On the basis of an empirical law of the drag at a rough porous plate, the Kutateladze-Leont'ev method of calculating the turbulent dynamic boundary layer at a smooth surface is extended to the case of flow around a surface in conditions of pronounced roughness.

The method widely used at present to calculate the parameters of a turbulent dynamic boundary layer at a permeable curvilinear surface is that of Kutateladze and Leont'ev [1], which is simple and clear, and agrees satisfactorily with experiment over a wide range of experimental conditions. This method, however, was developed for the case of flow around aerodynamically smooth surfaces, which limits its usefulness in technical applications characterized by high levels of roughness in the flow surfaces.

The specific case in which pronounced roughness appears is encountered, in particular, in calculating the aerodynamic characteristics of the blade units in turbines with porous cooling. In this form of cooling, the coolant, e.g., air, passes through microchannels (pores) in the contoured shell of the blade to the outer surface of the blade and, mixing with the hot gas of the main flow, forms a protective heat-insulating layer. Cooling of the blade also occurs as a result of heat withdrawal by the coolant inside the porous walls. However, the operating efficiency of a turbine using this method of cooling may be significantly impaired as a result of the deterioration in aerodynamic characteristics of the blade units associated with the above mentioned interaction of the coolant crossflow with the main gas flow [2, 3]. As shown in theoretical work [4], the increased roughness of the porous-blade surface is another cause of increased energy loss in such blade units.

For porous materials the concept of "roughness" — like the concept of a "wall surface" (y = 0) — is arbitrary in nature. In [5] it was proposed that the height of elements of roughness (protuberances) be measured from an arbitrary plane for which the longitudinal component of the mean velocity is zero — u = 0. Sometimes, in treating experimental data, a plane passing through the protuberance vertex is taken as the origin of measurements [6]. In the present work, the surface of the wall is identified with the midline of the profilogram, i.e., is a statistical concept. The degree of roughness is estimated from the height of the irregularities measured at ten points [7]

\[ R_z = \frac{1}{5} \sum_{i=1}^{5} H_{l_{\text{max}}} + \sum_{i=1}^{5} H_{l_{\text{min}}} \]  

Here \( H_{l_{\text{max}}} \) and \( H_{l_{\text{min}}} \) are the absolute heights of the five tallest convexities and the absolute depths of the five largest depressions within the limits of the baseline at the measurement surface.

Depending on the type of metallic gauze used in preparing the porous material for the turbine blades, the value of \( R_z \) was found to vary in the range from 29 to 94 \( \mu m \). This variation in roughness leads to a pronounced variation in the value of the contour losses [3].

Calculation of the boundary-layer parameters is hindered by the multiplicity of geometrical parameters determining the roughness (the height of the protuberances, the density of their distribution, the configuration, etc.), and also by the complexity of the effects to which they correspond. The parameter at present regarded as the most reliable for the quantitative estimation of the hydraulic effect of roughness is the "equivalent" (sand) roughness \( k_s \), which gives both the drag and the much-studied technical roughness, determined, for example, by the value of \( R_z \).

To determine \( k_s \), special measurements were made of the velocity profile at plates of porous material.
Experimental velocity profiles at a rough plate with $R_z = 94$ $\mu m$; $U_0 = 36.6$ m/sec (a) and 16.2 m/sec (b): 1) standard velocity profile; 2) $x_{RO} = 0.02$ m; 3) 0.09; 4) 0.16; 5) 0.02; 6) 0.09; 7) 0.16.

Fig. 2. Analysis of the experimental results in the form of a dependence of $\log \delta^*/x$ on $\log x/ks$: 1) approximation of the experimental results; 2-4) measurements at a porous plate ($R_z = 94$ $\mu m$) with $x_{RO} = 0.02$, 0.09, and 0.16 m, respectively, and $U_0 = 36.6$ m/sec; 5-7) the same for $U_0 = 16.2$ m/sec; 8-10) measurements at a porous plate ($R_z = 54$ $\mu m$) with $x_{RO} = 0.02$, 0.09, and 0.16 m and $U_0 = 36.6$ m/sec; 11-13) the same for $U_0 = 16.2$ m/sec; 14-16) measurements at a porous plate ($R_z = 29$ $\mu m$) with $x_{RO} = 0.02$, 0.09, and 0.16 m and $U_0 = 36.6$ m/sec; 17-19) the same for $U_0 = 16.2$ m/sec.

From the results of six measurements (at three cross sections for two values of the velocity $U_0$), the mean value $k_s = (389 + 393 + 390 + 392 + 384 + 392)/6 = 390$ $\mu m$ for a plate with $R_z = 94$ $\mu m$; $k_s = 240$ $\mu m$ for $R_z = 54$ $\mu m$ and $k_s = 40$ $\mu m$ for $R_z = 29$ $\mu m$.

By expressing the results as a dependence of $\delta^*/x$ on $x/k_s$ (Fig. 2), a relation may be determined for calculating the change in momentum-loss surface $\delta^*$ from the plate roughness surface, in the form

$$\delta^* = 0.0202 \left(\frac{x}{k_s}\right)^{-0.238}.$$  

It is characteristic that the deviation of the experimental values from the approximating relation in Eq. (3) is only observed for a plate with $k_s = 40$ $\mu m$, this discrepancy increasing over the length of the plate and with decrease in the velocity $U_0$. This is evidently explained by the decrease in relative roughness $k_s/\delta$ as a result of increase in $\delta$ over the plate roughness length. The effect of the velocity $U_0$ (for Re$_0$) on $\delta^*$ indicates that,