The convergence of the set of parameters \( \{g_k\} \) is satisfactory since the parameter \( g_2 \) makes a small correction to the two-parameter approximation of the universal equation.

The numerical results, presented in graphic form, indicate the domains of definition of the functions of the characteristic physical quantities of the boundary layer. These domains lie between a thick body and a long thin cylinder in a constant-velocity flow. For this reason in all the calculation variants the one-parameter Loitsyanskii solution (approximation) is retained for considering the sensitivity of the effect of the parameters \( g_1 \) and \( g_2 \) characterizing the slender body on the one-parameter Loitsyanskii solution.

LITERATURE CITED


SUPersonic boundary layer transition induced by roughness
on the attachment line of a yawed cylinder

A. S. Skuratov and A. V. Fedorov

The effect of a single two-dimensional irregularity and sandy roughness on boundary layer transition in supersonic flow over a yawed cylinder \( (M_\infty = 6) \) has been experimentally investigated. The characteristic flow regimes beyond the roughness are identified, and their limits are determined as a function of the Reynolds number and the ratio of the height of the roughness to the characteristic thickness of the boundary layer. A qualitative comparison is made with the flow regimes induced by roughness on the attachment line in incompressible flow over a cylinder [1-3]. The thermal indicator coating method is used to measure the heat fluxes along the attachment line and a comparison is made with calculations carried out in accordance with the methods of other authors.

1. Surface roughness may a source of turbulence in the boundary layer along the attachment line on the blunt leading edge of a swept wing. At hypersonic flow velocities an increase in the heat transfer to the wall is observed in the laminar-turbulent

transition zones and on the intervals of developed turbulent flow. Accordingly, for solving applied problems criteria of the onset of roughness-induced turbulence are required. On the other hand, laminar-turbulent transition on the attachment line differs qualitatively from the classical cases of transition on a plate or cone at zero angle of attack. This explains the interest in the detailed study of the problem.

Studies [1--3] constitute a good introduction to the problem. In [1] the generation of turbulence on the attachment line of a yawed cylinder by two-dimensional roughness was investigated experimentally at subsonic velocities and the governing parameters were found: the Reynolds number $R$ and the dimensionless height of the roughness $k$

$$R = \frac{U \eta}{v}, \quad k = \frac{k_*}{\eta}, \quad \eta = \sqrt{\frac{V_s}{\frac{dV_s}{dy}}}$$

(1.1)

Here, $U$ and $V$ are the $x$ and $y$ velocity components (see Fig. 1), $v$ is the kinematic viscosity, $k_*$ is the dimensional height of the roughness, $\eta$ is the characteristic thickness of the boundary layer on the attachment line, and the subscript $e$ denotes parameters at the outer edge of the boundary layer. In [1] regions corresponding to qualitatively different types of roughness-induced boundary layer turbulence were identified in the plane $R$, $k$. It was found that when $k \geq 1.8$ there is a critical number $R_\text{c} = 245$, starting from which turbulence is created directly behind the roughness element and persists over arbitrarily large distances downstream along the attachment line (self-sustaining turbulence regime). In [2] the criterion was extended to the case of supersonic flow $R_\text{c} = 245 \pm 35$.

The Reynolds number $R^*$ can be determined from the relation (1.1) provided that the kinematic viscosity coefficient is calculated from the temperature

$$T_* = T_r + 0.1(T_w - T_r) + 0.6(T_w - T_r)$$

Here, $T_r$ is the recovery temperature, and $T_w$ is the surface temperature. In what follows the Reynolds number $R^*$ is calculated in this way. In [3] an attempt was made to use the criterion $R_\text{c}^* = 245 \pm 35$ to predict laminar-turbulent transition along the attachment line on the windward surface of a delta wing at a large angle of attack. Flight data on the transition on the underside of the space shuttle can be interpreted from this standpoint.

In [4] experiments were carried out in a low-noise wind tunnel at a Mach number $M_\infty = 3.5$ on cylinders with yaw angles of 45 and 60°. An analysis of the data confirmed that the local parameters $R^*$ and $k$ are decisive for describing the transition induced by a single two-dimensional roughness element. For larger $k$ self-sustaining turbulence was observed at $R_\text{c}^* = 300$. 