# THE MOTION OF A GAS STREAM AND AN INCLUDED SOLID PARTICLE BEHIND A COMPLEX, INCLINED-BARRIER OBSTACLE

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The motion of a particle in a gas stream behind an inclined barrier on one side of a rectangular channel is studied. The forces acting on the particle are studied, and equations are obtained for calculating its velocity and trajectory.

A high-drag body in a channel in which the dimensions of the body are greater than the dimensions of the free part of the cross section we shall call a complex obstacle. Cases of flow around such an obstacle by a gas stream or a two-phase stream are encountered rather often in practice. But while there are solutions [1, 2] for the rectilinear motion of the particle, the flow around a complex obstacle has been practically ignored.

In particular, this refers to the motion of a particle of material in the air-fountain chamber of a drier.

Let us consider the motion of a particle in a gas stream behind an inclined barrier on one side of a rectangular channel. According to the theory for modeling the trajectory of solid particles, the motion of a single solid particle in a curvilinear stream with a given gas-velocity field is described by the equation [3]

$$\frac{d(m\bar{V})}{d\tau} = \sum_i \bar{F}_i. \tag{1}$$

Of the forces acting on the particle, let us consider the following:

1. The weight

$$\bar{F}_1 = m\bar{g}. \tag{2}$$

2. The Archimedes force

$$\bar{F}_2 = -m_0\bar{g}. \tag{3}$$

3. The drag force undergone by the particle in its relative motion in the gas stream

$$F_3 = \frac{\bar{C}_0}{\mathrm{Re}_4^n} f\rho \frac{V_0^2}{2} \bar{e}. \tag{4}$$

We shall let

$$K = \frac{1}{2} \frac{\bar{C}_0}{\mathrm{Re}_4^n} f\rho.$$

4. The force determined by the centrifugal acceleration undergone by the particle when it rotates with a circular velocity equal to the circular velocity of the gas stream

$$\bar{F}_4 = m\frac{d\bar{W}_\tau}{d\tau}. \tag{5}$$

5. The counterpressure, which is due to the fact that in a curvilinear stream there is a pressure gradient across the trajectory. Here, the counterpressure is expressed in conventional elementary form proposed by L. G. Loitsyanskii [4]:

$$\bar{F}_5 = -m_0\frac{dW_\tau}{d\tau}. \tag{6}$$

6. For processes related to a change in mass, we must introduce the reaction force

$$\bar{F}_6 = \frac{dm}{d\tau}\bar{U}. \tag{7}$$

Substituting all of the forces into Eq. (1), we obtain

$$m\frac{d\bar{V}}{d\tau} + \bar{V}\frac{dm}{d\tau} = (m - m_0)\left(\bar{g} + \frac{d\bar{W}_\tau}{d\tau}\right) + KV_0^2\bar{e} + \frac{dm}{d\tau}\bar{U}. \tag{8}$$

In this case, we obtained the Riccati differential equation, which usually is not integrated in quadratures. To solve this equation, we shall ignore the change in the mass of the particle. Taking into account, also, that

$$\bar{V} = \bar{W} + \bar{V}_0, \tag{9}$$

we can write Eq. (8) for fixed mass as

$$m\frac{d(\bar{W} + \bar{V}_0)}{d\tau} = (m - m_0)\left(\bar{g} + \frac{d\bar{W}_\tau}{d\tau}\right) + KV_0^2\bar{e}. \tag{10}$$

To simplify (10), we shall assume that:

1. $m_0 \leq m$; then

$$\bar{F}_2 = 0 \text{ and } \bar{F}_5 = 0. \tag{11}$$

2. For our case, the centrifugal acceleration is negligible [5]; then

$$\bar{F}_4 = 0. \tag{12}$$

Within the core of the stream, the gas velocity can be considered fixed, and

$$\frac{d(\bar{W} + \bar{V}_0)}{d\tau} = \frac{d\bar{V}_0}{d\tau}.$$

The complex of values denoted by K is a function of time and will be a constant:

$$K = 0.42 f\rho/2 = \text{const}.$$

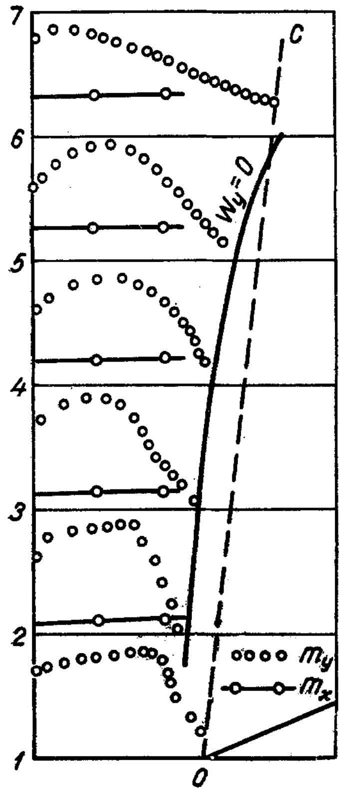


Fig. 1. Curves of dimensionless longitudinal and transverse velocities (OC is line of zero longitudinal velocities from [6]).

