2. I. P. Ginzburg, "Hydraulic shock in tubes of elastoviscous material," Vestn. Leningrad. Gos. Univ., Vol. 3, No. 13 (1956).
3. R. M. Sattarov, "Hydraulic shock of power-like and nonlinear viscoplastic media in tubes of viscoelastic material," Zh. Prikl. Mekh. Tekh. Fiz., No. 3 (1975).
4. R. M. Sattarov, "Some cases of nonsteady state motion of viscoplastic media in an infinitely long viscoelastic tube," Zh. Prikl. Mekh. Tekh. Fiz., No. 3 (1977).
5. R. M. Sattarov and R. N. Bakhtizin, "Pressure propagation in viscoelastic media in motion in tubes of elastoviscous material," Inzh. Fiz. Zh., 44, No. 3 (1983).
6. V. E. Zakharov, S. V. Manakov, S. P. Novikov, et al., Soliton Theory [in Russian], Nauka, Moscow (1980).
7. J. Wisem, Linear and Nonlinear Waves [Russian translation], Mir, Moscow (1977).
8. V. S. Didenko and V. N. Degtyarev, "Study of startup conditions for pipelines containing congealed petroleum," Neft. Khim., No. 3 (1977).
9. R. M. Sattarov, "Analysis of rheological properties of viscoelastoplastic media in motion in tubes," Inzh. Fiz. Zh., 41, No. 6 (1981).

FLOW DETACHMENT FROM THE LEADING EDGE OF A PROFILE AND THE EFFECT OF ACOUSTIC PERTURBATIONS

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UDC 532.526

The study of the phenomenon of detachment of a flow has long attracted the interest of researchers because of the wide extent to which detachment flows are found, and their major role in flow structure formation. It is known that two different flow regimes may exist after detachment [1]. In some cases the initial boundary layer passes above the region of recirculating liquid and then again attaches to the body at some point down the flow, separating "bubbles" of recirculating liquid. In other cases liquid from the boundary layer does not reattach to the body, but travels down the flow, mixing with the recirculating liquid and forming a wake. In this case for a profile oriented at a large angle of attack, detachment encompasses the entire upper surface.

The flow regimes described above determine the type of detachment. The detachment may be "localized," as in the first case, or may include the entire surface, as in the second.

The first type of detachment was realized in [2, 3]. In this case, a small "localized" detachment was formed in the midpart of the wing profile. It was shown in [2] that natural perturbations developing in the detachment region may lead to significant readjustment of the flow structure in this region. It was found in [3] that in the region of unfavorable pressure gradient acoustic perturbations are transformed to turbulent boundary perturbations (Tollmien–Schlichting waves), which propagate down the flow, which also have a strong effect on the structure of the laminar flow in the boundary layer and may lead to elimination of the detachment as in the case where perturbations are introduced into the boundary layer by a vibrating ribbon.

The goal of the present study is to generate a detachment encompassing the entire upper surface of the profile, i.e., a detachment of the second type, and to study its structure and the effect thereon of acoustical perturbations.

The experiments were performed in a T-324 low turbulence aerodynamic tube at the Siberian Branch of the Academy of Sciences of the USSR [4]. The test chamber dimensions were 1 × 1 m with length of 4 m. Flow detachment was studied with a symmetrical Zhukovskii airfoil 1 with chord of 292 mm and span of 1 m, located at an attack angle of 11° at a distance of 1.0 m from the beginning of the chamber. A diagram of the experimental setup is shown in Fig. 1. A loudspeaker 2 was installed in the tube diffusor to excite acoustical oscillations in the flow region to be studied. The loudspeaker was driven by a GZ-34 audio generator. A microphone located in the direct vicinity of the model and a PSI-202 precision pulse noise meter were used to measure the integral over spectrum of the sound intensity, which was maintained at $A_s = 90$ dB in the present experiments (background sound intensity 80 dB).

