IMPACT OF SOLID PARTICLES OF A TWO-PHASE FLOW ON A WEDGE (DIRECT PROBLEM)

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The problem of supersonic flow of a barotropic medium around an airfoil with solid particles, taking into account their elastic collision with the surface of the airfoil, is of practical importance when calculating the parameters of a jet flowing from a supersonic nozzle, the flight of bodies in gas-dust environments, etc. The authors [1,2] considered the problem of the impact of particles on a wedge in the case of a negligibly small volume of particles. They studied the structure of shock waves of a two-phase flow and determined the trajectory of particles before they hit the wedge and, thus, did not take into account the effects of particle reflection after the impact.

In this work, we propose a model for the flow of a two-phase medium around a thin airfoil, taking into account the effect of particle reflection from the airfoil surface and, in addition, provides a solution to some problems in a linear formulation under various assumptions regarding the volume occupied by particles and friction between phases.

Let the wedge inclination angle be givenβ_0 and it is required to determine the phase separation curve, that is, the streamline of a particle reflecting from the leading edge of the wedge. Let us consider the case when the coal volume occupied by the particles is small compared to unity. In this case, we will assume that the influence of particles on gas pressure and friction between incident and reflected particles in the region of three-speed flow can be neglected. Then, based on the linear theory of flow around a wedge [4], the gas velocity field will be known and the gas velocity potential $\varphi_1$will be expressed by the formula

$$\varphi_1(x,y) = -\frac{U_0\beta_0}{\mu}(x-\mu y) \tag{1.1}$$

Where; $M = U_0/a\_\ \mu^2 = M^2 - 1$; $U_0 -$ initial velocity of a two-phase medium; $a-$ speed of sound in gas.

The only force acting on the particles is the friction force between the phases. Therefore, after linearization, the equation of motion of incident and reflected particles will take the form:

$$U_0\frac{\partial u_2}{\partial x} = \frac{k}{\rho_2}(u_1-u_2), \qquad U_0\frac{\partial v_2}{\partial x} = \frac{k}{\rho_2}(v_1-v_2); \tag{1.2}$$

$$U_0\frac{\partial u_3}{\partial x} = \frac{k}{\rho_2}(u_1-u_3), \qquad U_0\frac{\partial v_3}{\partial x} = \frac{k}{\rho_2}(v_1-v_3). \tag{1.3}$$

Moreover $\rho_2 = \rho_{2i}(1-\gamma_0)$; $\rho_{2i} -$ true particle density; γ_0– volume concentration of gas per unit volume; I – phase interaction coefficient, determined by Stokes; u_1, v_1, u_2, v_2, u_3 and v_3 are components of the velocity of gas, particles, and particles of the reflected flow. Although (1.2) and (1.3) are formally the same, their boundary conditions are completely different. If we introduce the velocity potential into equations (1.2) φ_2 and multiply the first by dx, and the second by dy, then after their summation we obtain an equation in total differentials . The integral of this equation contains an arbitrary constant, which from the conditions at infinity turns out to be equal to zero.

Thus, equations (1.2) and (1.3) will be:

$$\varphi_{2x} - \alpha(\varphi_1 - \varphi_2) = 0, \qquad \varphi_{3x} - \alpha(\varphi_1 - \varphi_3) = 0 \tag{1.4}$$

Where $\alpha = \frac{K}{U_0 P_2}$; φ_1 is determined by formula (1.1). Note that system (1.4) is equivalent to systems (1.2) and (1.3).

The boundary conditions are as follows:

$$\varphi_2 = 0 \ \text{при} \ x - \mu y = 0, \tag{1.5}$$

$$\varphi_{3y} = U_0 \beta(x) \ \text{при} \ y = f(x), \tag{1.6}$$

$$2U_0\beta_0 = \varphi_{2y} + \varphi_{3y} \ \text{при} \ y = 0, \tag{1.7}$$

where $y = f(x)$ is the equation; $\beta(x) -$ angle of inclination of the dividing line. Condition (1.7) represents the law of specular reflection of particles from the surface of the wedge (the angle of incidence is equal to the angle of reflection). Let us assume that the dividing line is also a straight line with an unknown angle of inclination β, which is subsequently determined from condition (1.7). Then (1.6) will be written:

$$\varphi_{3y} = U_0 \beta \ \text{при} \ y = \beta \cdot x. \tag{1.8}$$

Solutions of equations (1.4) satisfying (1.5) and (1.8) are obtained in the form of quadratures, that is

$$\varphi_2(x,y) = \frac{U_0\beta_0}{\alpha\mu}\left[1 - \alpha\cdot(x-\mu y) - \exp\big(-\alpha(x-\mu y)\big)\right] \tag{1.9}$$

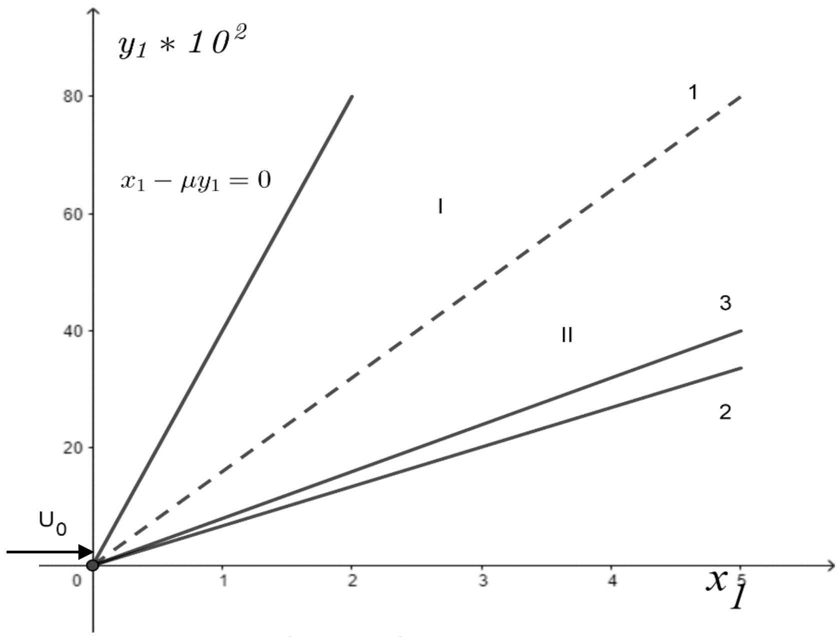
$$\varphi_3(x,y) = -\frac{U_0}{\alpha}\left[\frac{\beta_0}{\mu} + \beta(\beta-\beta_0)\right]\cdot\exp(-\alpha x) +$$

$$+\frac{U_0}{\alpha}\left\{\frac{\beta_0}{\mu}[1-\alpha(x-\mu y)] + \beta(\beta-\beta_0)\cdot\exp(-\frac{\alpha}{\beta}(\beta\cdot x - y))\right\} \tag{1.10}$$

Upon obtaining (1.10), another condition is satisfied $\varphi_{3x} = 0$ for $x = y = 0$. Substituting (1.9), (1.10) and (1.7) it is easy to see that $\beta = 2\beta_0$.

Solving the inverse problem in a similar way, we obtain similar results, since here the dividing line is set in the form of a straight line and the surface of the body in a streamline is found.

From this we can conclude that if the volume occupied by the particles is negligible, then when particles of a two-phase flow hit a wedge, the dividing line (stream line of particles reflected from the leading edge) is also straight with an inclination angle twice the wedge half-opening angle (see figure).



1 – section line; profile surface; 2 – at low and 3 – at significant particle concentrations.

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