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SPATIAL AERODYNAMICS OF BLUNTED CONES IN THE PRESENCE OF COMPLICATING FACTORS IN APPROACH SUPERSONIC FLOW

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The results of problem solution on blunted cone interaction with spherical heated region in approach at nonzero attack angle in supersonic flow in the absence and at the presence of strong localized blowing from surface as well as from falling at attack angle plane blast wave are presented.

The problems on interaction of fast body with heated region under study are of obvious practical interest. In [1] the problem on interaction of sphere with local heterogeneities of different form is solved in terms of axis-symmetrical statement. In [2] the case with centre of spherical heated region displaced relatively to body symmetry axis is considered. In [3] the results of initial stage in introduction of blunted cone into plane region at the attack angle are presented.

Non-stationary problem on interaction of blast wave with aircraft in approach supersonic flow is of particular practical interest from the point of view of changes in its aerodynamic properties. In axis-symmetrical case, by the example of hemisphere airflow, it has been solved in [4]. In present paper the case of interaction of blast wave with blunted cone (model of descent vehicle) has been considered at the presence of attack angle.

The purpose of the given study is to investigate aerodynamic properties of blunted cones at the interaction with local heated regions in supersonic motion at attack angle and interacting with falling plane blast wave.

Mathematical statement of the problem, based on the Euler equation set with corresponding initial and boundary conditions, is presented in [2]. Like in [2], for the solution S.K. Godunov's explicit finite-difference scheme of the first accuracy order [5], absolutely sufficient for determining integral aerodynamic characteristics has been used.

All results were obtained for the Mach number of approach flow M_∞=5 and adiabatic exponent γ=1,4.

1. Interaction of cone with local heated region

Investigation of interaction of blunted cone with local heated region in approach supersonic flow at nonzero attack angle was performed by the example flow of blunted spherical cone with half-angle 15° and radius of bottom section R_D=2,5R_0 at the attach angle α=10° with and without strong blowing localised at spherical bluntness with specific intensity $(\rho v_n)_w$=0,5 and complete enthalpy H_{0w}=0,5. In this case the density ρ is referred to that of approaching flow ρ_∞, velocity v is to $v_{\max,\infty}$ the maximum velocity of approaching flow, the enthalpy H_{0w} is to the magnitude $v^2_{\max,\infty}$, the pressure p is to the magnitude $\rho_\infty v^2_{\max,\infty}$, linear sizes are referred to R_0 the radius of spherical bluntness.

Presence of heated region in approach flow was designed by the following functional dependence of density on spatial coordinates and time.

$$\rho_n(x,y,z,t) =$$
$$= \rho_\infty \big/ \{1+9\exp\{-2[(x-x_0)^2+(y-y_0)^2+(z-z_0)^2]\}\},$$
$$x_0 = x_0' + t\left|v_\infty\right|\cos\alpha,\ y_0 = y_0' + t\left|v_\infty\right|\sin\alpha,\ z_0 = 0.$$

Here x_0, y_0, z_0 are coordinates of heating centre, the temperature of which is T_n=10T_∞. The initial value x_0'=–2, but y_0' takes the two values, which in the first case (fore interaction) centre of heated region comes across low point of sphere adjunction with cone y_w=–y_c and in the second case (stern interaction) goes through the point of cone lateral surface with the coordinate y_w=–1,75R_0.

In Fig. 1, *a*, the profile of streamlined body, head blast wave corresponding to stationary condition of streamline impermeable surface by undisturbed flow (curve 1) are presented. In the same Figure the positions of blast wave at the fore (2) and stern (3) interaction of heated region with blast layer by the moment of achieving minimal value of longitudinal force factor C_A are shown.

In Fig. 1, *b*, similar results for the case of strong blowing from the denoted area of cone surface are presented.

The presented results reflect the main peculiarities of head blast wave interaction with local heated region in approaching supersonic flow [1, 2].

