INFLUENCE OF PHYSICOCHEMICAL PROCESSES ON SURFACE FRICTION IN HYPERSONIC FLOW AROUND BLUNT BODIES

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The effect on surface friction of the physicochemical process occurring in a shock layer is studied on the basis of an analysis of numerical solutions.

An important role in the motion of blunt bodies with hypersonic velocities is played by processes involving the excitation of the internal degrees of freedom of the particles, by chemical reactions, and by radiation. The influence of these processes on the departure of a shock wave, on the heat flux to the surface of the body, on the pressure distribution, on the profile of the gasdynamic parameters, and on the concentration of the components in the shock layer has been studied in a whole string of papers. The results of these investigations are cited, for example, in [1, 2]. The influence of these processes on surface friction has been studied to a lesser extent. Here the results obtained to data relate in the main to the frontal part of the body. In the work reported here we use our previously obtained numerical solutions [3] for a viscous shock layer in equilibrium radiating air and calculations performed for a nonradiating gas with constant specific heat to investigate the effect of physicochemical processes on surface friction on the entire front and side surfaces of blunt bodies. By way of example we show in Fig. 1 plots of the coefficient of friction over the surface of a spherically blunted cone of apex half-angle 30° for $V_\infty = 12.2$ km/sec, $\rho_\infty = 0.2744 \cdot 10^{-6}$ g/cm³, r = 20 cm, $T_W = 2500$°K. The coefficient of friction is defined as the ratio of the friction stress to the velocity head $\rho_\infty V_\infty^2$. The solid curve shows the results of the calculation for equilibrium air; the dashed curve relates to the case $\gamma = 1.4$, Pr = 0.72, $\mu \sim \sqrt{T}$. For $s/r \leq 0.5$ the values of C_f for both variants of the calculation almost coincide. In the region $0.5 \leq s/r \leq 1.8$, including the point where the sphere contacts the cone, allowance for the real properties of the gas results in a certain diminution of the coefficient of friction, which

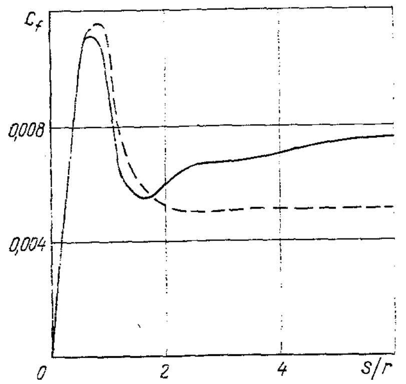

Fig. 1

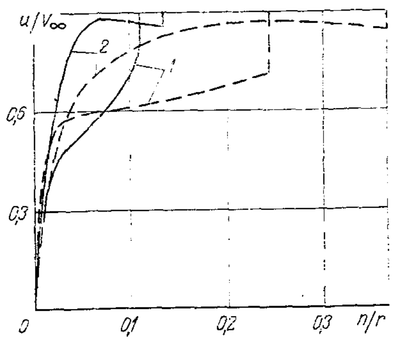

Fig. 2

Fig. 1. Variation of coefficient along surface of body. Solid curve) equilibrium air; dashed curve) the case $\gamma = 1.4$, Pr = 0.72, $\mu \sim \sqrt{T}$.

Fig. 2. Tangential velocity profiles: 1) s/r = 1.047; 2) s/r = 5.061; solid curves) equilibrium air; dashed curves) the case $\gamma = 1.4$, Pr = 0.72, $\mu \sim \sqrt{T}$.

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agrees with known results for a spherically blunted region [4, 5]. The opposite effect occurs on the conical part of the body for $s/r > 1.8$. Here, allowing for physicochemical processes results in an increase in the coefficient of friction. The nonmonotonic variation of C_f on the conical part of the body comes about because for equilibrium air the singularity arising at the point where the sphere contacts the cone has a much stronger effect than in the case $\gamma = 1.4$, $Pr = 0.72$, $\mu \sim \sqrt{T}$. The change in the departure of the shock wave and in the pressure on the surface of the body also become appreciably nonmonotonic [3]. We note that for hypersonic flow around bodies with a surface of continuous curvature the coefficient of friction on the corresponding part decreases monotonically [6, 7].

In Fig. 2 we show profiles of the velocity component u tangential to the surface of the body. It can be seen that on different parts of the surface of the body, allowing for physicochemical processes can cause either an increase or a decrease in the velocity gradient in the region near the wall. These results demonstrate the need to allow for physicochemical processes when determining friction stresses on the surfaces of blunt bodies in hypersonic flows.

NOTATION

s, distance measured from front critical point along surface of body; n, distance along normal directed away from surface of body; C_f, coefficient of friction; u, component of velocity tangential to surface of body; V_∞, ρ_∞, velocity and density of unperturbed flow; r, radius of spherically blunted portion; T_W, surface temperature of body; γ, ratio of specific heats; Pr, Prandtl number; μ, viscosity.

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HEAT LIBERATION FROM A SPHERE MOVING IN A VISCOUS LIQUID

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The method of [1] is used to solve the problem of heat liberation from a sphere moving in a viscous liquid, where the velocity field is given by the Stokes solution [2].

1. Method of Solution. A method proposed previously [1] makes it possible to determine the nonstationary temperature gradient on the boundary of a semiinfinite one-dimensional region without previous determination of the temperature field. In the present section we will describe the application of this method to nonstationary problems for a two-dimensional region.

We will consider the simplest case — the process of heating a semiinfinite lamina from its face:

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