FLOW OVER BLUNTED CONES AND SEGMENTAL BODIES

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An analysis of the aerodynamic characteristics of various modifications of blunted bodies of small length was made on the basis of the results of experimental investigations. The experiments were performed on an aerodynamic installation in the range of Mach numbers $M = 0.4$–3 at Reynolds numbers $Re = 7 \cdot 10^5$–$3 \cdot 10^6$, calculated from the midsection diameter of the models and the parameters of the oncoming stream. We tested models of segmental bodies (Fig. 1a, relative radii $R/D = 1.46$ and 1.18, where R is the radius of the sphere and D is the diameter of the base cut; the central angles are 40 and 50°, respectively) and of blunted cones (Fig. 1b) with large aperture half-angles ($\theta = 60$ and $70°$) and a degree of blunting $d/D = 0.25$ (where d is the diameter of the spherical blunting). The aerodynamic characteristics were obtained for different variants of blunted cones: with beveled bases (Fig. 1b, $\theta = 60°$, $d/D = 0.25$, $\gamma = 5$ and $10°$; $\theta = 70°$, $d/D = 0.25$, $\gamma = 40'$, $1°$, and $1°30'$); with edges cut off parallel (Fig. 1c, $\theta = 60°$, $d/D = 0$, $d'/D = 0.96$, 0.93, and 0.87; d' is the distance between the edges); with cylindrical grooves on the conical part (Fig. 1d, the radius of a groove equals the radius of the base cut) which cut the rear part into 12 faces ($\theta = 77°$, $d/D = 0.25$).