In Fig. 2 dependencies of aerodynamic properties of streamlined body on time are presented correspondingly at fore (a) and stern (b) interaction with local heated region in approaching flow both at blowing (full curve) and without blowing (dashed curve).

Here C_A is the longitudinal force factor; C_N is that of normal force; C_{mz} is that of pitch moment relatively to body forward point; C_D is the factor of pressure centre.

First of all, it should be noted that blowing itself results in significant increase in longitudinal force and decrease in normal force and pitch moment. In the case of stern interaction with heated region (Fig. 2, *b*) blowing does not essentially influence the character of changes in aerodynamic properties. At fore interaction (Fig. 2, *a*) blowing affects significantly the behaviour of pressure centre factor (curves 4) to the direction of increasing statistical stability storage. General character of change in

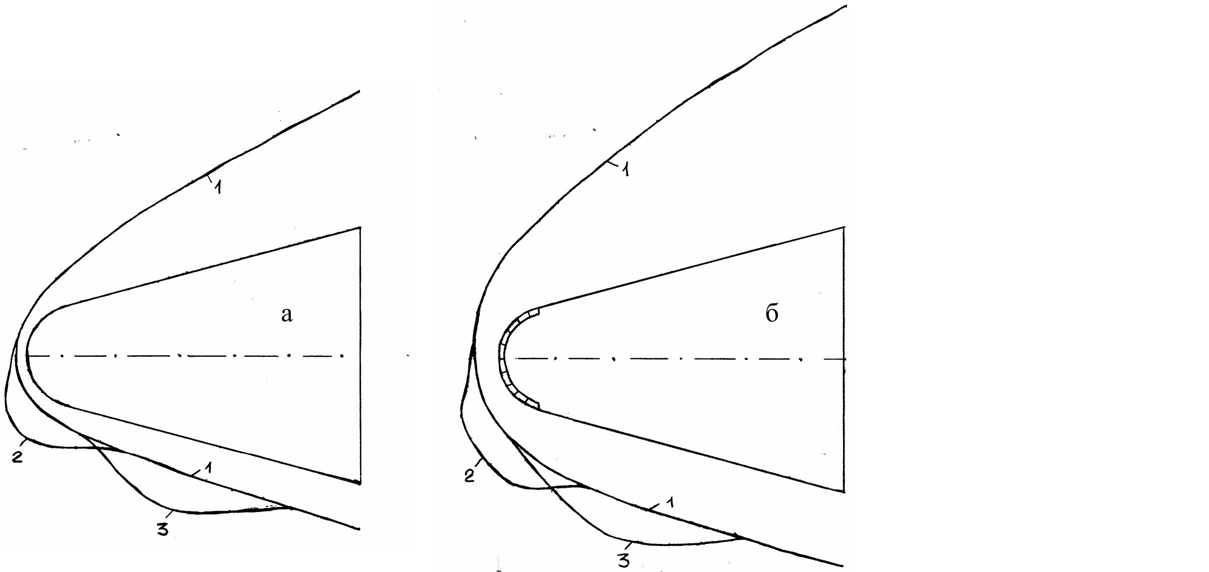

Fig. 1. *Patterns of supersonic flow of body surface: 1) t=0; 2) t=2,82, $y_0=-y_c$; 3) t =6,84, $y_0=-1{,}75$: a) at blowing; b) without blowing*

