VISUALIZATION OF SUPERSONIC FLOWS BY MEANS OF A PREBREAKDOWN DISCHARGE

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An arrangement for visualizing weak gas-dynamic nonuniformities by means of a prebreakdown discharge is described. The glow produced by the prebreakdown discharge was used to observe the vortex zones on the leeward side of models placed in a supersonic stream.

To visualize supersonic flows in low-pressure wind tunnels, methods based on the use of the glow excited by electron collisions with gas molecules are widely used. The most often used methods of excitation are by means of an electron beam [1, 2] and an electrical discharge (the glow discharge) [3, 7]. Different regions of the glow discharge are used but the region of the positive column is the most suitable for visualization.

In both methods the same mechanism of exciting the glow is used – electrons scattered by the electric field excite or ionize the gas molecules. The intensity of the glow, as a rule, is proportional to the gas density. This is due to the fact that the excitation function of the gas molecules depends weakly on the electron energy in the range of energies which are usually used for visualization. Hence, despite the fact that the electron energy changes when transferring from regions with different densities due to the change in the mean free path, which occurs in the visualization of the glow discharge, or is reduced due to collisions when the electron beam travels through the gas, the intensity of the glow depends only on the number of gas molecules per unit volume for a fixed number of electrons. Consequently, it is difficult to investigate the fine structure of the flow by this method.

It is well known that the excitation functions of the gas molecules by electron collisions have a very obvious threshold nature in a certain range of electron energies [8, 9]. If this effect is used to visualize gas flow it might be expected that the change in the brightness of the glow for a small change in the electron energy would be considerable.

However, it is not possible to use this effect to visualize the glow discharge since when the voltage on the discharge gap is reduced the current drops and consequently, the number of electrons also. To obtain electron energies necessary to observe the threshold effect the current in the glow discharge must be so small that the glow due to excitation is insufficient to obtain a visible picture.

For a fixed voltage on the electrodes we can reduce the electron energy to the threshold value by increasing the gas density. This effect has been observed in the prebreakdown discharge described in [10, 11]. Below we present some results obtained when using the threshold effect to visualize weak gas-dynamic nonuniformities. The position of the vortex zones on bodies streamlined for supersonic flow was determined. The static pressure of the flow varied from 0.5×10^4 to 1.5×10^4 N/m^2.

To ensure the best effect in the visualization we tested several electrode and model arrangements and selected the required electric field configuration. The point is that the glow region of the discharge decreases sharply as the gas pressure increases so that the arrangements described in the literature [3-7] are unsuitable.

During the course of the investigation we found that if the model is placed in the glow region of the discharge the visualized flow pattern is different from the actual pattern. Obviously, electrostatic inter-

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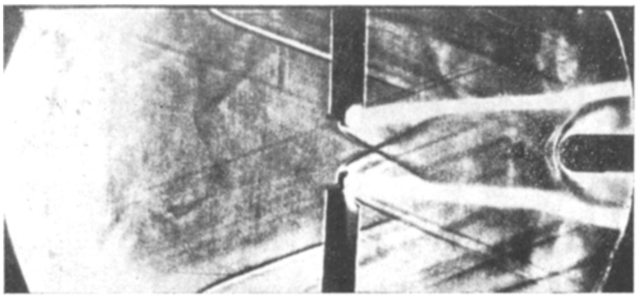

Fig. 1

action occurs between the charged particles in the flow and the model which, as a rule, is charged negatively with respect to the plasma. This was seen particularly clearly in experiments with a diffuse discharge [11], when the position of the leading shock wave was fixed simultaneously by means of a shadow device and the discharge (Fig. 1). The luminescent region in front of the model, which could be mistaken for the leading wave, settles much further from the model than the wave. This fact should be kept in mind when visualizing with a glow discharge in low-pressure wind tunnels if it is not possible to exercise control using a shadow device. While developing the method we tested an arrangement in which the model was the anode and the body of the tube was the cathode. This arrangement turned out to be unsuitable due to the fact that the electric field intensity was insufficient to obtain a bright glow and the rise in brightness due to the increase in the electric field strength led to breakdown from sharp points on the model.

To increase the electric field strength the discharge region was reduced to the dimensions of the zone in which the flow was investigated (Fig. 2). The model 1 was made from an insulating material with a metal insert 2, which was one of the electrodes. The second electrode was a pointed metal rod 3, placed so that the disturbance of the flow due to this electrode and its support 4 did not reach the region being investigated. The voltage on the electrodes was supplied from a high-voltage rectifier by cables 5. The polarity of the electrodes was important; in the case when the insert was the anode a corona occurred around it, and only when a negative potential was applied to the insert was the vortex zone which existed around the model clearly visualized.

An ANF-21 camera was used to take photographs.

During the experiments we found that the discharge current depends on the size of the vortex zones: when the angle of attack of the model was changed, when the size of a vortex zone was changed, the discharge current also changed. This fact can be used to make a quantitative estimate of the vortices.

Figure 3 shows typical photographs of vortices on the leeward side of a cone placed in a supersonic flow at the angle of attack at a flow Mach number of 2. The photographs clearly show light bands emerging from the front part of the model. To identify these bands with vortex trails, we carried out control experiments with models coated with a liquid film. A comparison showed that the visualized pattern is identical with the actual pattern.

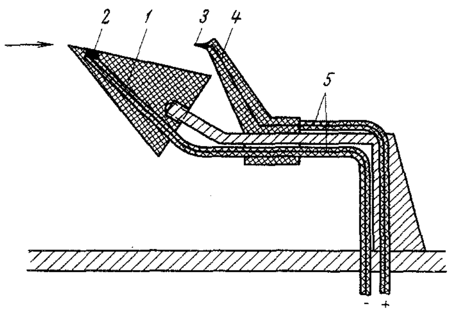

Fig. 2

The advantage of this method of visualization is the possibility of observing the flow pattern in regions shaded by different parts of the model, i.e., in those parts where it is not possible to use a shadow device. In visual observation one sees a three-dimensional flow pattern which can be fixed using a stereo-camera. Besides this the method enables one to observe vortices both attached and separated from the surface of the model, whereas using a liquid film one one can only observe the trails of attached vortices which disappear in the zone of separation. If photographs are

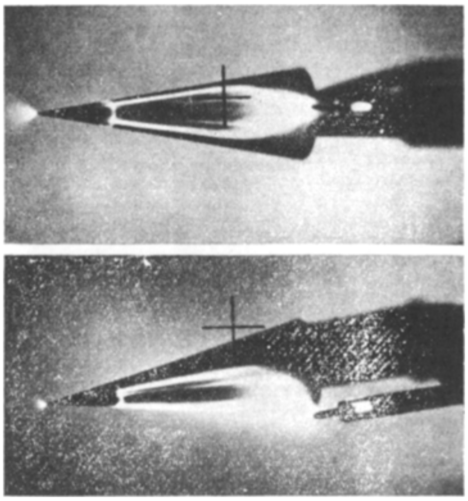

Fig. 3

taken at different angles to the model, one can estimate the thickness of a vortex and the distance at which it is separated from the surface of the model.

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