All the available data indicate that transition to turbulence in a circular pipe takes place within the initial section. This is confirmed by the conclusions of the linear theory of hydrodynamic stability, according to which the velocity profiles on the initial section of the pipe are unstable [1]. So far, however, there have been few investigations of initial-section flow at different values of the initial perturbation level \( \varepsilon_0 \) at the pipe inlet and different values of the length to diameter ratio of the pipe \( l/d \). We have now investigated the transition to turbulence in the boundary layer on the initial section of a circular pipe for various ratios of the thickness of the layer to the radius of the pipe and various levels of initial turbulence. The transition point in the boundary layer was found experimentally, since at present there are no reliable methods of calculating it. In particular, the susceptibility problem has not been solved, i.e., the problem of the initial amplitude of the Tollmien–Schlichting wave, the development of which results in transition to turbulence. It may be assumed that the initial amplitude of this wave is determined by the interaction of higher-frequency waves on the section preceding its growth zone [2]. Moreover, different views are held concerning the mechanism of transition to turbulence at \( \varepsilon_0 > 0.5\% \). At the same time, the results of the transition calculations for \( \varepsilon_0 > 0.5\% \) based on the three-parameter turbulence model [3] require experimental verification.

1. The experiments were carried out in the wind tunnel shown schematically in Fig. 1. Through the inlet section 1 (\( \varnothing 20 \text{ mm} \)) air was admitted from the high-pressure main. A perturbation suppressor was mounted in section 2. For the purposes of the experiments the velocity fluctuation level was controlled by means of a combination of screens 3 and 4. Between these screens the tunnel had an inside diameter of 120 mm. The design of the tunnel made possible a transition over a length of 29 cm from the flow in section 1 with a velocity fluctuation percentage in the tens to a velocity profile uniform over the entire section 5 with a fluctuation level reduced to tenths of a percent. The non-uniformity of the velocity profile did not exceed 3% of the velocity on the flow axis. The contraction between sections 4 and 5 was designed in accordance with the Vitoshinskii method. To section 5 we connected a circular pipe with an inside diameter of 49 mm. In the experiments we studied the transition for a variable mean-flow velocity \( U_p \) and pipes 50 and 411 cm in length (\( L = l/d = 10 \) and 04). The buildup of a boundary layer on the walls of the contraction effectively added about 16 cm to the length of the pipes. With this taken into account \( L \) was 13.2 and 85.4. The design of the wind tunnel also made it possible to drive the air with a DISA 55D41/42 fan, which was connected directly to section 2 (\( \varnothing 40 \text{ mm} \)). In this case the maximum velocity in section 5 reached 18 m/sec at \( \varepsilon = 0.3\% \), and the flow equalization losses did not exceed one flow velocity head calculated with respect to the mean-flow velocity in section 2.

The flow parameters were measured with a constant-temperature 55 M hot-wire anemometer and a similar apparatus made by DISA. We used a compensated 55E30 probe with the wire mounted at right angles to the direction of flow. The fluctuation level is everywhere taken to be the root-mean-square value of the longitudinal velocity fluctuations divided by the mean velocity on the pipe axis.

The onset of the transition to turbulence at the exit of the pipe was determined from the dependence on \( U_p \) of the ratio of the velocity \( U_1 \) measured in the boundary layer.
to the velocity $U_0$ measured outside it. At the point of commencement of the transition
from a laminar to a turbulent boundary layer $U_\delta$ the nature of this dependence changes.
Thus, for example, when $U_1$ is measured in the inner part of the layer at the point of
onset of the transition the rate of growth of the dependence increases [4]. Curve 1
in Fig. 2 is an example of this dependence obtained in the boundary layer at the exit
section of a pipe 50 cm long. The velocity $U_0$ was measured with a Pitot tube, and
the velocity $U_1$ with a hot-wire probe.

It was established that in the transition region the velocity fluctuation level on
the pipe axis $A_0$ increases, reaching a value of several percent, and with further in-
crease in velocity falls again (curve 2 in Fig. 2). This effect is evidently associated
with the fact that as $U_p$ increases the point of onset of the transition to turbulence
in the boundary layer moves towards the beginning of the pipe, fluctuating about each
new position. The thickness of the boundary layer on the pipe section also fluctuates,
and the constant flow rate condition leads to fluctuations of the velocity on the axis.
Thus, the transition in the boundary layer on the pipe wall leads to velocity fluctua-
tions outside it and, in particular, on the pipe axis.

2. In the case of a pipe 50 cm long the boundary layer on the walls was thin as com-
pared with the pipe radius $r$. Thus, when $U_p = 35$ m/sec the displacement thickness $\delta^*$
is equal to 0.9 mm ($\delta^*/r = 0.037$). The acceleration of the flow is characterized by
the Pohlhausen parameter

$$\lambda_\delta = \frac{\theta^2}{\nu} \frac{dU_\delta}{dx}$$

where $\theta$ is the momentum thickness, $\nu$ is the kinematic viscosity, and $x$ is the longitudinal
coordinate. The shape of the velocity on the walls of a pipe 50 cm long and the value of
$\delta^*$ coincided with the corresponding characteristics for the layer on the surface of a
flat plate over the entire interval of $U_p$ from 3 to 3.5 m/sec. Therefore from relations
(2.2) and the constant flow rate condition (2.3) it is possible to find the dependence
$\lambda_\delta(x)$ and determine its average value $\langle \lambda_\delta \rangle$ over the length $l$:

$$\delta^*(x) = 1.73 \sqrt{\frac{\nu x}{U_0}}; \quad \theta(x) = 0.66 \sqrt{\frac{\nu x}{U_0}}$$

$$U_\delta(x) [r - \delta^*(x)]^2 = U_p r^2$$

$$\langle \lambda_\delta \rangle = \frac{1}{l} \int_0^l \lambda_\delta(x) dx$$

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