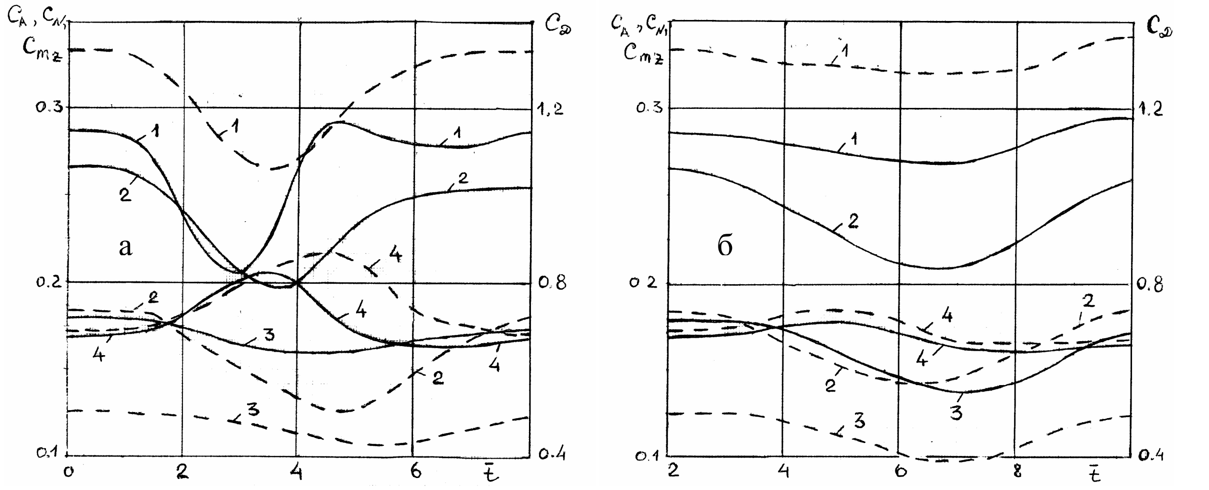

Fig 2. *Dependencies of aerodynamic properties $C_A(1)$, $C_N(2)$, $C_{mz}(3)$, $C_D(4)$; —– without blowing; – – – – with blowing: a) $y_0=-y_c$; б) $y_0=-1{,}75$*

aerodynamic properties in the process of interaction with local heated region (their decrease) is conditioned by drop of pressure from windward side of streamlined body.

The presented results allow us to conclude that in interaction of blunted cone with local heated region in approaching supersonic flow at nonzero attack angle, blowing from the surface is efficient only in the case when cloud centre comes across fore part of streamlined body, since only in this case pressure centre displaces sufficiently to the bottom section.

2. Interaction with plane blast wave

As initial data fluid-dynamics parameters of supersonic stationary flow of blunted is used in sphere cone with half-angle 45° and radius of bottom section $R_D=2{,}5R_0$ at attack angle 10°. The profile of streamlines body and position of head blast wave (curve 1) is presented in Fig. 3.

Presence of blast wave in approaching flow is designed by the plane, the normal to which coincides with velocity vector of approaching flow, but fluid-dynamics parameters on the left and right from it meet the basic conservation laws [5]

$$[\rho]\cdot D-[\rho u]=0,$$

$$[\rho u]\cdot D-[p+\rho u^2]=0,$$

$$[\rho e]\cdot D-[\rho u e+pu]=0,$$

$$e=\frac{1}{\gamma-1}\frac{p}{\rho}+\frac{u^2}{2}.$$

In writing the conventional denominations are used: ρ is the density; p is the pressure; u is the normal velocity component; e is the specific complete energy; D is the velocity of blowout motion.

As parameters on the right from blowout the parameters of undisturbed supersonic flow are taken and at specified value $D=V_\infty M_B/M_\infty$, (M_B=7) by solving the written out system of equation the parameters on the left from falling blast wave are defined. The choice of quadratic root relative to velocity after jump is made by solving the problem on breakdown of corresponding blowout.

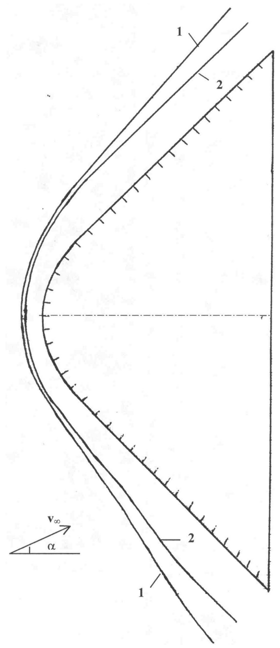

Fig. 3. *Patterns of streamline: 1) t=0 and t=∞; 2) F_A=max*

Moment of crossing of the point ($x_в$,$y_в$), situated on head blast wave through the surface of blowout is determined by changes in sign of the value of oriented distance to blowout plane δ

$$\delta = x_в \cos\alpha + y_в \sin\alpha - x_0 \cos\alpha,$$

$$x_0 = x_0' + Dt\,\cos\alpha\,,\; x_0' = -0{,}5.$$

Here α is the attack angle; t is the time; x_0 and x_0' are current and initial coordinates of axis by falling blast wave correspondingly.