Novosibirsk. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 112-115, March-April, 1985. Original article submitted January 2, 1984.

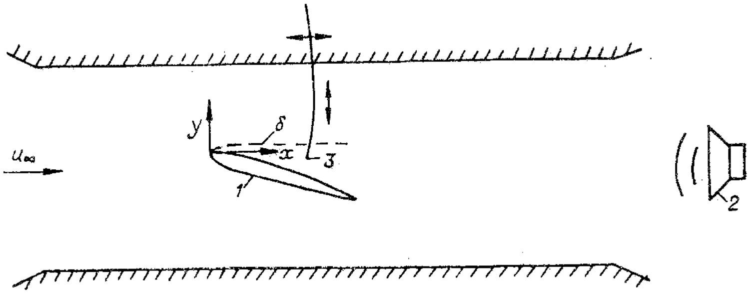

Fig. 1

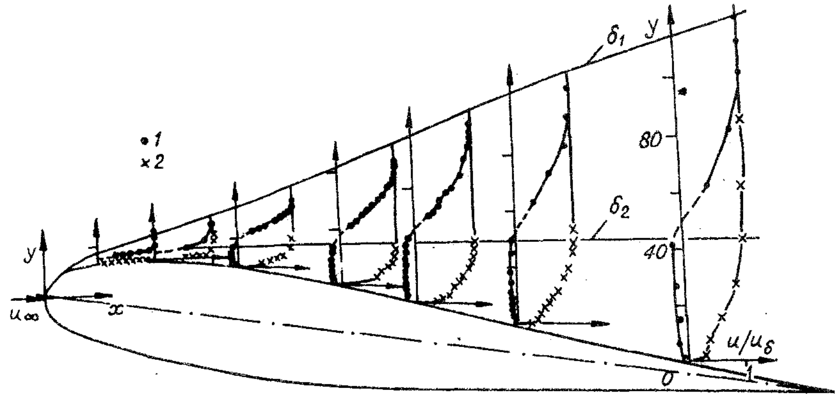

Fig. 2

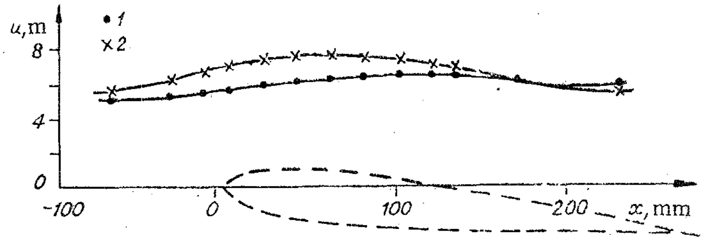

Fig. 3

Mean and instantaneous flow velocities were measured with a 55D00 DISA thermoanemometer with linearized characteristic. Sensor 3 was introduced into the flow through a window in the operating chamber. The sensor element, a hot filament 8 μm in diameter, was oriented across the flow direction. The average component of the sensor signal, corresponding to some combination of the velocity vector components, was recorded by a digital voltmeter with averaging time of 3 sec. When studying spectral integrals of the perturbation characteristics the pulsation component was recorded by an rms voltmeter and displayed on an S1-18 dual trace oscilloscope, allowing visual observation of perturbations. Measurements were performed at an incident flow velocity $u_\infty = 4.9$ m/sec, measured at the entrance to the operating chamber. In constructing the velocity profiles it was considered that the mean velocity in the detachment region has a negative value, which was allowed for in the construction, as in [5].

