7 show the distributions of the heat fluxes calculated from the three methods described above. It is seen that in the case of numerical modeling flow structure features lead to the peaks of heat fluxes. Ievlev method calculations were performed twice for top and bottom walls. In one case to the distribution of the parameters and properties of the gas from the results of numerical simulation with detailed chemical kinetics (red line on the chart) was taken, in the second case - the results of numerical simulation with the equilibrium approach (black line).

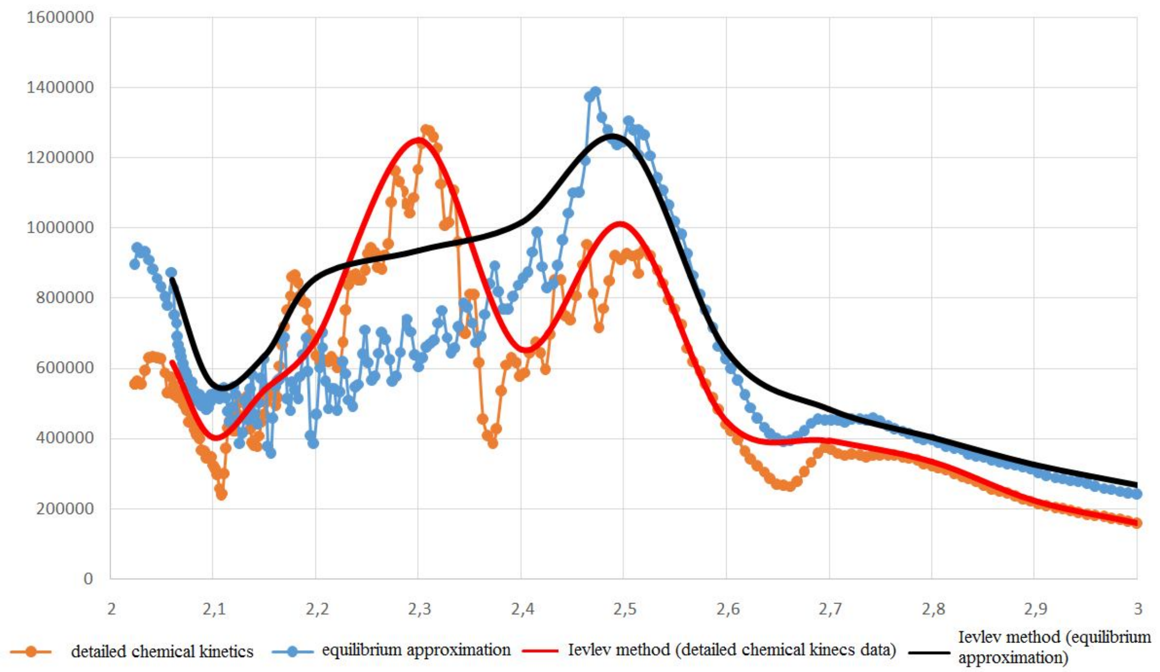

Fig.6. Heat flux distribution along a bottom wall of high-speed ramjet engine path

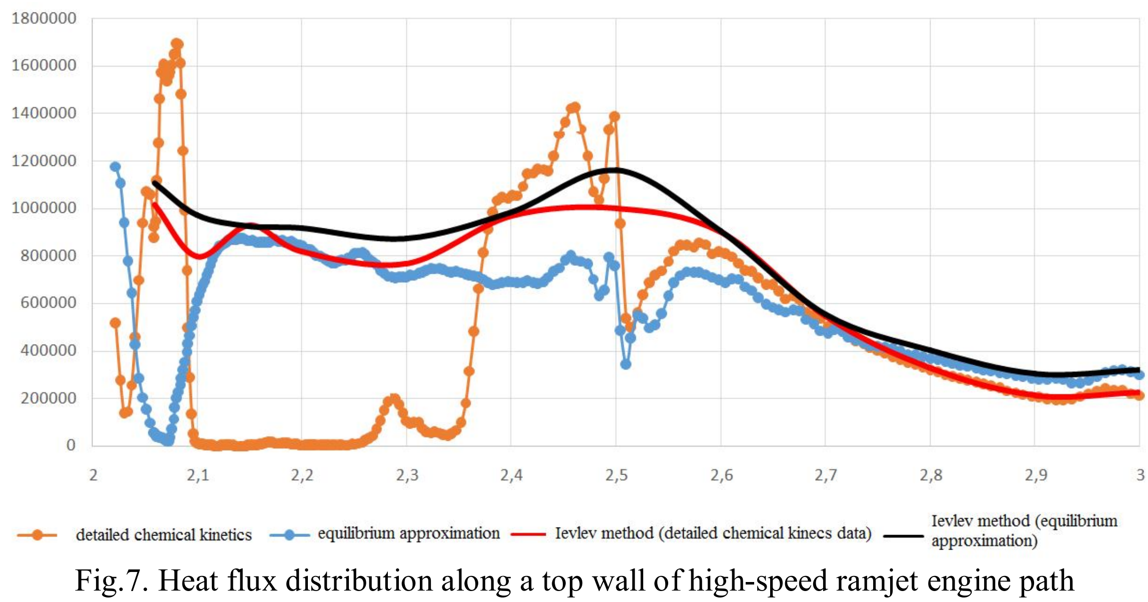

Fig.7. Heat flux distribution along a top wall of high-speed ramjet engine path

5. Conclusion

By comparing the heat sinking into the wall, calculated in each of the three methods, it is found that in the case of equilibrium approximation generated heat is 12.9% more than in the case of detailed chemical kinetics, and in turn generated heat calculated by the modified Ievlev method is 15.6% more than in the case of equilibrium approximation. Thus, the modified Ievlev method calculations can be used to evaluate the thermal state of high-speed ramjet engine path "from above", while calculation time is significantly reduced and simulation of complex physical phenomena is greatly oversimplified.

6. References

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