In Fig. 4, *a*, dependencies of longitudinal force F_A (1) and pressure centre factor C_D (2) on time are presented. In Fig. 4, *b*, dependencies of normal force F_N (1) and moment of rotation M_z (2) with respect to the point with the coordinates (1,5; 0; 0), taken as a gravity centre of streamlined body are shown.

Analysis of curves shows that longitudinal force F_A increases sharply and essentially in the process of body interaction with falling blast wave, achieving maximum value and then decreasing to some extent it gets the stationary value.

Position of head blast wave by the moment of achieving maximum in longitudinal force is depicted by curve 2 in Fig. 3. At that moment the head jump is situated much closer to streamlined body that leads to stronger compression of gas in blast layer than in the period of overshoot, when position of steady-state blast wave coincides with curve 1 conforming to the streamline of undisturbed flow with the graph accuracy.

The presence of minimums in dependencies F_N and M_z can be explained by the fact that falling blast wave at attack angle interacts first with windward side of streamlined body. Significantly more absolute values of F_N and M_z on the period of overshoot in comparison with the streamline with undisturbed flow are explained by considerably higher velocity pressure of flow after falling blast wave.

Local minimum in the dependence $M_z(t)$ is explained by the fact that at the initial moments of time approaching flow disturbed by falling blast wave interacts with fore part of streamlined body increasing negative constituent of total moment of rotation relative to gravity centre.

Increased load on fore part at the initial moments of time is reflected in the dependence $C_D(t)$. It indicates the fact that the attack point of total aerodynamic force is first displaced to the forward point of body and then during the period of overshoot returns to its initial position. In this case static stability factor defined as difference of gravity centre coordinates and those of pressure centre does not change sign in the process of interaction, which is the determining factor for dynamic stability of streamlined body.

As a result of solving the problem the non-stationary aerodynamic properties of blunted in sphere cone, corresponding to the process of its interaction with blast wave falling at attack angle in approaching supersonic flow are stated.

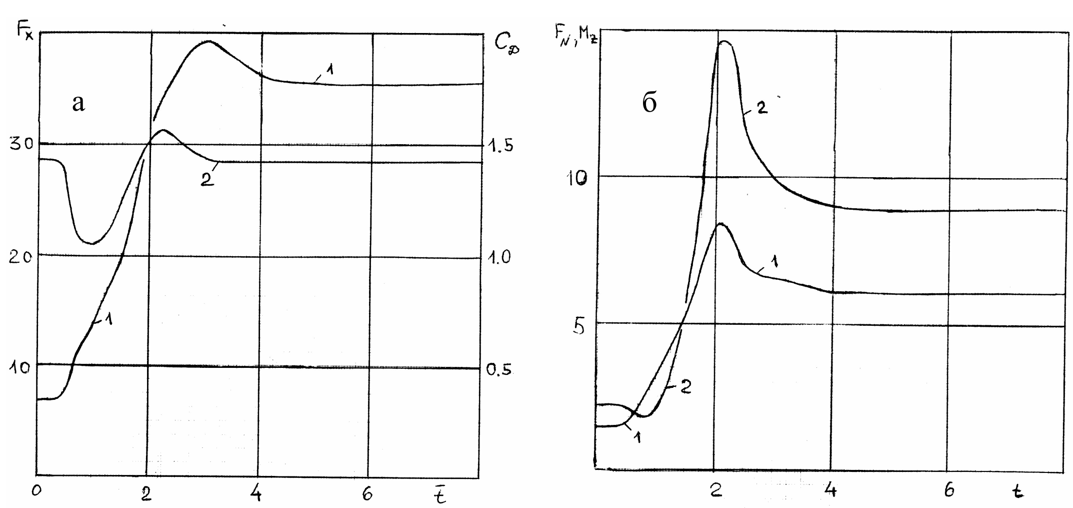

Fig. 4. *Dependencies of aerodynamic properties on time: a) 1 – F_A; 2 – C_D; b) 1 – F_N; 2 – M_z*

