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PRESSURE PULSATIONS IN A RECESS OVER WHICH A SUBSONIC OR SUPERSONIC GAS STREAM FLOWS

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Subsonic or supersonic flow over a recess of small depth with laminar, transitional, and turbulent modes of flow in the boundary layer ahead of the separation point are discussed. Under certain conditions (the Mach number of the external stream, the size and shape of the recess, etc.) discrete components are observed in the spectrum of pressure pulsations of the recess. This phenomenon has been investigated both experimentally [1-4] and theoretically [5] with turbulent flow in the boundary layer ahead of the recess. In [1, 4] the nonsteady flow pattern in the vicinity of a recess was revealed mainly using shadow photographs obtained with a short exposure ($\sim 10^{-6}$ sec). The frequencies of the discrete components in the pressure spectrum of a three-dimensional rectangular recess were determined in [3].

In the present report we investigate in detail the nonsteady flow pattern in a recess and its vicinity with laminar, transitional, and turbulent modes of flow in the boundary layer ahead of the recess. It is shown that with laminar flow in the boundary layer a nonsteady separation zone of small size, which periodically disappears and reappears, forms ahead of the recess because of the pressure pulsations in it. The compression shocks formed ahead of this zone of separation flow and the vortices formed in the zone are periodically carried off by the stream after the next disappearance of this zone.

1. The experimental investigation was performed in wind tunnels and on an aeroballistic course. The test models comprise two groups. The first group (I) includes cones with half-angles $\theta = 2.5\text{-}30°$ at the apex and with axisymmetric annular recesses on the lateral surface with a depth h and a relative length $l^0 = l/h$. The second group (II) includes flat plates, which comprised a side wall of the working section of the wind tunnel with a size of 70×50 mm. Recesses with a depth h, a relative length l^0, and a width of 70 mm were made in these plates. A capacitive detector of pressure pulsations was mounted on the bottom of the recess flush with its surface. The frequency characteristic curve of the detector has a maximum at the frequency f = 6.5 kHz, which corresponds to the natural frequency of the detector membrane. Therefore, all the measurements were made at frequencies f < 6 kHz. The parameters of the stream and the dimensions of the models used in the experiments are given in Table 1, where M_0 is the Mach number of the oncoming stream; T_W/T_0 is the ratio of the wall temperature to the stagnation temperature in the outer stream; α_1 and α_2 are the angles between the leading or trailing walls of the recess and its bottom; $z^0 = z/h$ is the relative length of the deflector; d is the diameter of the midsection of the model; Re is the Reynolds number, calculated from the parameters of the outer stream and the length of the model from the critical point to the leading edge of the recess; A and B are the groups of experiments conducted on the aeroballistic course and in wind tunnels, respectively. The parameters of the stream on the aeroballistic course were determined from the average velocity over a base with a length of 8 m; the error in measuring this velocity did not exceed 0.5%.

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TABLE 1

		M_0 (M_1)	Re	T_w/T_0	h, mm	l^0	α_1, deg	α_2, deg	θ, deg	z^0, mm	d, mm
I	A	0,6—3,5	$0{,}5\cdot10^6$—$5\cdot10^6$	1	2—3	0,6—5	90	90	5—40	0	52
I	B	2—4	$5\cdot10^4$—$6\cdot10^6$	0,5—1	2—5	0,4—5	90	80—150	2,5—30	0	13
II	B	2—4	10^6—$6\cdot10^7$	1	10—25	1—5	90	80—160	—	0—1	—

