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LAMINAR-TO-TURBULENT FLOW TRANSITION UNDER THE ACTION OF ACOUSTIC OSCILLATIONS

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The formation of two conical flows in the transition from laminar flow to the turbulent part of a free jet under the action of acoustic oscillations is observed experimentally.

The process of transition from laminar to turbulent flow under the action of acoustic oscillations is of considerable scientific and practical interest. In particular, the results of investigations are used in the design of pneumoacoustic devices [1]. Flow-visualization techniques afford one of the methods of studying the physical patterns of aerodynamic processes.

We have used smoke particles to visualize a free laminar jet on the experimental arrangement shown in Fig. 1.

The smoke generator saturated with smoke particles the flow entering the capillary tube 2, at whose exit a visible jet was formed. The supply pressure was chosen so that the jet at the exit from the capillary tube would have a laminar zone with a length of roughly 20d. The parameters of the flow were as follows in this case: Re ≈ 2000, d = 0.6 mm. The jet was irradiated with an acoustic signal generated by the piezoelectric crystal 4, to the faces of which was applied an alternating voltage from the oscillator 5. The visual flow was photo-

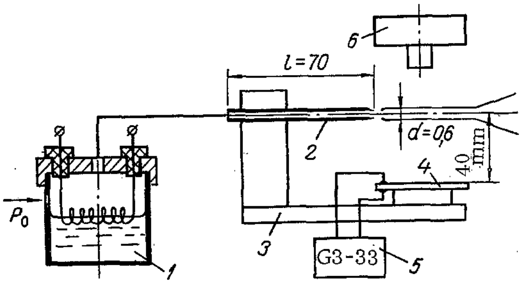

Fig. 1. Diagram of the experimental arrangement for visualizing a free laminar jet: 1) oil-burning smoke generator; 2) capillary tube; 3) bracket; 4) piezoelectric crystal; 5) audio oscillator; 6) camera attachment.

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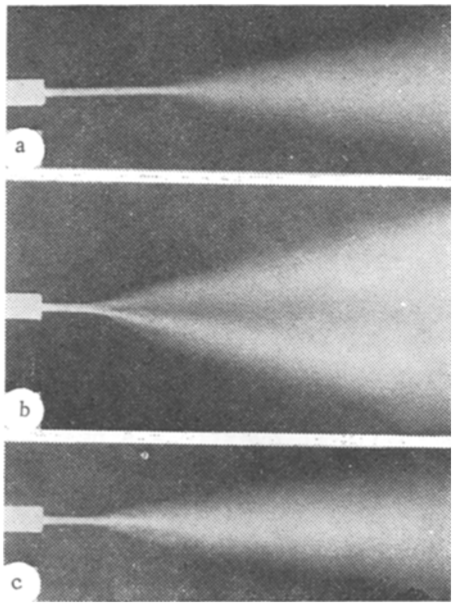

Fig. 2. Photographs of visualized flow without (a) and with (b, c) irradiation by an acoustic signal.

graphed by means of the camera attachment 6. The piezoelectric crystal 4 and the capillary tube 2 were decoupled acoustically by making the bracket 3 of a material having a high acoustic impedance (textolite) and providing it with a series of joints.

The acoustic frequency f produced by the oscillator 5 was set equal to one of the discrete frequencies to which the laminar jet was most sensitive [2]. In our experiment the frequency f = 9 kHz.

An analysis of the visualized flow pattern showed that when a free laminar jet is irradiated with sound it becomes turbulent, a result that is manifested in a reduction of the length of the laminar zone of the jet. However, the difference between the irradiated and nonirradiated jets does not end here. A detailed investigation of the transition zone of the jet showed that in this interval the flow acquires a configuration of two cones, the vertices of which are joined and are situated at the end of the laminar zone. These flows merge downstream and form a fully developed turbulent flow without any kind of singularities.

Figure 2 shows photographs of the jet without (Fig. 2a) and with (Figs. 2b, 2c) acoustic oscillations. In the first case, the jet, which experiences considerable natural turbulence, has a transition zone in the form of a single conical flow pattern with a vertex angle of 18–20°. Figures 2b, 2c show photographs taken from two mutually perpendicular directions. Figure 2b clearly reveals two conical flow patterns, each with a vertex angle of approximately 20°. In Fig. 2c one conical flow is behind the other, and only the closer one is visible.

A slight deviation of the acoustic frequency from the original setting produces a change in the position of the conical flows relative to the acoustic source.

The formation of two conical flows in the transition zone is not observed when a laminar jet is made turbulent by a transverse flow, as occurs in turbulence intensifiers [1]. Under the action of an acoustic signal, the given effect takes on a systematic behavior.

To preclude the influence of the smoke particles and warming of the air in the smoke generator, we performed an additional experiment, in which the exit flow from the capillary tube was directed onto the surface of water, making it possible to visualize the pattern of the approximate flow-velocity distribution in the jet.

The approximate nature of the velocity distribution pattern is attributable to the forces of surface tension and viscosity of the water. It was possible to observe the given pattern in different cross sections of the jet by varying the distance between the surface of the water and the exit orifice of the capillary tube. The velocity profiles in the common plane of the axes of the conical flows are shown in Fig. 3, in which the solid lines delineate the postulated boundary of the jet. In the cross section in the laminar zone of the jet, a concave surface was formed with a single crater, the contour of which is close to the velocity profile of a free laminar jet. In the transition zone of the jet the surface of the water acquired a double crater, indicating the presence of two flows. A further increase

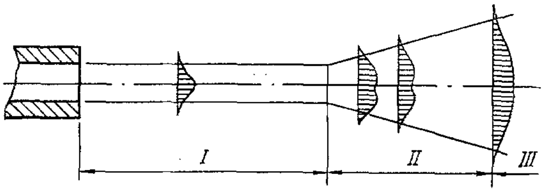

Fig. 3. Approximate velocity profiles in different cross sections of a jet irradiated with an acoustic signal: I) laminar zone; II) transition; III) turbulent zone.

in the distance between the exit orifice of the capillary tube and the surface of the water caused the concave surface to grow in size and gradually go over to a single-crater configuration, exhibiting the velocity distribution of a fully developed turbulent flow.

The observed effect can be explained as follows. A laminar flow is known to have a stratified structure [3], and after emergence from a capillary tube the individual layers can transport initial disturbances with different frequencies. When the flow is acted upon by acoustic oscillations with a frequency equal to the frequency of the initial disturbances of a particular layer, those disturbances are amplified by resonance effects, and the given layer becomes turbulent. The rest of the flow becomes turbulent somewhat later (Fig. 2b), accounting for the emergence of two flows.

A slight variation of the acoustic frequency causes another layer to become turbulent first, whereupon the conical flows change relative to the acoustic source.

Thus, the observed effect indicates the existence of acoustically heterogeneous parts of a laminar flow and a significant difference between the laminar-to-turbulent transition processes under the action of a transverse flow and under the action of acoustic oscillations.

NOTATION

P_0, supply pressure; d, inside diameter of capillary tube; l, length of capillary tube; f, frequency of acoustic signal; $Re = v_0 d/\nu$, Reynolds number; v_0, flow velocity at capillary tube exit; ν, kinematic viscosity.

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