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DIMINUTION OF THE THERMAL ACTION OF A GAS JET ON A PLATFORM BY DELIVERY OF COOLANT IN THE NEIGHBORHOOD OF THE CRITICAL POINT

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Results are presented of an experimental investigation of the thermal action of a high-enthalpy jet on a normally disposed platform and the means to diminish this effect.

The thermal action of a gas jet impinging on a normally disposed platform can be diminished by supplying coolant in the neighborhood of the critical point [1]. Investigations were performed on an experimental installation including an axisymmetric nozzle through which a preheated gas escaped onto the platform model (Fig. 1). The platform models were an asbestos-plastic slab and a steel plate with installed thermocouples to measure the gas flow temperature near the platform surface T_g^* and the platform surface temperature T_w. The models were moreover equipped with sensors to measure the heat flux density q by the auxiliary wall method [2, 3] and by alpha-calorimeters to measure the heat elimination coefficients by the α method of a regular thermal mode [2, 4]. The temperature T_g^* was measured near the surface when using the asbestos-plastic slab, however, because of the low heat conductivity of the slab this quantity is close to the wall temperature T_w. Measurement of the temperature T_{cool} and the mass flow rate G_{cool} of sprayed in water or blown-in air was provided for in the neighborhood of the critical point in the coolant delivery mainlines.

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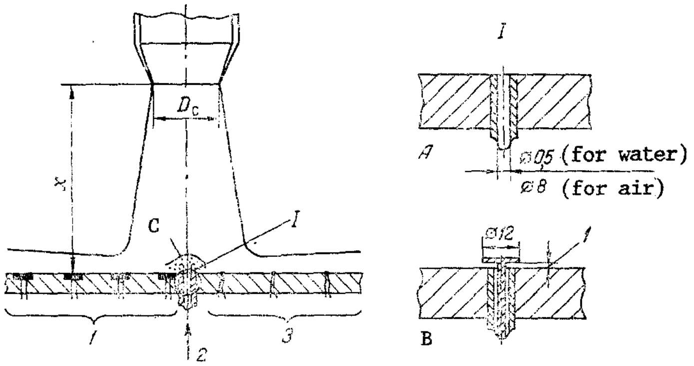

Fig. 1. Model diagram: 1) thermal flux sensor; 2) coolant delivery; 3) thermocouples; A) jet spray (blow-in); B) slot blower; C) domain shielding the platform surface from the action of the hot gas.

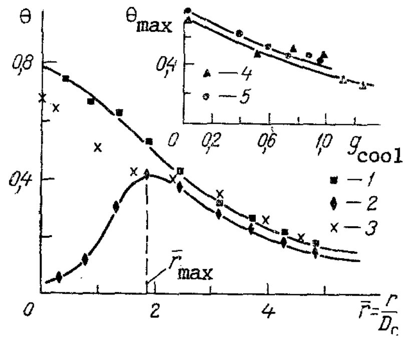

Fig. 2

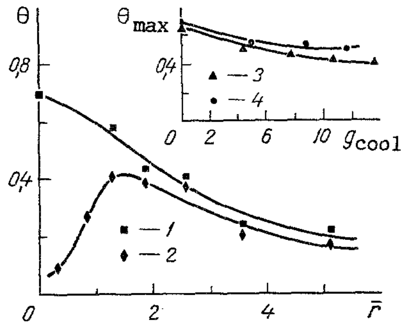

Fig. 3

Fig. 2. Distribution of the dimensionless temperature of the platform over the radius of the spreading jet for the case: coolant is water, modification A, D_n = 34 mm, $\bar{x}$ = 6, T_n^* = 993 K, T_{cool} = 293 K: 1) $\pi_{\tilde{m}}$ = 2.5, g_{cool} = 0; 2) $\pi_{\tilde{m}}$ = 2.5, g_{cool} = 0.94%; 3) data of [5] (g_{cool} = 0, $\bar{x}$ = 7.4, T_n^* = 973 K); 4) $\pi_{\tilde{m}}$ = 1.9; 5) $\pi_{\tilde{m}}$ = 2.5.

