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INVESTIGATION METHODS INTO FLOW IN A BOUNDARY LAYER WITH A LONGITUDINAL PRESSURE GRADIENT

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Abstract—The paper deals with a method and results of investigation of a boundary layer with a longitudinal pressure gradient. A two-dimensional problem of the external flow round a body is modelled in a channel of a "tray" type, one wall of which represents an investigated profile.

Résumé—Cet article traite d'une méthode d'étude d'une couche limite avec gradient de pression et des résultats obtenus. Le problème bidimensionnel de l'écoulement autour d'un corps est étudié dans une soufflerie du type "tray" dont une des parois est constituée par le profil à étudier.

Zusammenfassung—Es wird die Methode und das Ergebnis der Untersuchung einer Grenzschicht mit einem Druckgradienten in Längsrichtung besprochen. Ein zweidimensionales Problem der äusserem Umströmung eines Körpers wird in einem Kanal vom "Schalen"-Typ modellmässig so nachgebildet, dass eine Kanalwand das untersuchte Profil darstellt.

Аннотация—В статье излагаются методика и результаты исследования пограничного слоя с продольным градиентом давления. Двухмерная задача внешнего обтекания тела имитируется в канале типа "лоток", одна стенка которого представляет собой изучаемый профиль.

In the presence of a longitudinal pressure gradient the boundary layer flow follows curvilinear surfaces, for example, aerodynamic profiles used in aviation and for submerged wings of ships.

The whole picture of the flow profile depends on the character of the boundary layer. The non-separated flow profile is the most important condition for obtaining qualitative aerodynamic properties of the profile. Usually, the non-separated flow is disturbed at large attack angles, this is characteristic for aviation, e.g. for flight-landing regimes. The problem of the increase both in the attack angle and, consequently, in the lifting power is of great importance in water transport on ships with submerged wings. The annihilation of separated flow is achieved with the help of different ways of boundary-layer regulation.

For investigation of the ways of boundary-layer regulation in the presence of a longitudinal pressure gradient we developed and mastered special working sections of two types on an aerodynamic stand.

When investigating aerodynamic parameters of a boundary layer the gradient flow was created above a flat surface (Fig. 1a).

The air stream flowing from a rectangular nozzle passes through a tray formed by the blowed flat element, two flat lateral surfaces and by an upper curvilinear plate whose corresponding form creates the pressure distribution character required.

Such a type of working section allows one to carry out a precise experiment and when measuring makes it possible to single out the most important phenomena from a complicated series. Moreover, the use of a micrometer screw is simplified since the blowed flat element may serve over its whole area as a base for counting out a vertical co-ordinate.

Pressure curves along the flat surface compared well with a modelled surface of a wing profile. (Fig. 1b).

The experiment, if thoroughly carried out, allows one to obtain almost a complete coincidence of pressure curves.

In the working section there is a strongly

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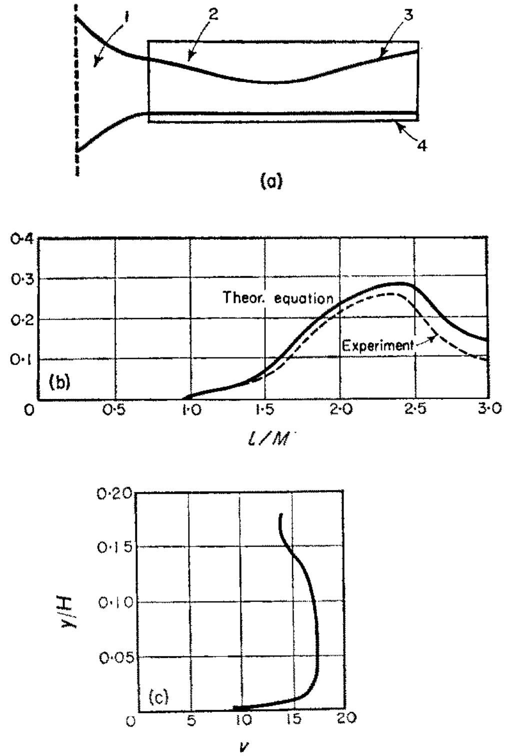

FIG. 1. Working section with longitudinal pressure gradient above a flat surface. (a) Scheme of working section: 1—nozzle, 2—lateral walls of tray, 3—upper curvilinear plate, 4—blowed flat element. (b) Pressure gradient curve. (c) Velocity curve in compressed area of working section.