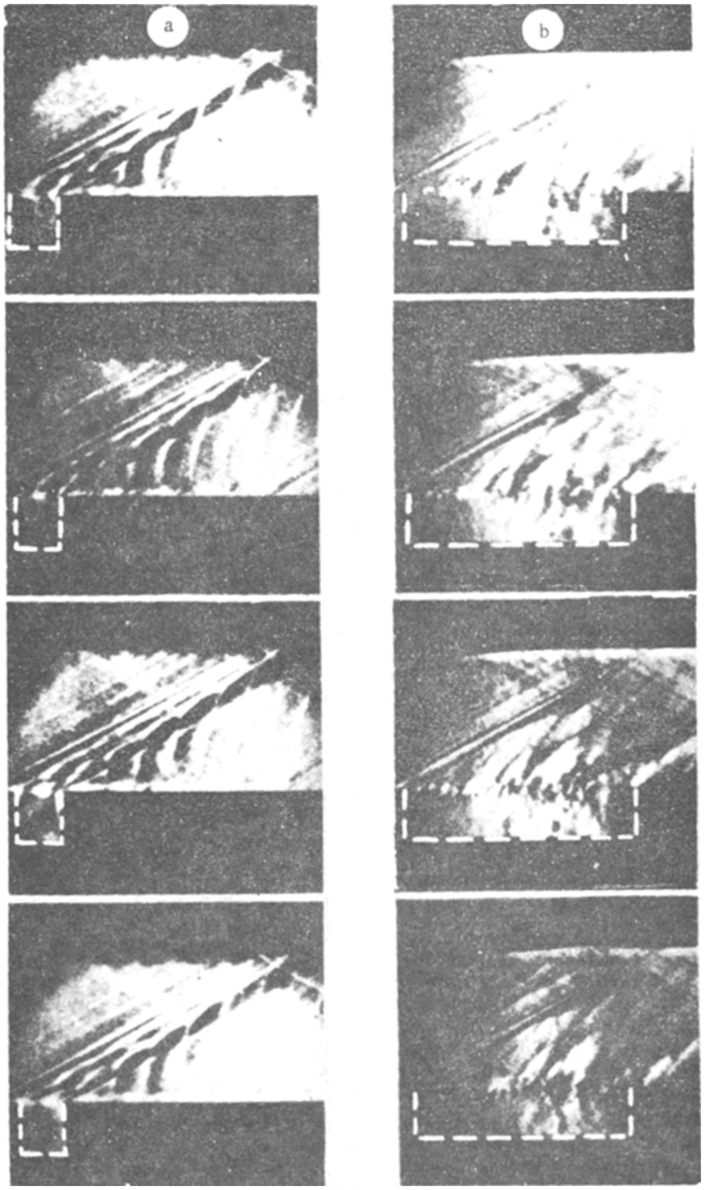

Fig. 1

Shadow photographs of the field of flow around the model (at a scale of ~1 : 1) with an exposure of ~10^{-7} sec were obtained at nine points of the trajectory on the aeroballistic course, while magnified (~6+) shadow photographs with an exposure of ~10^{-6} sec were obtained in the wind tunnels.

The repetition frequencies of the compression shocks and the compression waves were measured in the wind tunnels with a disk scanner [6], the slit of which was mounted perpendicular to the outer boundary of the mixing layer formed above the recess. The measured frequency was determined as the frequency of the wavy track recorded on film with the disk scanner. The error in measuring the frequency did not exceed 5%. The propagation velocities of the disturbances were determined in the wind tunnels with the same scanner but with the slit mounted parallel to the bottom of the recess. The error in measuring the propagation velocity of the disturbances did not exceed 30%. High-speed motion-picture photography (250,000-500,000 frames/sec) was also conducted in the tunnels using an SFR-2m high-speed streak camera. The high-speed motion-picture photography allowed us to determine the propagation velocity of the disturbances with an error ~15%.

The pressure pulsations in the recess were measured with a capacitive detector, the signal from which was recorded by an M-168 tape recorder. The signal was analyzed and treated using an instrument of the Brull and Kehr firm. The spectral characteristics were determined for frequency bands with a width $\Delta f = 10$ Hz; the error in measuring the levels of the pressure pulsations was 2-3 dB.

2. Let us consider the nonsteady flow in the vicinity of a recess when a supersonic stream flows over it. First we take the case of turbulent flow in the boundary layer ahead of the separation point. In Fig. 1 we present shadow photographs of the flow over a thermally isolated model ($T_W = T_0$), obtained with the high-speed camera when the Mach number of the outer stream was $M_1 = 2.1$ and the Reynolds number, determined from the parameters of the outer stream and the length of the plate from the critical point to the recess, was $Re = 7 \cdot 10^6$. These photographs demonstrate the nonsteady pattern of flow over a recess with a depth h = 10 mm at two values of the relative length: $l^0 = l/h = 1$ (Fig. 1a) and $l^0 = 5$ (Fig. 1b).