Fig. 3. Distribution of the dimensionless temperature of the platform over the radius of the spreading jet for the case: coolant is air, D_n = 25 mm, $\bar{x}$ = 6, $\pi_{\tilde{m}}$ = 1.4, T_n^* = 798 K, T_{cool} = 273 K: 1) modification B, g_{cool} = 0; 2) modification B, g_{cool} = 13.7%, 3) modification B; 4) modification A.

Two coolant delivery methods were investigated: along the normal to the surface through a jet sprayer (jet blower or sprayer (Fig. 1, modification A)); along the slab surface (slot blower (Fig. 1, modification B)).

The gas mass flow rate through the nozzle G_g, the pressure p_n^* and the temperature T_n^* of the decelerated flow through the nozzle were also measured during the experiment. The experiments were performed under the following conditions: nozzle diameter D_n = 25 and 34 mm, assumed degree of gas pressure reduction in the nozzle $\pi_m = p_n^*/p_s$ = 1.4...2.5 (p_s is the pressure of the surrounding medium), the temperature is T_n^* = 798...993 K, the relative distance between the nozzle exit and the platform is $\bar{x} = x/D_n$ = 2, the relative coolant flow rate is $g_{cool} = G_{cool}/G_g \times 100\%$: water 0.39...1.26, and air 3.8...14.6%.

Processing the experimental data was reduced to determining the dimensionless wall temperature $\Theta = (T_w - T_{cool})/(T_n^* - T_{cool})$, where the coolant (water or air) temperature is $T_{cool} \approx T_s$ (T_s is the temperature of the surrounding medium) and the heat elimination coefficient by known methods [2].

A domain C shielding the platform surface from the action of the hot gas is formed under a jet spraying of water against the flow in the neighborhood of the critical point (Fig.

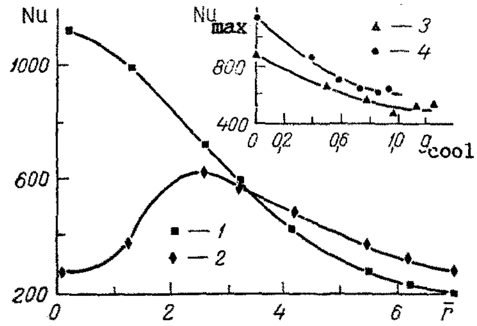

Fig. 4. Distribution of the numbers Nu along the radius of the spreading jet for the case: coolant water, modification A, D_n = 34 mm, $\bar{x}$ = 6, T_n^* = 993 K, T_{cool}^* = 293 K: 1) π_m = 2.5, g_{cool} = 0; 2) π_m = 2.5, g_{cool} = 0.94%; 3) π_m = 1.9; 4) π_m = 2.5.

1). The wall and near-wall jet layer temperature in this domain is close to the temperature of the cooling fluid, i.e., the complex Θ is close to zero (Fig. 2). The shielding effect of the jet diminishes with distance from the critical point because of water evaporation. This explains the presence of the peripheral maximum on the graph of the dependence $\Theta = \Theta(\bar{r})$ (Fig. 2). An increase in the cooling fluid flow rate results in both a diminution in Θ, and an increase in the extent of the domain C whose size can be taken as proportional to the distance between the critical point and the point $r = r_{max}$ corresponding to the peripheral maximum of Θ.

Utilization of air as coolant has a number of singularities as compared with water: An equal degree of wall temperature reduction is achieved in the neighborhood of the critical point for a high coolant flow rate; this is explained principally by the substantially high cold resource of water; a reduction in the protective effect is observed when cooling air is delivered at high pressure ($(3\text{-}5)\cdot 10^5$ Pa); this is caused by a growth in the long range action of the air jet and is associated with this diminution in the coolant concentration in the gas jet near the surface; in case the gas and the cooling air flows are not coaxial, a nonsymmetric shielding surface is formed that reduces the protective effect.