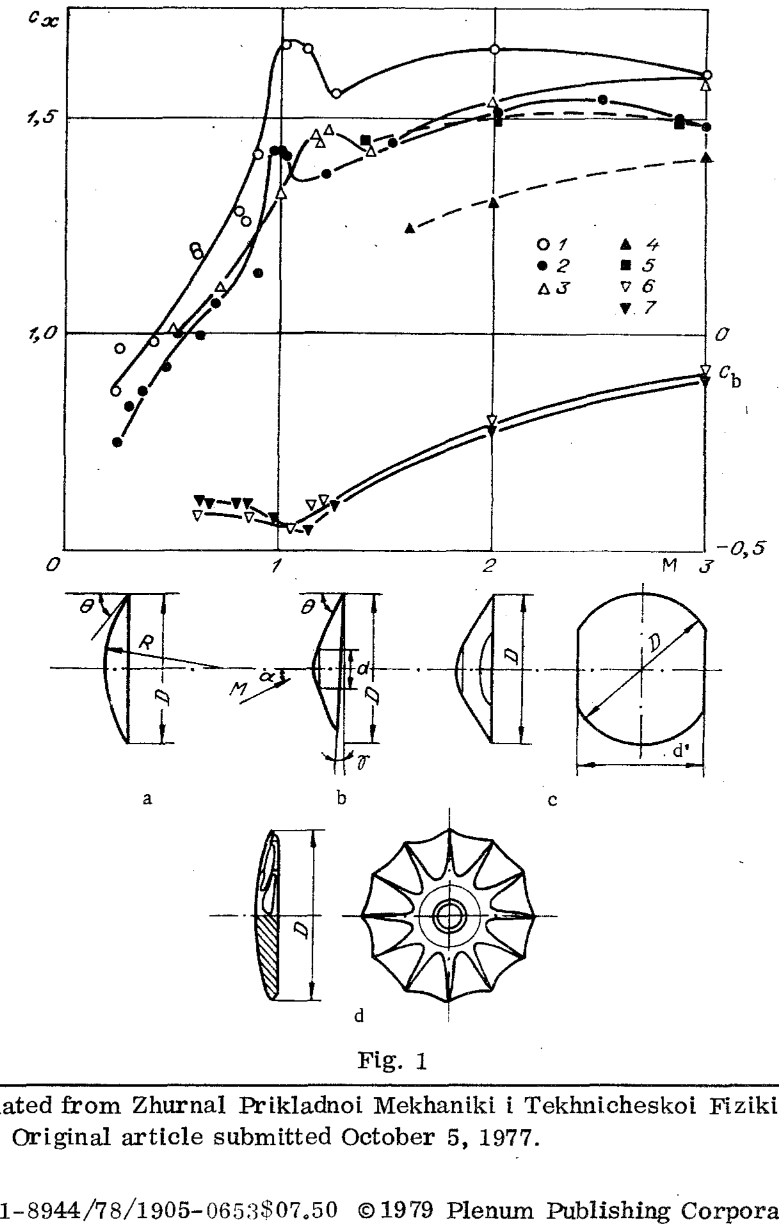

Fig. 1

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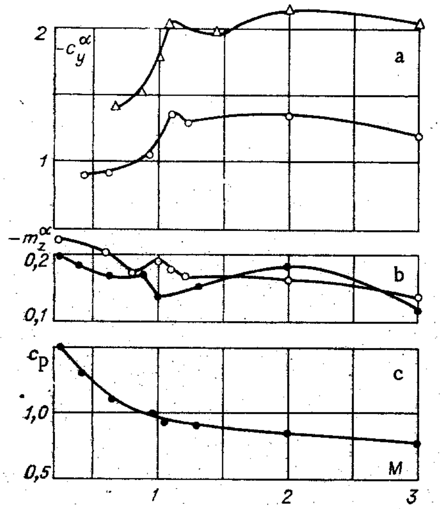

Fig. 2

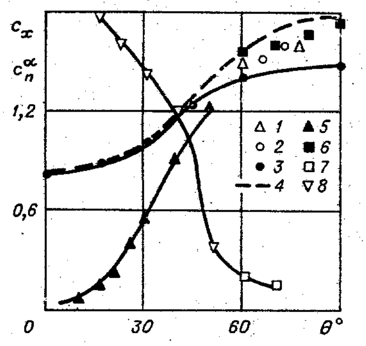

Fig. 3

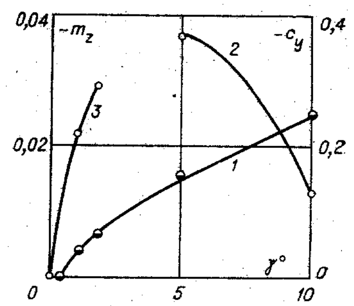

Fig. 4

The maximum diameter of the middle cross section of the model and the area of the middle cross section were taken as the parameters in the calculation of the aerodynamic coefficients. The total rms error in the measurements of the aerodynamic coefficients of the tangential force c_τ, the normal force c_n, and the pitching moment m_z did not exceed 6% for subsonic velocities and 3% for supersonic velocities.

With an increase in M the drag coefficient c_x of blunted bodies of small length first increases at near-sonic velocity, decreases somewhat at a low supersonic velocity, and reaches a maximum value at M=2-3 (Fig. 1, 1 is a segmental body, R/D=1.5; 2 is a blunted cone, θ=60°; 3 is a blunted cone with cylindrical grooves, θ = 77°; 4 (dashed line) is a segment, R/D =1 [1]; 5 (dashed line) is a cone, θ =60° [2]). A decrease in the relative radius of the segmental body from R/D=1.46 to 1.18 leads to a 5-7% decrease in resistance in the entire range of Mach numbers investigated. The influence of the bevel angle γ of the base cut on the resistance of cones depends on the velocity of the oncoming stream: an increase in γ at subsonic velocities alters c_x slightly, increases it at near-sonic velocities, and decreases it at supersonic velocities.

To allow for the base drag of the holder we measured the base pressure with two drain openings emerging through the fairing of the strain-gauge–holder at a distance of 2 mm toward the base end of the models. The base pressure behind a segment of θ =50° is somewhat greater for subsonic flow and less for supersonic flow than that behind a segment of θ = 40° (Fig. 1, 6 is θ =40° and 7 is θ =50°). Since the ratio of the area of the holder to the area of the model base is 11%, with allowance for the base drag of the holder the frontal drag coefficient of the models increases by 1.4-2% at M > 1 and by 3-6% at M ≤ 1.

The coefficients of normal force for conical bodies and of lifting force for segmental and conical bodies are linear functions within the limits of the angles of attack investigated, which was also noted in [1, 3].

On a segmental front surface in the presence of an angle of attack a normal force develops with the same sign as the value of α. Only for a model of a segmental body with R/D=1.5 at subsonic or near-sonic velocities of the oncoming stream and small angles of attack does the coefficient c_n behave like that for segmental–conical bodies in [4], i.e., have a negative value. But whereas this effect for segmental–conical bodies is connected with the pressure distribution on the conical surface, for a segmental model it evidently is caused by the anomalous movement of the leading critical point at subsonic velocities and by the asymmetrical formation of local supersonic zones near the rims at near-sonic velocities.