The disturbances generated near the leading edge propagate above the recess in the direction of its trailing edge. The measurements with a streak camera showed that their propagation velocity, normalized to the velocity u_1 of the outer stream, was $c^0 = c/u_1 \approx 0.5$. Thus, one of the sources of pressure pulsations is located at the leading edge of the recess, and the disturbances produced by this source propagate in the supersonic region of flow. A second source of disturbances is located at the trailing edge of the recess. The experimental results (pulsed shadow photographs, streak photography frames, and photographs of disk scanning of the shadow pattern) show that the disturbances from this source propagate both in the supersonic outer stream and inside the recess. And because of the interaction of the mixing layer with the trailing wall of the recess a pressure wave forms which propagates inside the recess and reaches the leading wall. Being reflected from it, this wave propagates back to the trailing wall of the recess. The results of the measurements of the propagation velocity of the pressure waves using streak photography showed that the velocity u_W of these waves is close to the speed of sound a_0 at the stagnation temperature T_0 of the stream. A third source of disturbances of the outer stream is the entire mixing layer, which generates sound waves propagating in the direction perpendicular to the dividing streamline and simultaneously carried off by the stream.

We also investigated the flow patterns in a zero-gradient supersonic stream at sufficiently large distances behind the recess (Fig. 1a). In this case the complex pattern of disturbances degenerates into a simpler pattern with regular compression waves from the first and second sources. A similar pattern is also observed on free-flying models (Fig. 2b, $M_0 = 1.89$). Disturbances from the third source are greatly attenuated and are not seen in the photographs. The results of the present report agree with the results of [4], where a detailed investigation was made of the flow pattern in the vicinity of a recess with $M_1 = 1.6$-3.5 and $Re = (0.13$-$40) \cdot 10^6$.

Vortices of large size are observed in the mixing layer above the recess; they form near the leading edge of the recess and move along the stream, rapidly increasing in size. In the interaction of such vortices with the trailing edge of the recess a large "bulge" forms in the mixing layer. The small and the large vortices both move with about the same velocity. The size of the small vortices increases considerably slower and their shape remains almost constant. In Fig. 1b, a large vortex whose motion is traced rather clearly is marked by a cross in the first and last frames. Measurements of the velocity of motion u_* of the vortices made using streak photography with $M_1 = 2.1$ and $l^0 = 1$-5 showed that the relative velocity of motion of the vortices is $\lambda = u_*/u_1 = 0.45$-0.65.

The flow pattern described above is observed in the case of short ($l^0 = 1$) and long ($l^0 = 5$) recesses in plane and axisymmetric flows. The angle of inclination α_2 of the trailing wall does not affect the nonsteady flow pattern (which is observed for $\alpha_2 < 135°$ in the case of $M_1 = 2.1$ under consideration). From the mixing layer behind the recess a boundary layer forms in which a train of large vortices is generated, following each other with almost equal intervals l_*. Analysis of the photographs showed that when $M_1 = 1.5$-2.1 the relative quantity l_*/l equals 0.8-1.2. The velocity of the large vortices in the boundary layer behind the recess is increased in comparison with their velocity in the mixing layer. In the section of $s/l = 0.2$-0.5 behind the recess it reaches values corresponding to $\lambda = 0.7$-0.8. In the turbulent boundary layer the relative velocity of motion of the vortices is $\lambda \approx 0.8$ [7]. Thus, at distances $s/l > 0.5$ the large vortices induced by the recess evidently propagate just like ordinary vortices in a turbulent boundary layer.