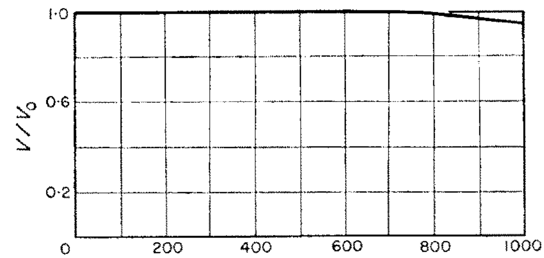

FIG. 2. Velocity curve in a core of constant velocities in a tray above a wing.

shaped core of constant velocities. The velocities were measured in some cross-sections so that two-dimensional flow conditions could be maintained. Measurements showed (Fig. 1c) that over the whole working section boundary layers do not close up near the blowed plane and the upper curvilinear surface.

For the direct investigation of flow in the boundary layer above a curvilinear surface we investigated another type of working section, i.e. flow above the wing. The stream was limited by the curvilinear surface on one side and by the flat walls of the tray on two lateral sides.

The experiment showed that with nozzle dimensions of 190 $\times$ 380 mm the core of the constant velocities is preserved for a length of about 2 m (Fig. 2), this allows one to investigate the gradient flow under conditions imitating the flow of an infinite flat-parallel flow over a wing. The velocity remains practically invariable over the whole length of the tray.

Curves of the velocity within the boundary layer in the tray, which are plotted according to experimental data, coincide well with analogous curves obtained by other authors in a wind tunnel of an ordinary type (Fig. 3).

For a solution of the problem of whether the form of the working section influences the character of flow turbulence, measurements of pulsations were carried out with the help of an electrothermo-anemometer near the curvilinear surface. The results of measurements (Fig. 4) cause one to believe that a longitudinal pulsation component is invariably preserved in the flow core but while approaching the curvilinear surface the pulsations increase both in relative and in absolute calculus.

The pressure distribution on the wing surface was measured in the range of attack angles from 0° to 12° and in the range of velocities from 30 to 120 m/s.

At different attack angles and at the constant velocity $v = 120$ m/s the pressure curves give a high rate of coincidence with data known in the literature and obtained for general conditions (Fig. 5). In our experiment a wing of 11 per cent thickness with a maximum at a distance of 0·4 l from the nose was blown.

The experimental points of a pressure value ($\overline{\Delta p} = 2\Delta p/\rho v^2$) which are obtained for equal velocities practically coincide (Fig. 6). One may conclude that the distribution of pressure is

