VORTICAL MOTION IN THE REGION BEHIND AXISYMMETRICAL SOLIDS

M. G. Morozov, B. A. Sapogov,
and A. G. Otenko

UDC 532.526:532.527

The results of an investigation into flow phenomena taking place in the region behind spheres and other solids for Mach numbers of 2, 3, and 4 are presented. Visualization of the flow by means of a soot–oil film shows that strong cross currents exist in the region of meeting of the flows.

The problem of flow in the region behind solid bodies is perhaps the simplest of all problems relating to breakaway flows. Despite the large number of papers which have been written and advances made in this connection, however, this problem is still far from being solved. In many cases we have no knowledge of the true picture of the flow, quite apart from the almost complete absence of finished theoretical and

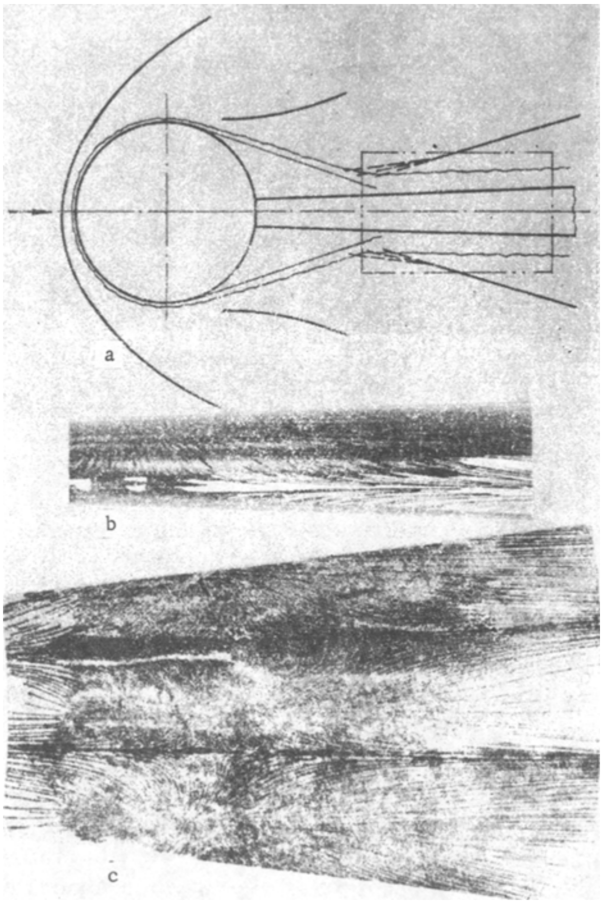

Fig. 1. Spherical model in a supersonic flow at M = 2 (the part of the bottom holder photographed is shown in the rectangle): a) holder after the experiment, covered with a soot—oil film; b) scan of the surface of the holder obtained by superimposing the paper (c).

Institute of Theoretical and Applied Mechanics, Siberian Branch, Academy of Sciences of the USSR, Novosibirsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 25, No. 5, pp. 918-921, November, 1973. Original article submitted December 28, 1972.

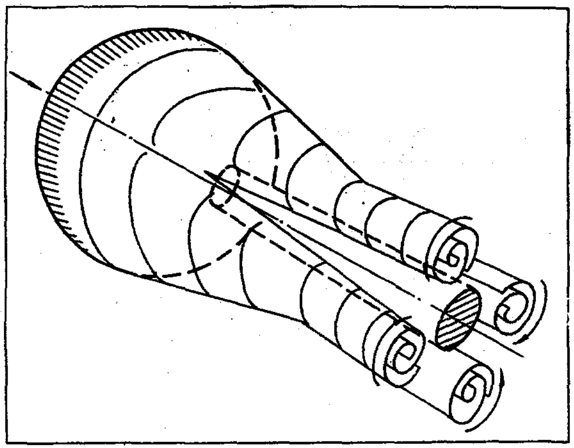

Fig. 2. Scheme of the flow behind a sphere subjected to a supersonic circumfluent stream.

experimental investigations into the heat- and mass-transfer effects associated with the breakaway of the flow. There is certainly insufficient evidence as to the nature of the flow in the actual breakaway region and in the region encountered after the external flow has been joined. In the generally-accepted model of plane or axisymmetric Chapman–Korst flow [1, 2] it is generally assumed that this junction is effected in planes normal to the surface of the body, and in the axisymmetric case passing through the symmetry axis of the latter. It was established in [3] that in the departure of a supersonic flow from a step, the flow is not two-dimensional but is complicated by regular transverse currents. A similar phenomenon was described in [4]. On the other hand under analogous conditions in [5] and in our own similar experiments no such cross currents were recorded at all.

