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Abstract

Full Text

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HYDROMECHANICS

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DENSITY NEAR THE FORWARD STAGNATION POINT OF A BLUNT BODY IN A SUPERSONIC FLOW OF RAREFIED GAS

(Presented by Academician G. I. Petrov on 21 VII 1964)

A decrease in the density of a supersonic flow past a blunt body leads to a thickening of the boundary layer and of the detached shock wave. When the latter merge with one another, a continuous region of nonisentropic flow is formed in front of the body. The process by which this region is formed, and the mechanism of the flow within it, have until now been almost uninvestigated experimentally. The determination of the density near the forward stagnation point of a blunt body, carried out in the present work, makes it possible to reveal some characteristic features of such a flow regime and, possibly, will prove useful in constructing a model of the flow.

Fig. 1. Density field in front of a disk

Fig. 2. Density field in front of a sphere

The work was carried out in a low-density aerodynamic tube ([1]). Air was used as the working gas. The density fields were determined by means of the electron-probe method ([2]), based on the phenomenon of scattering of electrons from a collimated beam by gas molecules present in the volume under investigation. The main elements of the apparatus

and the procedure for conducting the experiments were similar to those described in the article by Hurlbut (3). The angular aperture of the electron detector was $1.5 \cdot 10^{-3}$ radians. The size of the recorded electron beam was an order of magnitude smaller than the thickness of the compressed region in front

Fig. 3

Figure 2: Fig. 3

Fig. 4

Figure 3: Fig. 4

of the body being flowed over. The energy of the electron beam was 2.2 keV and was chosen with the expectation that the mean free path of the electrons in the beam in the volume under study would be equal to the distance from the electron gun to the detector.

Fig. 3. Density profile along the stagnation line for a disk. 1 –experiment; 2 –Mott-Smith calculation; 3 –discontinuity in the continuum

Fig. 4. Density profile along the stagnation line for a sphere. 1 –experiment; 2 –Mott-Smith calculation; 3 –discontinuity in the continuum

Since the gas flow available to us was axisymmetric, the local density was determined by means of a method analogous to that used in shadow and interferometric density measurements. The models studied were a sphere 15 mm in diameter and a flat disk of the same diameter, mounted perpendicular to the oncoming flow. The Mach number of the flow, M, determined from measurements with a Pitot tube ([1]), was equal to 6. The Reynolds number, Re_∞, calculated from the parameters of the oncoming flow and the radius of both bodies, had the value 220. A comparison of the density in the isentropic core of the undisturbed oncoming flow, obtained from measurements with the electron beam and calculated from the number M, revealed quite satisfactory agreement.

Figures 1 and 2 present the experimentally determined density fields in front of the disk and the sphere. Here the ordinate axis gives the distance from the flow axis, r, and the abscissa axis gives the axial coordinate of the flow, z, with the origin of the z axis placed respectively at the surface of the disk and at the center of the sphere. The different curves correspond to different values of the ratio of the density $\rho(r, z)$ at the point r, z to the density ρ_∞ in the oncoming flow.

Figures 3 and 4 show the change in density in front of the same disk and sphere along the stagnation line.

The dashed curves represent the structure of a normal shock wave calculated according to the Mott-Smith theory ([4]). These curves were superposed on the experimental ones so as to obtain coincidence of the ordinates of the zero point of the Mott-Smith profile with a certain point z_* of the experimental profile. The distance from the point z_* found in this way to the forward critical point of the body proved to coincide with the continuum shock stand-off distance in the case of the disk and to differ from it for the sphere.

In the case of a disk behind a detached shock wave, there exists a rather extended region in which the density changes only very slightly right up to the body itself and, within the accuracy of the experiment, coincides with its calculated value behind a normal shock for continuum flow. This result indicates that the flow conditions near the disk are close to continuum conditions and makes it possible to calculate the thickness of the laminar boundary layer in the vicinity of the forward stagnation point by methods developed for a continuous medium (^5). For the case of a thermally insulated surface, which approximately corresponded to the conditions that obtained in the experiments, the calculated boundary-layer thickness was $\delta = 0.44$ mm. A similar estimate made for the case of flow about a sphere gave $\delta = 0.22$ mm.

Comparison of the boundary-layer thickness determined in this way with the experimentally measured thickness of the shock wave shows that the thickness of the shock wave increases faster than the thickness of the boundary layer. At the same time, the shock-wave thickness is considerably closer to the mean free path of the molecules in the oncoming flow λ_∞ (under our conditions $\lambda_\infty = 1$ mm) than to the mean free path λ_s behind the shock ($\lambda_s = 2$ mm), as was assumed in (^6). Thus, the results of the present investigation are in contradiction with the possibility of the existence of the "regime of a viscous layer" introduced by Probstein.

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Note: Figure translations are in progress. See original paper for figures.