EXPERIMENTAL STUDY OF HYDRODYNAMICAL STABILITY
ON RIGID AND ELASTICALLY DAMPING SURFACES

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The results of an experimental investigation into the hydrodynamic stability of a flow of water carried out on a rigid surface in a hydrodynamical test-bed of low turbulence by the tellurium method are presented. The method here developed for determining the neutral curves also facilitates the study of hydrodynamic stability on elastically damping surfaces.

1. Study of Hydrodynamic Stability on a Rigid Surface

The experimental installation, apparatus, and method were set out in [1]. The tellurium method [2] was used for measuring the field of velocities and recording the neutral vibrations. The construction of the neutral curves was carried out in both traditional and new coordinates. The neutral curves, expressed in coordinates of dimensionless frequency, wave number, and phase velocity for longitudinal flow around a rigid plate, agree closely with the known curves derived theoretically and experimentally by other authors. The values of the increments determined experimentally by the method developed in [3, 4] also agree closely with known data.

The measurements firstly enabled us to verify the experimental method and secondly revealed that the measured values agreed best of all with the calculations of Shen [5].

In the course of measurements carried out with a vibrator amplitude of 0.32 mm and a degree of turbulence no greater than 0.04%, we found that at each point along the working part oscillations occurred within a strictly specified frequency range. These frequencies were analyzed in dimensionless form and plotted on the graph of the neutral curve in the form of points (Fig. 1). The limiting values of these points defined the region outside which oscillations of any particular frequency did not occur in the boundary layer. The curve embracing this region was called the limiting neutral curve (dotted and dashed line).

For comparison the figure also indicates our measurements of the neutral oscillations (continuous line). The figure is plotted in coordinates of the dimensionless frequency $\beta' = \beta \nu / U^2$ and the Reynolds number $R'$ calculated from the displacement thickness $\delta^*$, $\beta$ is the angular frequency of the perturbing oscillation, $\nu$ is the kinematic viscosity, $U$ is the longitudinal velocity of the unperturbed flow. The limiting neutral curve clearly defines the region of instability associated with nonlinear effects. The limiting neutral curves were also plotted in new coordinates defining the relationship between the dimensionless wave numbers and phase velocities and the dimensionless frequency. These relationships in fact have a specific slope for every velocity of the incident flow.

We also studied the influence of the turbulence of the main flow and the amplitude of the perturbing motion on the hydrodynamic stability. The tellurium method may be used for velocities of the main flow not exceeding 0.2 m/sec. The amplitude of the oscillations of the vibrator $A$ should be of the order of 0.2–0.5 mm, while the transverse velocities which they create should not exceed 2% of the velocity of the main flow. For a ratio of these velocities equal to 2.5%, the transition of the laminar boundary layer into the turbulent flow occurs immediately behind the vibrator. In this case $A > 0.7$ mm, while the dimension-
less wave number $\alpha\delta^*$ and rate of propagation of the perturbation $c/U$ tend toward 0.5 and 0.6 respectively over the whole thickness of the boundary layer. Here $\alpha$, $c$ are the wave number and phase velocity of the perturbing oscillation. The degree of turbulence of the main flow should not exceed 0.05%.

We then determined the course of development of the perturbing motion and the distribution of its kinetic energy over the thickness of the boundary layer. The maximum values of the velocity components of the perturbing motion lay within the ranges $(0.15-0.30)\gamma/\delta$ ($\gamma$ is the vertical coordinate, $\delta$ is the thickness of the boundary layer). On moving toward the outer limit of the boundary layer the value of $\alpha\delta^*$ diminished, while $c/U$ increased. The results of our measurements of the kinetic energy of the perturbing motion across the thickness of the boundary layer are set out in [6].

A perturbing motion was also created in the boundary layer by nonsinusoidal oscillations of a stepped character, these being created by means of a vibrating relay. Analysis of the stepped perturbation by expansion into a Fourier series showed that the main energy-carrying harmonic was the first.

By establishing the values of the neutral frequency with respect to the first harmonic, we plotted the neutral curves, which embraced a greater range of unstable oscillations than in the case of the sinusoidal perturbations. The dependences of $\alpha\delta^*$ and $c/U$ on the dimensionless frequency were similar to the analogous dependences associated with the sinusoidal perturbation, and also depended very little on the velocity of the main flow.

Apart from quantitative measurements, the tellurium method enabled us to carry out qualitative visual examinations which agreed closely with the results of [7].

Measurements showed that the point of stability loss was characterized by a number of distinguishing features. Close to this point we find the highest frequenices and shortest wavelengths of the neutral oscillations and the greatest range of frequencies of the unstable oscillations; the wave of perturbation is expressed more sharply, and its crest turns more rapidly and closer to the vibrator.

2. Study of Hydrodynamic Stability at Elastically Damping Surfaces

Various theoretical investigations into the hydrodynamic stability of flow around elastically damping surfaces have been carried out in the last 10 years. Recently the effect of the individual mechanical properties of flexible skins has been studied. Experimental investigations have been carried out into three forms of skins. The membrane skin consisted of a polyethylene film 0.1 mm thick drawn out over a rigid frame. The construction of the skin allowed longitudinal strips of foam polyurethane to be placed under the membrane so as to obtain a composite membrane skin. The third form consisted of viscoelastic skins made from sheets of foam polyurethane 5 and 3 cm thick, these sheets having different mechanical properties.