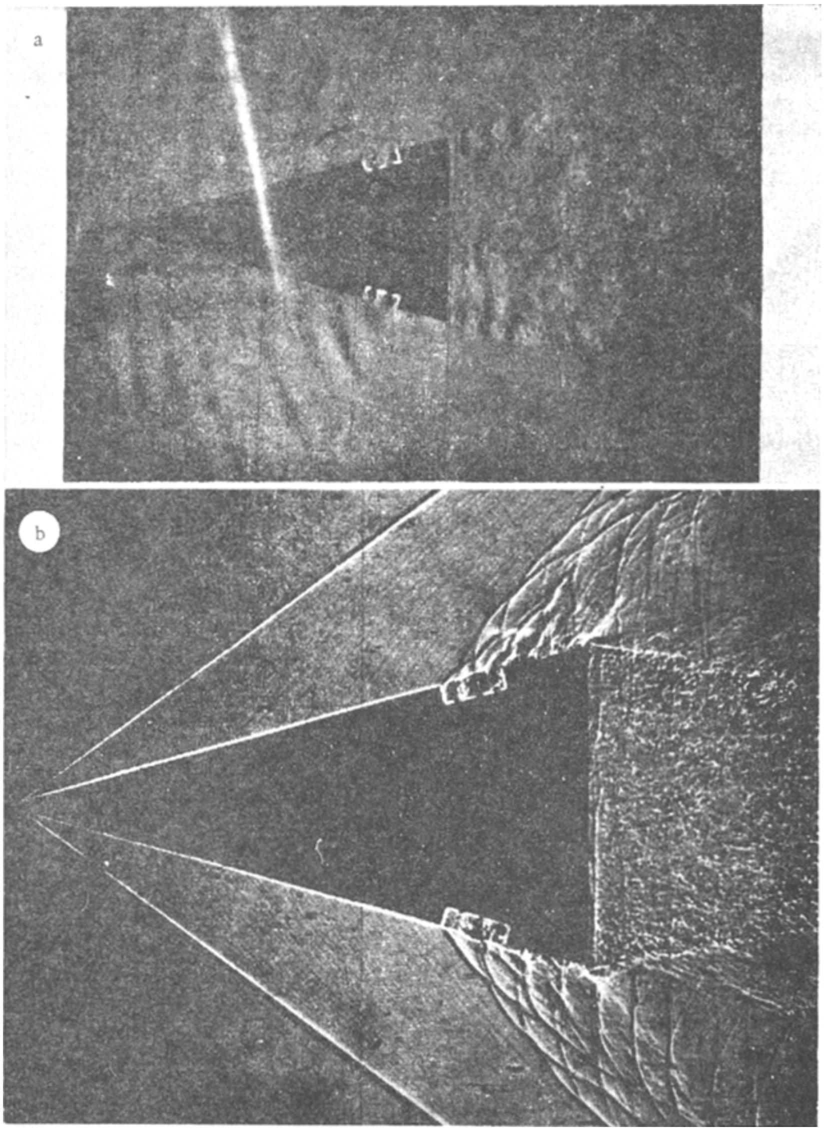

Fig. 2

Now let us consider the case of a laminar mode of flow in the boundary layer ahead of the separation point. When the propagation velocity of disturbances was determined with a disk scanner whose slit was placed parallel to the generatrix of the cone at a small distance from the recess it was discovered that the disturbances move upstream near the leading edge of the recess. A more careful investigation of the flow pattern was required to explain this unexpected phenomenon.

For this purpose we obtained enlarged pulsed shadow photographs. They showed that a region of separation flow having a very small size periodically appears and disappears ahead of the recess. In the case of laminar flow in the boundary layer the critical pressure drop causing separation of the boundary layer is small. Therefore, when a compression wave arrives at the leading edge across the recess a pressure drop exceeding the critical one is created, as a consequence of which the microseparation of the boundary layer ahead of the recess occurs.

The pressure in the zone of this separation flow is determined by the acoustic wave, so that it reaches a maximum and then falls. Accordingly, the zone of separation flow first grows and then contracts and disappears. Ahead of the zone of separation of the boundary layer a compression shock forms which moves upstream simultaneously with the increase in the length of the zone of separation flow, and then stops and moves in the opposite direction. After the disappearance of the zone of microseparation of the boundary layer ahead of the recess it is carried off by the stream.

