ON THE PROBLEM OF RAREFIED GAS FLOW PAST BLUNT AXISYMMETRIC BODIES

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Shock layer separation in flows of rarefied gas past axisymmetric models is determined by interferometric methods. The form of the density jump is established.

The development of highly sensitive methods for the investigation of rarefied gas streams has yielded a number of interesting data on the supersonic flow of such streams past models [1-3]. Density fields upstream of a disk and of a sphere and, also, the density distribution in the shock layer in the region of shear flow were investigated. It should be noted, however, that the mechanism of the interaction between the body and the stream, as well as certain properties of rarefied flows past blunt bodies, have not been fully explained. Moreover, reliable experimental data can provide means for checking the correctness of theoretical schemes and methods of calculation.

Certain properties of supersonic flow of rarefied gas past blunt bodies (a sphere and a disk) in the region of initial shear flow are outlined in this paper. The photometric method of multiple-wave interferometry, as proposed earlier in [1], was used for visual observation. Methods of experimentation and of interferogram processing are given in [1, 3].

An important characteristic of interaction between a stream and a body is the magnitude Δ of shock wave separation relative to the radius R taken as the characteristic dimension. As shown in [2, 3], an increase of the front thickness is observed in the region of shear flow of a stationary shock wave upstream of a body placed in a supersonic stream of rarefied gas. This increase is greater than calculated by Mott-Smith [4]. Hence different calculation results are obtained depending on the selection of the point of the shock wave profile from which the extent of separation is measured.

In [2] the distance between the body and the point of intersection of the Mott-Smith curve was taken as the magnitude of separation, with the two curves matched so as to obtain the same ordinates for the experimental profile points and the inflection point of the Mott-Smith curve. In [5] the magnitude of shock wave separation was taken as equal to the distance from the body to that point of the density profile of the shock front at which the density differed from that of the oncoming stream by, say, 5%. The latter gives a more correct representation of the wave front boundary, although in many instances the measurements of separation is subject to specific errors. It should be noted that asymmetry of the density profile of a shock wave [2, 3, 5, 6] indicates the different spread of the shock wave up- and downstream of the flow. This makes difficult the selection of the central point of the profile from which the measurement of separation is to be made. Owing to insufficient experimental investigation of the structure of shock wave, the choice of Δ is, generally speaking, arbitrary, and it is at present difficult to suggest one or another method for measuring the separation.

The results quoted above were based on measurements from the midpoint of the boundaries of the shock wave front. Under conditions of flow considered here, the front cannot be assumed infinitely thin: its thickness is of the order of several lengths l_∞ of the mean free path of particles in the oncoming stream (the shock wave thickness b is taken to be $b = (\rho_2 - \rho_\infty)/(\partial\rho/\partial z)_{max}$, where ρ_2 is the density behind the shock and z is the distance along the stream axis). At $M \approx 4$ the experimentally obtained $l_\infty/b \approx 0.22$, which is close to the data in [7].

The dependence of shock wave separation on the Reynolds number Re_2 calculated from parameters of the flow downstream of the shock wave and radius of the body is shown in Fig. 1. The pattern of curves 1

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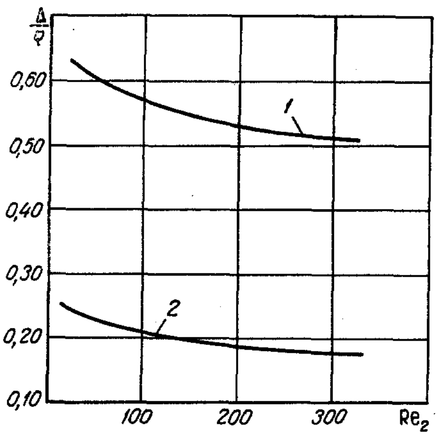

Fig. 1

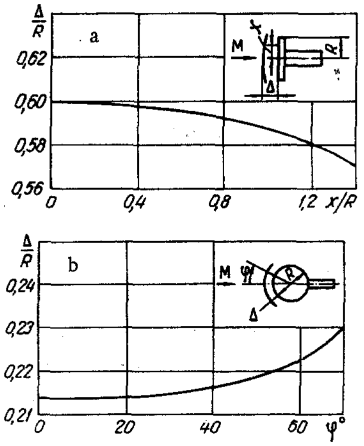

Fig. 2

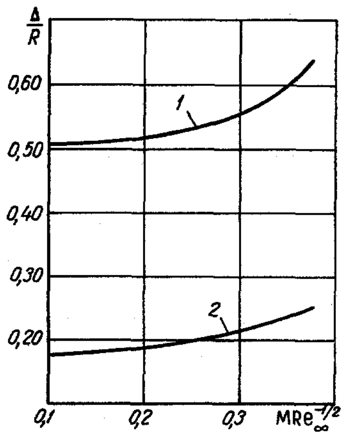

Fig. 3

Fig. 1. Dependence of shock wave separation on the Reynolds number: 1) for a disk; 2) for a sphere.