In order to achieve a long shielding effect, a slot air delivery (Fig. 1, modification B) was investigated in addition to the axial delivery. Despite the qualitative and almost quantitative agreement between the platform surface temperature distributions along the radius ($\Theta = \Theta(\bar{r})$) (Fig. 3), the slot coolant delivery turned out to be more preferable: it is less responsive to coolant delivery pressure and noncoaxiality of the gas and cooling air flows.

Analysis of the dependences of the dimensionless maximal temperatures Θ_{max} on the coolant flow rate g_{cool},%, shows that an increase in the latter is effective just to specific values. Thus, the tempo of Θ_{max} diminution is reduced noticeably by 0.8...1.0% for water and more than 10% for air (Figs. 2 and 3) as g_{cool} is increased.

Results of measurements of the heat elimination coefficients are represented in the form of dependences of the Nusselt number $Nu = \alpha D_n/\lambda$ (λ is the heat conduction coefficient for the gas temperature near the platform surface) on the platform radius and the water flow rate. It is seen from Fig. 4 that these dependences are similar to analogous dependences in the temperature $\Theta = \Theta(\bar{r})$; in the nature of their progress; the elevated values of the number Nu in the domain $\bar{r} > 3$ as g_{cool} increases are apparently explained by the additional turbulization of the flow because of the coolant delivery.

Therefore, the investigations performed displayed the possibility of diminishing the thermal action of a gas jet on a platform surface by delivering coolant in the neighborhood of the critical point. A coolant flow rate in the quantity of 0.8...1.0% (for water) and on the order of 10% (for air) will assume 40...50% reduction in the maximal values of the platform surface temperatures.

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INVESTIGATION OF THE HEAT TRANSFER LAWS IN A THREE-DIMENSIONAL VISCOUS SHOCK LAYER ON BLUNT BODIES AT ANGLE OF ATTACK AND SIDESLIP

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The authors analyze the results of numerical solution of the equations of the three-dimensional thin viscous shock layer over triaxial ellipsoids of different shapes in a flow of supersonic viscous gas, with no symmetry planes.

In many applied tasks one needs to investigate the basic laws of heat transfer in three-dimensional flow of a supersonic viscous heat-conducting gas over blunt bodies of complex shape, over a wide range of Reynolds numbers. The thin viscous shock layer theory, first proposed in [1], is widely used to solve these problems. Being comparatively simple mathematically (a problem of parabolic type) this theory allows one to eliminate a number of defects present in the widely-used boundary layer theory. On the one hand, in shock layer theory one need not divide the entire flow region into individual sublayers, because the appropriate equations are uniformly applicable in the entire perturbed flow region from the shock wave to the body surface. On the other hand the shock layer equations describe the flow correctly, asymptotically, over a substantially wider range of change of Reynolds number, from small through medium to large [2].

However, the shock layer model possesses a number of limitations, associated in particular, with the fact that the use of a simplified momentum equation along the normal leads to the appearance on the surface of a convex body of zero pressure lines (separation lines), beyond which the solution cannot be continued.

On the whole, however, as is confirmed by analysis of numerous comparisons of solutions of shock layer equations with experimental data and with computations on a more complete formulation (see the review in [3]), the thin viscous shock layer model has good accuracy over quite a wide region of the forward surface of blunt bodies for which the shock layer thickness is small compared with a characteristic body dimension, and the surface pressure p_w is on the same order as the stagnation point value p_0 ($p_w/p_0 \gtrsim 0.05$-0.1).

Taking into account the above limitations, in this study we have solved the three-dimensional thin shock layer equations in their region of application in the case of flow over triaxial ellipsoids of different shapes at angle of attack and sideslip. We have analyzed the influence of body shape, Reynolds number, and the other governing parameters of the problem on the basic heat transfer laws. Previously the thin shock layer equations have been solved for different special cases of three-dimensional flows in [4-11]. In [4, 5] the authors investigated flow over delta wings of infinite size at angles of attack and sideslip, in [6] the authors investigated flow over rotating axisymmetric bodies at zero angle

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