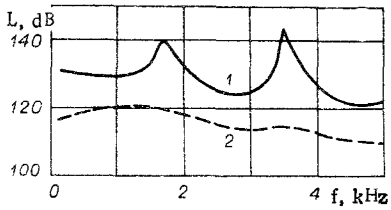

Fig. 3

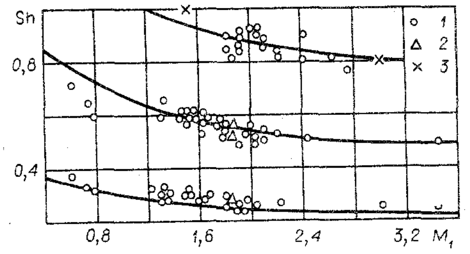

Fig. 4

In [2, 4] in an investigation of turbulent flow in a recess the pressure pulsations in it are explained by the separation of turbulent vortices from the leading edge. In the case of laminar and transitional flows such an explanation cannot be used. With a laminar mode of flow in the boundary layer ahead of the recess a decrease in the Reynolds number should lead to a decrease in the amplitude of the pulsations, since turbulent vortices degenerate at low values of Re, so that resonance oscillations in the recess should disappear.

The experiments show the opposite, however. With a decrease in the Reynolds number the ratio of the amplitude of the pressure pulsations to the static pressure ahead of the recess, $\Delta p/p_1$, does not decrease but increases, and intense pulsations are observed at low values of Re ($Re = 5 \cdot 10^4$, for example).

If the formation of a vortex in the laminar mixing layer in the recess is considered as the concluding phase of the process of disappearance of the zone of separation flow which forms periodically ahead of the recess, then such a contradiction does not arise.

We also investigated the nonsteady flow in the vicinity of a recess when a subsonic stream flows over it. A shadow photograph of the flow pattern with $M_0 = 0.58$ is presented in Fig. 2a. The acoustic waves emitted by the recess propagate upstream, with the source of the acoustic disturbances being located at the trailing edge of the recess. Behind the recess a boundary layer forms in which a train of large vortices is generated, especially clearly noted in the photograph in the mixing layer of the base region of the cone. These vortices follow each other with about the same separation l_*.

3. The amplitude of resonance oscillations in a recess depends on the Mach number M_1 of the outer stream ahead of the recess, the Reynolds number Re, the configuration of the recess, and other parameters. Discrete components are observed in the spectrum of pressure pulsations in the presence of resonance oscillations. For example, with $M_1 = 2.1$, $l^0 = 3.2$, $Re = 4.5 \cdot 10^6$, and $T_w/T_0 = 1$ the discrete components (curve 1 in Fig. 3) have a level L = 142 dB and exceed the continuous noise level by 15-20 dB. The spectrum of pressure pulsations at the surface of a model without a recess (curve 2 in Fig. 3) does not contain discrete components, while the intensity of the continuous noise in the frequency range f = 500-5000 Hz lies at the level L = 110-120 dB. Thus, the root-mean-square amplitudes of the resonance pressure oscillations in a recess exceed the root-mean-square amplitude of the continuous noise at the surface of a model without a recess by 12-40 times, while they exceed the amplitude inside the recess by 10 times.

The presence of a discrete tone in the spectrum of pressure pulsations is connected with the disturbances originating at the leading edge of the recess. The correspondence of the frequency f_* of the discrete components to the frequency of these disturbances was verified experimentally on models of the second group (depth of recess 15-25 mm), on which shadow photographs could be obtained and the spectrum of pressure pulsations measured simultaneously. The frequencies of the disturbances measured with the disk scanner coincided with the frequency of the discrete component (the difference did not exceed 5%). Therefore, in the wind tunnels on small models where it was impossible to mount a detector of pressure pulsations, the frequency of the discrete component was measured with the disk scanner.

At subsonic velocities of the outer stream the experimental values of f_* were determined from photographs obtained on the ballistic installation. In this case it was assumed that disturbances in the stream propagate through the gas with the speed of sound. Then the distance between two successive compression waves near the surface of the cone is $b = (a_1 - u_1)\tau_0$, where a_1 and u_1 are the speed of sound and the stream velocity near the surface of the cone and $\tau_0 = 1/f_*$ is the period of the oscillations. The quantity b was measured on the photographs while the value of f_* was calculated from the equation $f_* = \frac{a_1 - u_1}{b} = \frac{u_1}{b}\left(\frac{1}{M_1} - 1\right)$, $M_1 = \frac{u_1}{a_1}$. In these calculations it was also assumed that $M_1 = M_0$ in the investigated flows. Additional experiments showed that this equality is satisfied with an accuracy of $\sim 5\%$ for a subsonic flight velocity and cones with half-angles $\theta \leq 15°$ at the apex.