Fig. 2. Shape of the compression jump for a disk (a) and for a sphere (b).

Fig. 3. Dependence of shock wave separation on the rarefaction parameter: 1) for a disk; 2) for a sphere.

(for a disk) and 2 (for a sphere of the same radius) is the same: the shock wave separation Δ/R diminishes at a decreasing rate with increasing Reynolds number. The increase separation of the shock front at decreasing Reynolds number is due to two factors: the increase of the boundary layer thickness (owing to the increasing effect of viscosity) and the thickening of the shock wave front (owing to the increased mean free path of particles).

These effects lead to an increase of the effective dimensions of the body in the stream, leading to the increase of magnitude Δ at diminishing Reynolds number. Figure 1 shows that at the same Re the shock wave separation in the case of a disk is greater than in that of a sphere. Since at increasing Re number the magnitude Δ/R tends to its value in the continuum, it is obvious that at higher Reynolds numbers the effect of changes of flow parameters on the structure of the compression jump and on the geometry of the shock front will tend to decrease. At low densities the form of the compression jump for both, the disk and the sphere differs from that obtaining in a continuous medium.

The shape of the compression jump for a 10 mm diameter disk is shown in Fig. 3 for $M = 3.8$ and $Re_2 = 70$. A characteristic feature is the curvature of the shock wave front, which increases with the distance from the line of drag. At high Reynolds numbers the curvature in the vicinity of the forward critical point increases, and gradually tends to infinity. Hence one cannot talk of a straight compression jump in front of a disk even in the initial stage of shear flow. In this case the straight line concept can have any meaning only in the proximity of the drag line. In the case of a disk [3] there exists a fairly extended region of virtually constant density in which the Hugoniot relationship applicable to a straight shock is reasonably well satisfied. This shows that for a disk the pattern of gas flow behind the shock wave is close to a continuous one. A similar conclusion was reached in [2] for considerable rarefactions. In the case of a sphere and the same flow parameters (Fig. 2) the compression jump remains concentric only within the limits of ~20.

The dependence of shock wave separation on the rarefaction parameter $M/Re_\infty^{1/2}$ (for our conditions $M/Re_\infty^{1/2} < 1$) is of interest. The magnitude Δ/R increases at an increasing rate with increasing $M/Re_\infty^{1/2}$.

The data presented here were obtained for a narrow range of Mach numbers (3.8-4.2). It is precisely for this reason that an increase of the shock wave separation at increased rarefaction parameters was observed. These results correspond to physical concepts of the mechanism of interaction between a rarefied gas stream and a body, as well as with experimental data obtained by the electron beam method [6, 7].

NOTATION

Δ	is the shock wave separation;
Re_2 and Re	are the Rynolds numbers calculated from the radius of the model and flow parameters, respectively, behind the shock wave and those of the oncoming stream;

R	is the radius of the model;
M	is the Mach number;
ρ_∞ and ρ_2	are the densities of the oncoming stream and of the stream behind the jump;
z	is the stream axis;
b	is the shock wave thickness;
l_∞	is the mean free path of particles.

LITERATURE CITED

1. F. A. Korolev, A. I. Akimov, G. I. Kromskii, and I. V. Skokov, Pribory i Tekhnika Éksperim., No. 4 (1965).
2. A. V. Ivanov, Dokl. Akad. Nauk SSSR, 161, 312 (1965).
3. I. V. Skokov and V. A. Emel'yanov, Inzhenerno-Fizicheskii Zhurnal, 11, No. 1 (1966).
4. H. M. Mott-Smith, Physical Review, 82, No. 6, 885-892 (1951).
5. I. F. Zavarzina and I. V. Skokov, Dokl. Akad. Nauk SSSR, 172, No. 3 (1967).
6. A. V. Ivanov, Zh. Prikl. Mekh. i Tekhn. Fiz., No. 6 (1964).
7. A. V. Ivanov, Izv. Akad. Nauk SSSR, Mekhanika Zhidkostei i Gasov, No. 2 (1967).