In the subsonic and near-sonic velocity ranges an increase in the Mach number causes an increase in the absolute value of c_y^α for segments and cones, while for supersonic flow the value of c_y^α varies slightly (Fig. 2a; the notation corresponds to Fig. 1; c_y^α and m_z^α, 1/rad).

In order to compare the data on cones and segments we took as a parameter the angle θ, which in the first case is the aperture half-angle of the cone while in the second case it is the angle between the tangent to the contour of the model at the corner point and the axis of symmetry (see Fig. 1). A pointed cone changes into a segment as the spherical blunting d/D of the cones varies from 0 to 1.

Some generalized functions c_x and c_n^α for test bodies, cones with large aperture half-angles [5, 6], and segments [1] are presented in Fig. 3, where 1-6 are c_x; 7-8 are c_n^α; 1 is a blunted cone, $\theta = 60°$, and a cone with grooves, $\theta = 77°$; 2) are segments, R/D = 1.18 and 1.46; 3 and 4 are experiment and calculation by Newton's method (dashed line) for a segment with R/D = 1 [1]; 5 and 6 are cones [5, 6]; 7 is blunted cones, $\theta = 60$ and 70°; 8 is cones [5]. For all the cones and segments, starting with $\theta = 60°$, the frontal drag coefficient depends weakly on the shape of the body, i.e., the angle θ and the degree of blunting of the cone, with the experimental values of c_x for a segment with $\theta > 45°$ being less than the values calculated from Newton's theory [1]. Good agreement between the calculated and experimental data is observed in the range of angles $\theta = 0$–45°.

An increase in the relative radius R/D (or the angle θ) of a segmental body and an increase in the half-angle at the apex of a conical body are accompanied by an increase in the absolute value of the lift coefficient c_y, with the value of the latter being negative at positive angles of attack. This is explained by the fact that for bodies of small length the coefficient of tangential force considerably exceeds the coefficient of normal force, as a consequence of which negative values of c_y are obtained when calculating the forces in the flow coordinate system.

For segments the quantity c_n^α increases with the transition to larger Mach numbers. For pointed cones the absolute value of c_y^α increases with an increase in the angle θ [6].

For blunted cones with bases cut off at an angle the largest absolute value of c_n occurs at a zero angle of attack (the value of c_n is negative and c_n decreases with an increase in α). An increase in the bevel angle leads to an increase in $|c_n|$; e.g., a change from 5 to 10° increases $|c_n|$ by 40–50%. A shift in the balancing angle toward larger values of α with an increase in the bevel angle is characteristic for the tested cones. A concept of the influence of the bevel angle of the rear section on the variation in the lifting force can be obtained on the basis of the data for a blunted cone with $\theta = 60°$ (Fig. 4, M = 3, $\alpha = 0$; curve 1 is c_y).

For models with rims cut off parallel one observes a decrease in the coefficient of normal force with an increase in the bank angle (at a zero bank angle the cutoff planes are parallel to the plane of the angle of attack). For these models the value of c_n has a local maximum at near-sonic velocities and increases for supersonic flow.

For segmental bodies (see Fig. 2b) in the entire range of Mach numbers one observes longitudinal static stability, with the stability being higher for a segment with a smaller relative radius. With an increase in the Mach number the reserve of longitudinal static stability decreases. In the region of angles of attack $\alpha = 3$–13° the curve $c_n = f(\alpha)$ for a model of a segmental body with R/D = 1.5 passes through zero at subsonic and near-sonic velocities. If the normal force is equal to zero then the resultant of the aerodynamic forces acting on the body is equal in magnitude to the tangential force and acts parallel to the axis of the body. In the general case, being displaced from the axis of symmetry of the craft, it can create a longitudinal moment, which has been observed in experiments. At any positive angles of attack the tangential moment for segments was negative and its absolute value increased monotonically with an increase in the angle of attack α. In the entire investigated range of angles of attack cones with a large aperture half-angle have a negative derivative m_z^α (see Fig. 2b) and hence are stable relative to some position determined from the condition $m_z = 0$. A decrease in stability with a decrease in the degree of blunting is characteristic for cones. The restoring moment grows as M increases and the balancing angle shifts toward larger values of α.