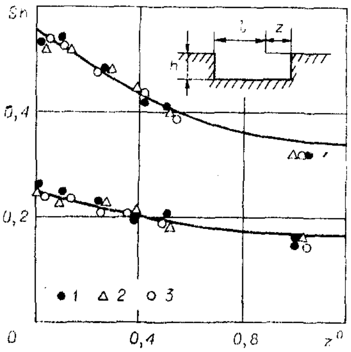

Fig. 5

Let us consider the dependence of the dimensionless frequency of resonance pressure oscillations, $Sh = f_* l/u_1$, in a rectangular recess ($\alpha_1 = \alpha_2 = 90°$) on the parameters M_1, Re, T_w/T_0, l^0, and δ/h (δ is the thickness of the boundary layer ahead of the recess) determining the flow in the recess. In the investigated range the Strouhal number Sh hardly depends on the length of the recess, the Reynolds number, the relative temperature, or the relative thickness δ/h of the boundary layer ahead of its separation at the leading edge of the recess. The Strouhal number also does not depend on the mode of flow in the boundary layer ahead of the recess (laminar, transitional, or turbulent). With a laminar mode of flow in the boundary layer ahead of the separation point the presence of a transition in the mixing layer does not affect the Strouhal number. The determining parameter for the dimensionless frequency of the discrete component of pressure pulsations in a rectangular recess is M_1. In Fig. 4 we present experimental dependences of the Strouhal number on the Mach number of the outer stream ahead of the recess (three tones of the resonance oscillations) (points 1 are the results of the present work, 2 are those of [1], and 3 are those of [3]). The value of Sh decreases with an increase in M_1. The level of the discrete component in the spectrum of pressure pulsations also decreases, and at $M_1 \approx 3.5$ the discrete components (resonance oscillations) disappear. The results of the experiments performed in the present work agree with the results of [1, 3], in which the Strouhal number was measured with $M_1 = 1.5$, 1.8, and 3. In the present work the range of variation of the determining parameters is expanded. The results presented cover the intervals of $M_1 = 0.6$–3.5, $Re = 5 \cdot 10^4$–$6 \cdot 10^7$, $T_w/T_0 = 0.5$–1.0, $l^0 = 1$–5, and $\delta^{**}/h = 0.5 \cdot 10^{-2}$–$2.0 \cdot 10^{-2}$ (δ^{**} is the momentum-loss thickness in the boundary layer ahead of the recess).

The influence of the angle of inclination α_2 of the trailing wall of the recess on the frequency of the resonance oscillations was investigated. Variation of α_2 in the interval of 80–160° hardly affects the dimensionless frequency f_* of the discrete components of pressure pulsations, although it does influence the amplitudes of these components. In particular, with $M_1 = 1.5$ and 2, $Re = 1.6 \cdot 10^5$–$5 \cdot 10^5$, $l^0 = 2$, and $T_w/T_0 = 1$ the discrete components in the pulsation spectrum are not observed at $\alpha_2 \geq 160°$, while with $M_1 = 2.5$ and the same values of Re, l^0, and T_w/T_0 they are not observed at $\alpha_2 \geq 130°$.

Let us consider the influence of an additional cavity formed by mounting a deflector of length z at the trailing edge of a rectangular recess ($\alpha_1 = \alpha_2 = 90°$). In Fig. 5 we present the results of experiments with $M_1 = 2.1$, $T_w/T_0 = 1$, and $l_1^0 = 2.5$ ($l_1^0 = (l + z)/h$, l being the distance from the leading edge to the deflector). Points 1-3 correspond to values of $Re = 1.5 \cdot 10^6$, $4.5 \cdot 10^6$, and $1.6 \cdot 10^7$. The value of $Sh = f_* l/u_1$ decreases with an increase in $z^0 = z/l$. The level of the discrete component falls simultaneously; e.g., it is 15 dB lower with $z^0 = 1.5$ than with $z^0 = 0$.