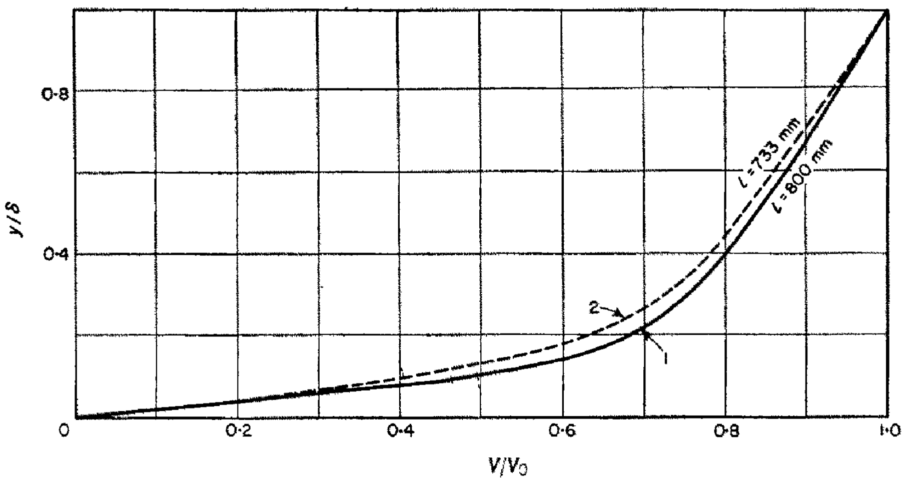

FIG. 3. Velocity curve in a boundary layer above a wing: 1—measurements made in the Kiev Polytechnical Institute: 2—measurements made in Göttingen.

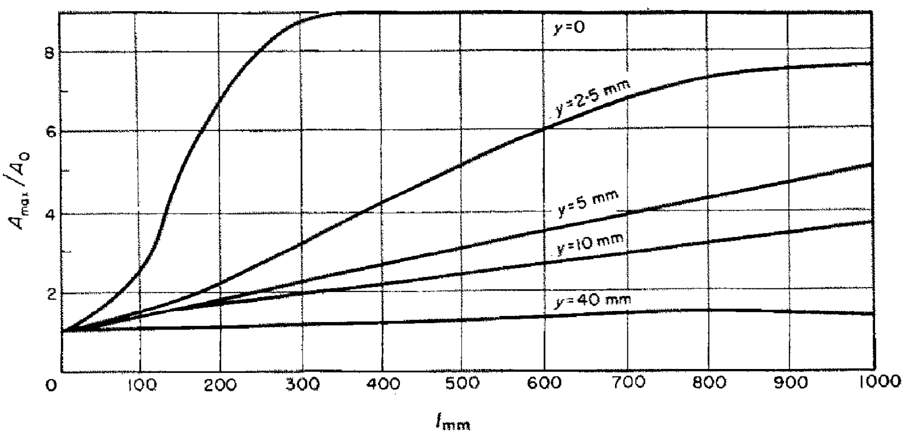

FIG. 4. Distribution of pulsations above a wing.

preserved in rather a wide range for different outflow velocities from the nozzle.

At large attack angles a separation zone was determined with the help of the electrothermo-anemometer by the screen of a cathode oscillograph. When the probe of the electro-thermo-anemometer reaches the separation zone, the amplitudes and frequencies of pulsations increase sharply. In this way the separation zone is determined rather precisely and simply.

Results of the experimental investigation of a boundary layer at gradient flow in the tray show that the application of new types of working section allows one:

(1) To investigate a two-dimensional problem imitating the flow profile by the infinite flow.

(2) To carry out an experiment on a model whose length exceeds by about 10 times the dimensions of the nozzle.

(3) To carry out an experiment at the minimum possible power of delivery pumps. Thus, for example, technical possibilities of the stand made in the Kiev Polytechnical Institute (compression ratio 1:8; mass flow rate 8 kg/s)