Figure 2 shows mean valocity profiles (sections x = 20, 40, 70, 107, 134, 170, 230 mm), realized in the boundary layer in the detachment region without (points 1) and with (points 2) acoustical perturbations. The sound amplitude at frequency f = 230 Hz was maintained equal to 90 dB. The profiles are depicted in a laboratory coordinate system (Fig. 1) in which the transverse coordinate y = 0 is related to the surface of the profile, the longitudinal coordinate is measured from the leading edge of the profile, and in each section values are normalized relative to the maximum value. Characteristic distributions of mean velocity ahead of the model and on the boundary of the boundary layer are shown in Fig. 3. It is evident that

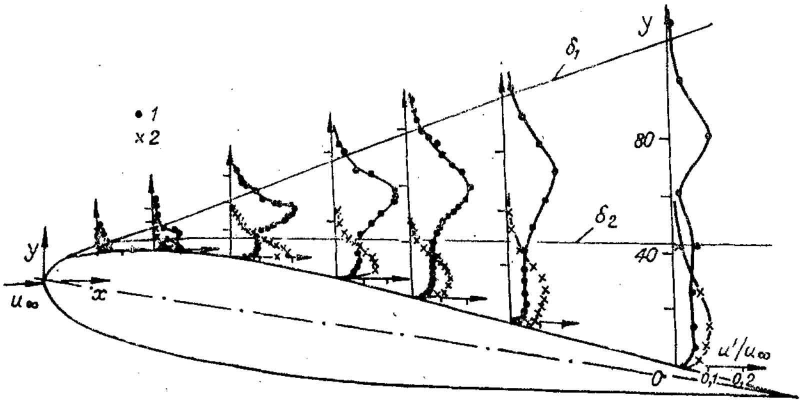

Fig. 4

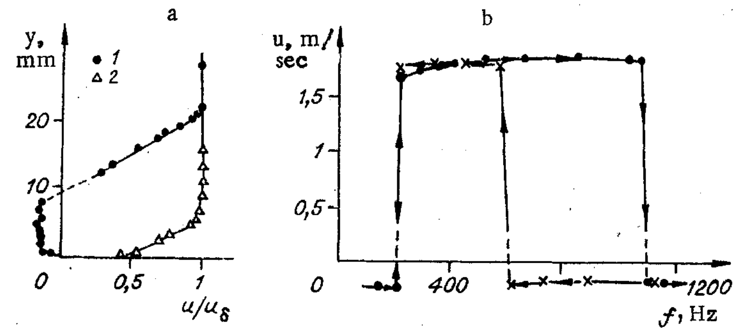

Fig. 5

in the presence of acoustical action 2 the pattern of external flow over the model changes significantly. Analysis of mean velocity profiles revealed that without acoustic action (points 1) at a distance x = 5 mm from the leading edge laminar flow detachment has already developed, and in this region a packet of perturbations begins to grow, leading to transition to turbulence at x = 65 mm, but no reattachment of the detached flow to the wing profile takes place as in [2], but the "fluid" from the boundary layer travels down the flow, mixing with recirculating fluid and forming a wake. The detachment encompasses the entire upper surface.

Figure 4 shows profiles of the pulsation component of velocity for this case (points 1). We note that the maximum in velocity pulsations in the case of laminar and turbulent flows is found far from the wall, its position coinciding with the inflection point in the mean velocity profile (see Fig. 2). When the acoustical field is applied (points 2) over a certain frequency range within the laminar detachment region at x > 10 mm large amplitude Tollmien–Schlichting waves occur (see Fig. 4, sections x = 20 and 40 mm), which was also confirmed by phase measurements, i.e., in this region acoustical perturbations are transformed to turbulent ones, as had already been noted in [3]. Just as in the studies referred to above, this leads to a change in structure of the laminar detachment region in the present case, and its elimination in this region and further down the flow on the entire upper surface (Fig. 2). The maximum in longitudinal velocity pulsations then approaches the surface and the pulsation profile has the form typical of a detachment-free turbulent boundary layer up to the final sections where apparently a turbulent detachment begins to form.