The qualitative character of the variation in the stability of blunted cones having a beveled rear section is presented in Fig. 4 (M = 3, $\alpha = 0$, curve 2 is $\theta = 60°$, 3 is $\theta = 70°$). As the bevel angle increases the tangential moment of the models first grows rapidly, reaches a maximum in the region of $\gamma = 2$–5°, and then starts to decline. The stability of models of blunted cones with edges cut off parallel decreases with an increase in the banking angle as the edge cutoffs approach each other.

Let us consider the influence of the Mach number and the angle of attack on the location of the center of pressure of models of blunted bodies of small length. In subsonic flow over a model of a segmental body with $R/D = 1.46$ the center of pressure c_p moves from 2-5 calibers ahead of the model at $\alpha = 5°$ to 2.5-20 calibers behind the model at $\alpha = 10°$ as a result of a change in the sign of the normal force. In supersonic flow over segments both the angle of attack and the Mach number have a weak effect on the location of the center of pressure, which is located behind the model (by 3-5 calibers for a model with $R/D = 1.46$, for example). For blunted cones the location of the center of pressure is at a distance of 0.3-1.5 calibers behind the model and depends little on the blunting radius. With an increase in the Mach number the center of pressure approaches the model (see Fig. 2c).

In the case of flow over cones having a beveled base the value of c_p grows as the angle of attack increases. Edges cut off parallel have little effect on the location of the center of pressure of a blunted cone in the investigated range of Mach numbers and angles of attack.

LITERATURE CITED

1. J. Nichols and E. Nierehgarten, "Aerodynamic characteristics of blunt bodies," Jet Propulsion Lab. Calif. Inst. Tech., Technical Rept. No. 32-677 (1964).
2. R. A. Lau and J. C. Hussong, "The Viking Mars lander decelerator system," AIAA Paper No. 70-1162 (1970).
3. A. P. Bazzhin and S. V. Pirogova, "Calculation of the flow over cones with large aperture angles," Uch. Zap. Tsentr. Aerogidrodin. Inst., 6, No. 6, 89-91 (1975).
4. T. P. Dearing, "Laminar heat-transfer distribution for a blunted-cone, trustem reentry configuration at Mach 10," NASA TND-5146 (1969).
5. R. Owens, "Aerodynamic characteristics of spherically blunted cones at Mach numbers from 0.5 to 5.0," NASA TND-3088 (1965).
6. J. F. Cambell and D. T. Howell, "Supersonic lifting capabilities of large-angle cones," NASA TND-5499 (1969).

DIFFUSION SLIP AND BARODIFFUSION OF A GASEOUS MIXTURE IN PLANE AND CYLINDRICAL CHANNELS

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In the forced flow of a gaseous mixture in a capillary or a porous medium in a field of partial-pressure gradients, a number of effects occur (the diffusion baroeffect [1, 2], the mixture-separation effect [3, 4], etc.), a rigorous analysis of which requires the inclusion of Boltzmann's kinetic equation. The main object of the kinetic consideration in this case is to obtain expressions for the flows of the mixture components, averaged over the cross section of the channel or referred to unit surface of the porous medium. This problem has been solved in a number of papers [5-7] for channels of correct geometry (a plane slit or a circular cylindrical capillary) using the linearized kinetic equation with the model BGK integral of the collisions in the Hamel form [8]. In [9] the flow of a mixture in a plane channel was considered using the accurate linearized collison operator, but subsequent use of the moment method of solution was confined to the solid-sphere model of the molecules. The limitation of the models used does not enable the accuracy of the results obtained to be guaranteed, particularly with regard to such kinetic quantities as the diffusion slip coefficient or the barodiffusion constant of the gaseous mixture in the channel. It is well known, in particular [8], that no matter how the parameters of the slip in the BGK model for the mixture are chosen, it is not possible to ensure an adequate description of the diffusion and the viscosity of the mixture simultaneously even for normal hydrodynamic flow. Below we solve the problem of the flow of a mixture in a channel using the linearized kinetic equation with the collision operator in the model form proposed by McCormack [10]. The advantage of this model, based on the equivalence of the N-order mo-

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