INTRODUCTION

Many studies have been made of jet (film) cooling. In the studies made at the beginning of the fifties, it was assumed that the main part of the mixing zone of two gas flows satisfies the laws of propagation of a free turbulent jet in a wake and that the small part next to the wall satisfies the laws of a boundary layer. Approximate methods were developed for calculating the flow, equilibrium values of the temperature, and the coefficients of heat transfer. These made it possible to calculate the wall temperature under conditions of complex heat transfer. The results of these studies are partly contained in [1-3]. In the majority of the later studies, for example, [4-9], it was assumed, in contrast to [1-3], that the flow satisfies the laws of a boundary layer in the case of jet cooling. None of these quoted studies contains systematic experimental data on the flow in the mixing region at velocities in the slot appreciably exceeding the velocity of the main flow. In these cases, the velocity of the gas mixture near the boundary of the wall layer attains an extremum, which makes it possible to estimate clearly the relative importance of the boundary layer in the turbulent mixing zone.

The aim of the present paper is to describe and analyze experimental data on the velocity and temperature distributions in the turbulent mixing zone of two air flows when the ratio of the velocity in the slot to the velocity of the wake satisfies $m = u_1/u_0 > 1$.

1. Flow Scheme and Assumptions

Schematically, the flow pattern is shown in Fig. 1. Hot gas flows past the wall with parameters $u_0$ and $T_0$. Tangentially to it, through a slot of height $h$, cooling air with parameters $u_1, T_1$ is supplied. It is assumed that at some distance from the wall the flow satisfies the laws of propagation of a free turbulent jet in a wake. It is necessary to distinguish the dynamical and the thermal mixing zones. A dynamical boundary layer develops from the front edge of the plate, while the thermal boundary layer develops from the point of intersection of the outer (relative to the main flow) boundary of the thermal mixing zone and the plate. It is well known [2] that in the case of flow out of a nozzle of finite size the region of mixing of the two flows can be divided conditionally into three parts: the initial (region I), the transitional (region II), and the main (region III).

The profiles of the relative excess velocities and temperatures in the main section of the jet in the case of equal specific heats and subsonic velocities of the mixed flows are described by the dependences

\[
\frac{u - u_0}{u_m - u_0} = \Delta u = (1 - \eta_u)^{1/2}, \quad \eta_u = \frac{y}{b_u}, \quad b_u = 0.2 \frac{1 - m}{1 + m} \frac{x}{}, \quad (1.1)
\]

\[
\frac{T - T_0}{T_m - T_0} = \Delta T = (1 - \eta_T)^{1/2}, \quad \eta_T = \frac{y}{b_T}, \quad b_T = 1.2b_u \quad (1.2)
\]

where $u_m$ and $T_m$ are the flow parameters on the axis of the jet, and $b_u$ and $b_T$ are the widths of the dynamical and the thermal mixing zone. Under the assumptions we have made, $(u_m - u_0)/(u_1 - u_0) = \Delta u_m = q(x)$ and $(T_m - T_0)/(T_1 - T_0) = \Delta T_m = q_T(x)$ $(x = x/h)$ can be determined from the conservation of the excess momentum and the heat content [1-3].

If there is an initial turbulence in the mixed jets, then in the neighborhood of $m = 1$ the angle of expansion of the mixing zone does not depend on $m$ [1-3]. For example, if the initial turbulence is 3%, then $b_T/x = \text{const}(m)$ for $0.5 \leq m \leq 2$. The thickness of the dynamical boundary layer can be calculated by successive approximation in accordance with the following formula, and the velocity distribution in it satisfies the law...
The thickness $\delta_T$ of the thermal boundary layer is determined in the same way as the thickness of the dynamical boundary layer. The temperature gradient across the thickness of the thermal boundary layer is assumed to be negligibly small (the wall does not conduct heat), and the equilibrium value of the temperature $T_\text{e}$ is determined by (1.2) for $y = \delta_T$.

In Fig. 2, in the coordinates $\eta$, $\Delta u$ and $\eta_T$, $1-\Delta T$, we show the velocity and temperature profiles (curves 1 and 4), which characterize the jet flow in any section of the main part. We have also plotted the velocity and temperature profiles in the boundary layer. The velocity profiles in the boundary layer are calculated for $u_m/u_0 = 2$, $\delta_u/b_u = 0.2$ (curve 2) and for $u_m/u_0 = 0.5$, $\delta_u/b_u = 0.2$ (curve 3). For $m < 1$, the velocity distributions calculated in accordance with (1.1) and (1.4) (see curves 1 and 3) are equal to each other over an appreciable part of the boundary layer, and this explains the good agreement between the experimental and calculated values of the velocity in [1]. For $m > 1$, the calculated velocity distributions differ strongly from one another (see curves 1 and 2) and, therefore, the actual distribution will lie between curves 1 and 2. In [2, 10], the mixing zone is also divided into two parts: the jet and wall boundary layers. However, the regions of similarity and nonsimilarity flow are separated by a formal criterion, namely, the value of $u = u_{\text{max}}$. It must be expected that near the edge of the wall boundary layer the similarity flow will have a strong influence on the velocity distribution, while the influence of the turbulence will become weaker as the wall is approached. We shall not go into a detailed study of this interesting phenomenon, and in what follows, when making a comparison with experimental data, we shall use the arithmetic mean value of the velocity in the boundary layer. This velocity profile for $u_m/u_0 = 2$ and $\delta_u/b_u = 0.2$ is shown by curve 8 in Fig. 2.

The temperature profiles in the thermal boundary layer were constructed for $\delta_T/b_T = 0.1$ in three cases: $T_\text{e} = T_\delta = T_\text{w}$, an adiabatic wall that does not conduct heat (curve 5); $T_\text{e} > T_\text{w}$, when heat is taken from the wall (curve 6); and $T_\text{e} < T_\text{w}$, when heat is supplied to the wall (curve 7). The temperature distribution in the thermal boundary layer was calculated in accordance with the formula

$$\delta_u = 0.296 \left( \frac{\rho_0 u_0 x}{\mu_0} \right)^{-0.3} \int dx$$

$$u'/u_0 = (y/\delta_u)^{1/5}$$