STUDY OF THE PATTERN OF SUPERSONIC SPATIAL FLOW PAST A BODY OF SEGMENTAL SHAPE

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Fig. 1

Figure 1: Fig. 1

Abstract

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V. B. MINOSHCH V, G. F. TELENIN, G. P. TINYAKOV

STUDY OF THE PATTERN OF SUPERSONIC SPATIAL FLOW PAST A BODY OF SEGMENTAL SHAPE

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The paper gives the results of a study of supersonic flow, at angles of attack, past an axisymmetric body whose contour in the spherical coordinate system (r, θ, ψ) is specified by the analytic expression

$$r^n + (\theta/\theta^*)^n = 1.$$

For the values adopted in the work, $n = 40$ and $\theta^* = 30^\circ$, the body under consideration is close to a spherical sector with a central angle equal to 60°, and with rounded–

Fig. 1

in the region of the midsection is of the order of 3-4% of the radius of the corresponding spherical segment, taken as the characteristic linear dimension. The center of the introduced spherical coordinate system is located at the vertex of the corresponding spherical sector, and the angle θ is measured from the body axis clockwise. To compute the subsonic and supersonic regions of the flow, the methods set forth in papers ([1–4]) were applied. The flow of a perfect gas with adiabatic exponent $\gamma = 1.4$ was computed for $M_\infty = \infty$ and angles of attack α up to 30°.

In Figs. 1 and 2, for angles of attack α equal to 15 and 30°, respectively, two projections of streamlines and isobars ($p/p_{\max} = \text{const}$, where $p_{\max}$ is the pressure at the stagnation point on the body) on the body surface are given. These figures also show the positions of the shock waves and isobars in the plane of symmetry of the flow. Figure 3 gives the position of the shock wave and isobars in the section $x = 0.45$ for the angle of attack $\alpha = 30^\circ$. In Figs. 1-3

Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

the streamlines, the body surface, and the shock waves are shown by solid lines, and the isobars by dashed lines.

Let us consider some characteristic features of the flow. In Fig. 2 the nature of the behavior of the streamlines in the neighborhood of the stagnation point is clearly visible. All streamlines, with the exception of two lying in the plane of symmetry, approach the stagnation point while having a common tangent perpendicular to the plane of symmetry.

For α of the order of 30°, the derivative of the velocity magnitude with respect to arc length along a streamline in the plane of symmetry exceeds by a factor of 2–2.5 the corresponding derivative in the direction of the common tangent; and for α up to 15° their ratio is close to unity, and the geometrical pattern of spreading from

Fig. 2

the critical point practically does not differ from the dicritical node. The motion of the stagnation point with angle of attack α is shown in Fig. 4 by the solid line; the dashed line shows the position of the stagnation point calculated according to Newton' s theory. The indicated character of spreading at the critical point on the body surface and its position are also valid for other axisymmetric bodies with monotonically increasing curvature forming away from the axis of symmetry. With a monotonic decrease in curvature, all streamlines at the stagnation point have a common tangent lying in the plane of symmetry, and the coordinate $|y|$ of the critical point is greater than the corresponding coordinate determined by Newton' s theory. It should also be noted that the position of the stagnation point for a given body and fixed angle of attack can, with high accuracy, be represented as a single-valued dependence on the density ratio on both sides of the corresponding straight shock, which is also valid for real gases. The sonic line, which is an isobar on the body surface ($p/p_{\max} = 0.528$), is shown in Figs. 1 and 2 by a dash-dot line. At an angle of attack $\alpha = 30°$ it is strongly deformed, being compressed in the vertical plane.

Fig. 3

Fig. 4

Figure 4: Fig. 4

Fig. 4

When the gas flows around the rounding, the gas stream is strongly accelerated and the pressure in the shadow region of the flow drops sharply, practically to zero.

It is interesting to note that, when some constant value of the pressure $p_{\min}$ is prescribed in the region where, according to the calculations, it turns out to be close to zero, then, over the range of variation of $p_{\min}$ from $0.5 \cdot 10^{-3} p_{\max}$ to $0.5 \cdot 10^{-2} p_{\max}$, the values of the gas-dynamic parameters outside this region practically do not depend on the magnitude of $p_{\min}$. The density in the shadow region near the body is also very small; thus, for example, for the calculation results shown in Fig. 3, within the region with values $p/p_{\max} < 0.0025$ the quantity $\rho/\rho_c < 0.02$, where ρ_c is the density behind the shock wave. Figure 4 presents the flow density in the section $x = 0.45$ for the case $\alpha = 30^\circ$ as a function of the variable

$$\xi = \frac{|y| - |y_t|}{|y_c| - |y_t|},$$

where y_c and y_t are the coordinates of the wave and the body. Near the body surface on the leeward side ($\psi = 0$), the flow density is an order of magnitude lower than on the windward side ($\psi = \pi$). All

These properties of the flow in the shadow region indicate that near the body, on the leeward side of the flow, there is a region of flow where the gas is practically absent.

Thus, the general pattern of flow of an ideal gas around the lateral surface of the body under investigation, outside the separation region, is close to the pattern of flow of a viscous gas around the body. The separation region itself may be replaced by a corresponding region with a small (practically zero) value of the pressure in it. The boundary of the separation region, as experimental data show, is close to the line $p = \text{const}$. The corresponding isobar, obtained as a result of the calculation of the flow by an ideal gas, qualitatively determines the separation region.

At the end of the calculated flow region ($x \approx 0.7$ for $\alpha = 30^\circ$ and $x \approx 0.75$ for $\alpha = 15^\circ$), the velocity component along the x-axis near the body on the leeward side ($\psi \approx 60^\circ$) becomes sonic, and the surfaces $x = \text{const}$ then cease to be surfaces of the "spatial" type. The circumferential component of the velocity at this point is considerably greater than the speed of sound.

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Scientific Research Institute of Mechanics
of Moscow State University
named after M. V. Lomonosov

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