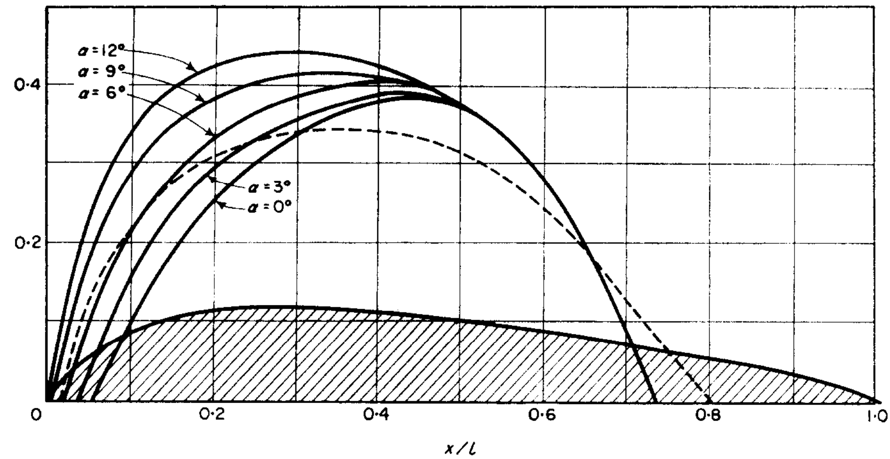

FIG. 5. Pressure curves above a wing both at velocity of running flow (120 m/s) and different attack angles. Pressure curve is shown by a dashed line for blowing of an approximately analogous profile in a wind tunnel of an ordinary type.

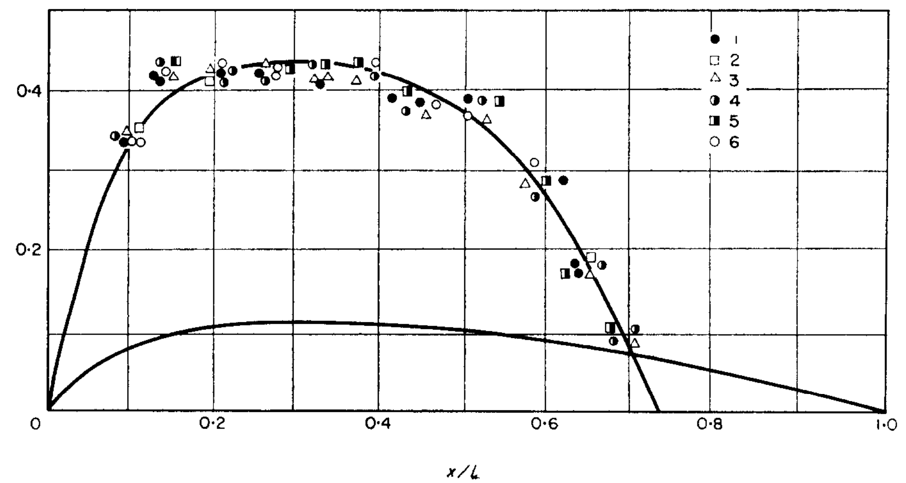

FIG. 6. Pressure curve at attack angle of 12°.
1—v = 43 m/s; 2—v = 68 m/s; 3—v = 88 m/s; 4—v = 92 m/s; 5—v = 105 m/s; 6—v = 114 m/s.

allows one to carry out investigations at velocities up to 120 m/s, at Reynolds numbers up to 4×10^7 and at the chord length of a profile of about 2 m.

Besides the electrothermo-anemometer, a micrometer screw which was remote-controlled and with three-dimensional travel was applied. The travel length of the micrometer screw carriage was 2000 mm along the working section, 400 mm across and 400 mm along the vertical line. The measurement accuracy of horizontal displacements was 0·5 mm and of vertical displacements 0·05 mm. The displacement was carried out along micrometer screws by the rotation of nuts with the help of reversible motors PD-09. The displacement was controlled both visually and remotely by a rheo-chord scheme.

In the vertical screw there was a longitudinal axial hollow into which was inserted the probe of the electrothermo-anemometer and pneumo-packings to measure velocity and static pressure.

On the two types of working section described above the heavy electric and magnetic fields, resonators and ultrasound were applied as a physical influence upon a turbulent layer. When applying the first method, the separation point of the turbulent boundary layer is displaced on account of its additional turbulization; the effect due to the application of the second method is explained by the decrease in the second (volumetric) air viscosity when the ultrasound is passing; when applying the third method the ions, formed by natural or artificial ionization, are accelerated along a flow communicating energy to the air in a region near the wall and thus eliminating the separation.

At present, investigations of qualitative and quantitative properties of the mentioned methods of boundary-layer regulation are being carried out.