4. A method of calculating the frequencies of the discrete components in the pressure pulsation spectrum can be constructed on the basis of the nonsteady pattern of flow over a recess presented in Sec. 2. The period τ_0 of resonance pressure oscillations in a recess is equal to the sum of three quantities: the time $\tau_1 = l/u_*$ of passage of a vortex from the leading edge of the recess to its trailing edge, the time τ_2 of passage of a compression wave inside the recess from the trailing to the leading edge with allowance for the time of reflection from the walls, and the delay time τ_3 in the descent of the vortex, i.e., $\tau_1 + \tau_2 + \tau_3 = n\tau_0$, where n is the number of the tone. This expression can be written in the form of a phase relation

$$\varphi_1 + \varphi_2 + \varphi_3 = 2\pi n; \tag{4.1}$$

$$\varphi_1 = k_1 l, \quad \varphi_2 = k_2 l_{ef} = \arctan \frac{\sum_i A_i \sin \varphi_i}{\sum_i A_i \cos \varphi_i}, \tag{4.2}$$

where $\varphi_i = k_2 l_i = 2\pi u_1^0 l_i^0$ Sh; $k_1 = 2\pi f_* u_*^{-1}$; $k_2 = 2\pi f_* a_0^{-1}$; $Sh = f_* l u_1^{-1}$; $u_0^1 = u_1/a_0$; $l_i^0 = l_i/l$; a_0 is the speed of sound in the recess; l_i is the distance from the i-th source to the leading edge of the recess.

The pressure pulsations inside the recess depend on the shape of its boundaries, the location of the actual acoustic source, and the wavelength of the oscillations. The actual source, as shown in Sec. 2, is located at the point of interaction of a vortex with the trailing edge of the recess. The virtual sources are constructed by the method of reflection of the actual source in the solid boundaries of the recess, which are treated as mirror surfaces.

As was shown, for a laminar boundary layer a vortex of large size is formed in the zone of microseparation of the boundary layer ahead of the recess. If the flow in this zone is assumed to be quasisteady, then disruption of the microseparation will occur after $0.25\tau_0$ (the time from the maximum pressure in the wave to a value of $\Delta p = 0$ in it), and hence the delay in the descent of a large vortex is $\tau_3 = 0.25\tau_0$ ($\varphi_3 = \pi/2$).

Then from Eqs. (4.1) and (4.2) we obtain

$$\mathrm{Sh} = \lambda\left[(n - 0.25) - \frac{1}{2\pi}\arctan\frac{\sum_i A_i \sin\varphi_i}{\sum_i A_i \cos\varphi_i}\right]. \tag{4.3}$$

Calculation by Eq. (4.3) is carried out by the method of successive approximations. As the zeroth approximation one takes the Strouhal number Sh_0 calculated for one actual source only (without reflection of waves inside the recess):

$$\mathrm{Sh}_0 = \frac{n - 0.25}{u_1^0 + 1/\lambda}. \tag{4.4}$$

For a turbulent boundary layer ahead of the recess the values of φ_1 and φ_2 remain the same as for laminar flow. If one assumes that the phase φ_3 also equals $\pi/2$ for a turbulent boundary layer, then the value of Sh will be determined by Eqs. (4.3) and (4.4), as with a laminar mode of flow in the boundary layer.

For a supersonic turbulent mixing zone with $M_1 = 2.1$ a value of $\lambda = 0.45$–0.65 was obtained in the present work. In the middle of the turbulent mixing zone of a subsonic jet escaping into the atmosphere the velocity of motion of vortices is $\lambda = 0.52$–0.65, according to the experimental data of [8]. To make calculations by Eqs. (4.3) and (4.4) we take $\lambda = 0.6$ for both a turbulent and a laminar mixing zone. The results of a calculation by Eq. (4.4) are presented in Fig. 4. The calculated dependences (solid lines) agree with the experimental data (points 1-3) in a wide range of M_1.