Figure 5 shows various boundary layer states realized as a function of acoustical field frequency of constant sound amplitude equal to 90 dB: a) mean velocity field and acoustical field effect (points 2, i.e., when detachment is eliminated, and points 1, no effect); b) points characterizing acoustic field effect with frequency swept up and back down (measurements performed at x = 70 mm, y = 0.5 mm). It is evident that upon continuous shift from low to high frequency at constant acoustical field amplitude such an effect (elimination of the detachment) begins at 200 Hz and terminates at 1125 Hz, while for sweeping in the opposite direction the frequency range narrows significantly, the effect beginning at 600 Hz and ending at 200 Hz, i.e., the phenomenon shows significant hysteresis (i.e., is significantly dependent on prehistory).

Thus, the present study has determined the characteristics of a global detachment formed on the leading edge of a profile and encompassing practically the entire upper surface of that profile. It has been found that in the presence of an acoustical field at certain frequencies near the leading edge at the beginning of the detachment Tollmien–Schlichting waves are formed at the same frequency, leading to a significant change in the structure of the mean flow, i.e., reattachment of the boundary layer and elimination of the global detachment. It has been shown that this phenomenon exhibits hysteresis with respect to the direction in which frequency is varied.

The author expresses his gratitude to Z. A. Korchagina for her assistance in processing the results.

LITERATURE CITED

1. J. Williams, "Turbulent motions of a liquid," in: Mechanics, No. 21 [Russian translation], (1979).
2. A. V. Dovgal', V. V. Kozlov, et al., "Effect of acoustical perturbations on flow structure in a detachment region," Dokl. Akad. Nauk SSSR, 258, No. 1 (1981).
3. A. V. Dovgal' and V. V. Kozlov, "Effect of acoustical perturbations on flow structure in a boundary layer with unfavorable pressure gradient," Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 2 (1983).
4. G. I. Bagaev, V. K. Golov, G. V. Medvedev, and N. F. Polyakov, "T-324 low turbulence low velocity aerodynamic tube," in: Aerophysical Studies [in Russian], Novosibirsk (1982).
5. A. K. Gupta, S. N. Sinkha, and M. M. Oberai, "Laminar detachment flow over steps and cavities. Part 1. Flow over a cavity," Raket. Tekh. Kosmon., 19, No. 12 (1981).

FLOW IN THE REGION OF INTERACTION OF AN UNDEREXPANDED LOW-DENSITY STREAM WITH A PLANE BARRIER PERPENDICULAR TO ITS AXIS

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UDC 533.6.011.8

The study of the effect of rarefaction on supersonic streams is based mainly on the results of density measurement by the method of electron-beam analysis. This method ensures that the measurement is sufficiently local in character while retaining high accuracy. Also, it does not disturb the gas flow. It has been used to conduct a broad experimental study of underexpanded streams discharged into a low-density space [1], the results obtained here having been used to then establish similarity parameters for the flows. The study [2] used data from density measurement to study the effect of rarefaction on the thickness of the Mach cone in free underexpanded streams.

Presented below are results of a study of the density distribution in a shock layer associated with an underexpanded low-density stream flowing onto a perpendicular plane barrier. We used the method of electron beam analysis in the x-ray range. The experimental data was used to evaluate the thickness of the central shock and to classify flow regimes in the shock layer according to degree of rarefaction.

1. Local density was measured using the standard system of an EOSS-2 electron gun and the recording equipment of an SSD counter. The gun was powered by a VIP-2-50-60 high-voltage source. The energy of the beam electrons was 20-25 keV, while the beam current was 1-5 mA. The energy spectrum associated with the x rays generated in the interaction of the beam electrons with molecules of the gas target was recorded with SRPO-16 and SI-12R proportional counters. The method used made it possible to measure density in the range 10^{18}-$5\cdot10^{21}$ m$^{-3}\cdot$sec with a local resolution of 1 mm^3. The total measurement error was comprised of the error of the equipment complex and the calibration error and did not exceed 15%.

Density measurement near the surface of the barrier was made considerably more complicated by the presence of background x-rays formed in the interaction of scattered electrons of the beam with the barrier material. Local values of density can be obtained in this case only

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Leningrad. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 115-120, March-April, 1985. Original article submitted February 13, 1984.

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