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ON CALCULATION OF PARAMETERS AND EFFICIENCY OF ENERGY TRANSFORMATION WITH RAILGUN

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The calculation formulas of pulse duration and amplitude of growing current at specified values of maximum velocity and weight of accelerated body by railgun have been obtained. To provide minimum values of railgun current and source strength it is necessary to obtain current impulse close to rectangular shape from the source and to have the most railgun inductance. The dependencies defining power conversion factor of railgun including the energy losses in rails possible in electric arch and remaining energy in the railgun magnetic field are presented for current rectangular impulse. It is shown that conversion factor increases with increasing mass of accelerate body and its maximum velocity as well as with decreasing the railgun length at optimal values of accelerated body's cubic density and its initial velocity.

Railgun is an electromechanical device converting electromagnet energy of current impulse into mechanical energy of accelerated body. At present railguns are considered to be promising electromagnet accelerators of bodies with the weight of 0,001...1 kg to velocities amounting 10 km/s, to be applied in space engineering, scientific investigations. Railgun consists of two parallel rails (buses), between which the accelerated body moves, Fig. 1. When flowing current along the rails and body due to electrodynamic force the body accelerates and can achieve the velocity significantly higher than 1,8 km/sec. The velocity 1,8 km/sec is maximum for accelerators using gas-dynamic pressure of chemical combustion materials, for example, powder. However, to achieve such velocities it is necessary to supply railgun from a very power impulse source of electromagnet energy capable of generating current pulses with the amplitude to 1 MA and more, durability to 5 msec and energy to 1 MJ and more [1]. Rotating generator with discontinuous inductance can be used as such source [2].

Calculation of parameters and revealing the factors causing the increase in efficiency η of electromagnetic energy transformation into kinetic energy of accelerated body by railgun for the purpose of decreasing source power is an urgent problem.

To calculate the parameters and efficiency η of railgun let us consider inductance and resistance of railgun depend on the distance covered by the accelerated body in railgun approximately and linearly:

$$Lp(t) \approx L_0 \cdot x(t); \quad Rp(t) \approx R_0 \cdot x(t),$$

where L_0, R_0 is the railgun inductance and resistance per unit of length.

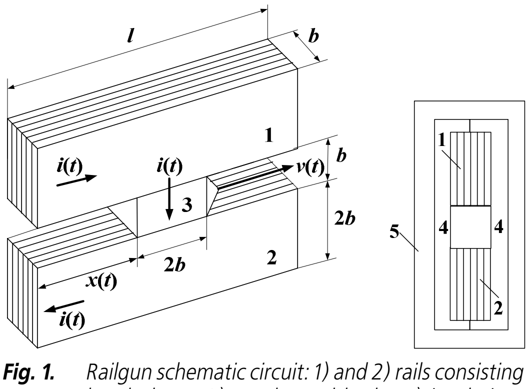

Fig. 1. *Railgun schematic circuit: 1) and 2) rails consisting of isolated plates; 3) accelerated body; 4) insulation; 5) fasteners; v(t) is the body velocity; x(t) is the distance covered by the body in railgun; i(t) is the electric current; l and b are the length and width of rails*

Then the force accelerating the body we define as [3]

$$F = \frac{d}{dx}\left[\frac{Lp(t)\cdot i(t)^2}{2}\right] \approx \frac{i(t)^2}{2}\cdot L_0.$$

If one neglects friction on rails and insulation and assumes that accelerated body of m mass moves in vacuum, then on the basis of the second Newton's law one can write down the equation