The influence of the depth of the recess can be estimated using Eq. (4.3). The appropriate calculations were made with allowance for four sources, one actual and three virtual. It was assumed that all the sources have the same power. The results of the calculations showed that there is a small decrease in the Strouhal number with an increase in the depth of the recess (with a change in l^0 from 5 to 1 the value of Sh decreases by ~5%). A decrease in the power of the virtual sources by 1.5 times in comparison with the power of the actual source changes the result by ~1%.

One can use Eq. (4.3) to determine the Strouhal numbers for recesses of arbitrary shape with sharp rims present on the leading and trailing walls of the recess. Rounding of the profile of the trailing wall of the recess in the region of the point of attachment of the mixing layer can lead to the disappearance of the resonance oscillations, while rounding of the edge of the leading wall affects the formation of a vortex. Equations (4.3) and (4.4) allow one to calculate Sh both with $M_1 > 1$ and with $M_1 < 1$.

In the present work Eq. (4.3) was used to determine the influence on the Strouhal number of the interference of an acoustic wave inside the recess upon a change in the shape of the latter. In Fig. 5 we present the results of a calculation of the dependence of Sh on the length z^0 of the deflector (solid lines) for a recess with a deflector near the trailing wall ($l^0 = 2.5$) for $M_1 = 2.1$. The results of the calculation are in satisfactory agreement with the experimental data.

Calculations of the influence of the angle of inclination α_2 of the trailing wall of the recess on the Strouhal number for $M_1 = 1.5$ and 2.0 were also made from Eq. (4.3). An increase in α_2 from 90 to 160° leads to a slight decrease in Sh. The experimental data confirm this result.

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ELECTROMAGNETIC METHOD OF MEASURING MASS VELOCITY AND ELECTRICAL CONDUCTIVITY WHICH VARY ALONG THE STREAM

A. V. Pinaev UDC 53.082.7+538.4

1. A theory of velocity measurement in an MHD channel with allowance for nonuniformities of the magnetic field, mass velocity, and electrical conductivity across the channel is presented in [1, 2] in connection with the problem of the electromagnetic measurement of flow rate. The solution of the problem of the electric field distribution for a stream with a constant electrical conductivity and a mass velocity which varies along the channel is presented in [2]. A method of electrical contact measurements is presented in [3, 4] which gives a good enough resolution to obtain the profile of electrical conductivity which varies along the stream on the example of a detonation wave in a solid explosive, and an estimate of the accuracy of the method is given. A survey of electrical measurements of electrical conductivity is given in [5].

Noncontact methods of measurement, which are modifications of Lin's method [6], are unsuitable for measuring the electrical conductivity of a medium when the velocity varies along its stream. The electrical contact method [4] allows one to obtain the profile of electrical conductivity in a detonation wave with good spatial resolution, but it does not yield any data on the mass velocity of the stream.

In a number of practical problems, such as in the case of the investigation of shock and detonation waves, the dependence of the mass velocity and the electrical conductivity on the coordinate along the stream proves important. The accuracy of the MHD contact measurement of a mass−velocity profile was estimated in [7] and it was shown that MHD contact measurements of the profile of electrical conductivity are possible when the mass-velocity profile is not known in advance.

However, the MHD contact method is unsuitable for determining the mass-velocity profile when it varies significantly along the stream, such as in a detonation wave, since the error of the velocity measurement is large [7]. And for the same reason it is undesirable to use the method of electromagnetic measurements suggested in [8] to determine the profiles of mass velocity and resistance in detonation waves.

In the present report a method of contact electromagnetic measurements is described and the conditions for such measurements are found which allow one to eliminate the influence of the nonuniformity of the mass velocity and electrical conductivity on the accuracy of their determination.

2. A schematic diagram of the measurements is presented in Fig. 1. A medium with a mass velocity $v(z)$ and an electrical conductivity $\sigma(z)$, where z is the coordinate along the stream, propagates along the z_0 axis of a channel of circular cross section with conducting walls. A coaxial conductor 1 is fastened at the center of the channel. The channel consists of a cylindrical capacitor, the central 1 and outer plates 2 and 3 of which serve as the electrodes. The outer plate is formed by two metallic cylinders separated by an insulating spacer 4. The cylinders are electrically connected with each other by a connector 5.

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