It was found in [6] when studying the breakaway of a flow from the side of a cylindrical solid with an expanding tail section that there was no axial symmetry at all in the breakaway flow. However, in an analogous case [7] with a high M number no deviations from axial symmetry were observed.

When studying breakaway flow in the case of a supersonic stream passing around a series of spheres, we made the region of confluence visible by depositing a soot–oil film on the bottom support holding the model. Tests were carried out in a supersonic aerodynamic tube at M numbers of 2, 3, and 4. The Reynolds number calculated from the diameter of the sphere lay in the range $Re = 2.3\text{-}5.4 \cdot 10^6$. The holder had a slightly conical form as indicated in Fig. 1. As our visualization of the flow clearly shows, the axially-symmetrical form of the flow, which hitherto acted as a basis for general discussions and schlieren photograph analyses, and which was assimilated into the classical flow of model, is entirely absent. By way of example, Fig. 1 illustrates the passage of a flow with a Mach number of $M = 2.0$ around a sphere, as constructed from the corresponding schlieren photographs. Figure 1b shows the holder (covered with a soot–oil film) after the experiment. The region photographed is indicated in Fig. 1a by a broken line. Figure 1c, furthermore, shows a scan of the surface of the part of the holder under consideration. The scan is taken from the holder of a spherical model after tests in a flow with $M = 4$, since the corresponding scan for the example indicated in Fig. 1a and b was of too poor a quality for reproduction.

We see from the scan that the pattern of the limiting current lines indicates the existence of two pairs of very large, longitudinal vortices close to the flow-meeting region. For control purposes we also visualized the flow-meeting region behind a hemisphere and a conical–cylindrical model of the same diameter as the test spheres. In addition to this, analogous experiments were carried out with another aerodynamic tube, using a model of smaller diameter and a cylindrical holder, in order to check the influence of the flow and the conical angle of the holder. In every test results analogous to those indicated in Fig. 1 were obtained.

The foregoing results indicate that the flow pattern in the bottom region takes the form schematically indicated in Fig. 2. This flow is created in the following manner. The boundary layer breaking away from the surface of the sphere (or the trailing edge of the hemispherical or conical–cylindrical model) forms a contracting vortical shroud, which, being unstable, breaks up in the longitudinal direction with the formation of longitudinal vortices having a mutually opposed direction of rotation. Here we should note the unusually high spatial stability of the vortex system so formed. In rare cases (about one every ten to fifteen), more than two lines of convergence and divergence of the flow were observed; these may correspond either to a larger number of vortices or to a displacement of the vortices around the circle. The dimensions of the vortices are also not always the same, as may be seen even from Fig. 1c.

In considering the conditions required for the development of the cross currents, it is reasonable to assume that these only appear for fairly large dimensions of the separation region (compared with the thickness of the boundary layer). Otherwise the two-dimensional or axisymmetric pattern remains unimpaired.

In conclusion we may say that, as witnessed by the foregoing data, a continuation of our investigations into the spectra of breakaway flow may provide many new and possibly unexpected results.

LITERATURE CITED

1. H. H. Korst, J. Appl. Mech., No. 4, 523 (1956).
2. D. R. Chapman, NACA, Rep., 1051 (1951).
3. J. J. Ginoux, Proc. Heat Transfer and Fluid Mech. Institute, Standford (1960).
4. A. Roshko and G. I. Thomke, AIAAJ, 975 (1966).
5. G. E. Gadd, W. F. Cope, and J. I. Attridge, A. R. C. RM No. 3148 (1960).
6. J. P. Reding, R. A. Guenter, L. E. Ericsson, and A. D. Loff, AIAAJ, 1374 (1969).
7. H. A. Whitehead, AIAAJ, 1173 (1970).