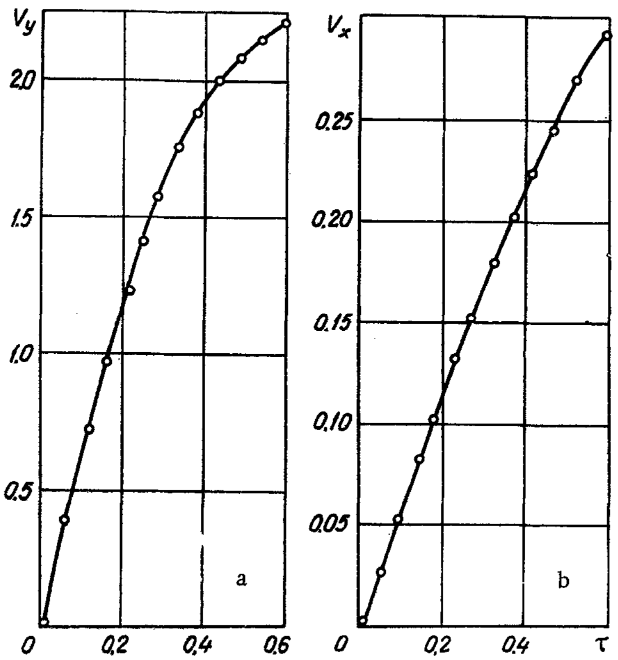


Fig. 2. Calculated curves of relative longitudinal (a) and transverse (b) velocities of particle versus time.

Considering all of the above, we can write Eq. (10) in the final form

$$m\,\frac{d\bar{V}_0}{d\tau} = m\bar{g} + KV_0^2\bar{e}. \quad (13)$$

Projected onto the axis of the abscissas, Eq. (13) has the form

$$m\,\frac{dV_{0X}}{d\tau} = KV_{0X}^2. \quad (14)$$

If we solve it for $V_{0X}$ and substitute this into Eq. (9), we obtain an expression for the projection of the absolute velocity of the particle onto the axis of the abscissas:

$$V_X = W_X\left(1 - \frac{m}{m + KW_X\tau}\right) = W_X\left(1 - \frac{1}{1 + \frac{KW_X}{m}\tau}\right). \quad (15)$$

To obtain an expression for the displacement of the particle from the axis of the abscissas, we integrate (15):

$$X = W_X\left[\tau - \frac{m}{KW_X} \times \ln\left(1 + \frac{KW_X}{m}\tau\right)\right]. \quad (16)$$

Projected onto the axis of the ordinates, Eq. (13) has the form

$$m\,\frac{dV_{0Y}}{d\tau} = KV_{0Y} - mg. \quad (17)$$

Solving this equation as the previous one, we obtain equations for the projection of the velocity unto the axis of the ordinates

$$V_Y = W_Y - a \times \left[1 + \frac{W_Y - a}{W_Y + a}\exp\frac{2aK}{m}(-\tau)\right] \Big/ \left[1 - \frac{W_Y - a}{W_Y + a}\exp\frac{2aK}{m}(-\tau)\right] \quad (18)$$

and the displacement

$$Y = (W_Y - a)\tau - \frac{m}{K}\ln\left[\left(1 - \frac{W_Y - a}{W_Y + a}\exp\frac{2aK}{m}\right)(-\tau) \Big/ \left(1 - \frac{W_Y - a}{W_Y + a}\right)\right], \quad (19)$$

where $a = \sqrt{mg/K}$.

To solve the derived equations, we measured the magnitude and direction of the gas velocity in a channel behind a barrier under various flow conditions. The main part of the apparatus was a chamber in the form of a rectangular parallelepiped. Obstacles in the form of inclined barriers were installed in the front part of the chamber. Measurements were made at 45 points on the median plane of the chamber. The angles between the gas velocity at a given point and the horizontal and also the projection of the velocity onto the axis of the ordinates were measured directly. The results were processed in dimensionless form and are shown in Fig. 1. Here, we can compare our results with those of Abramovich [6] for gas flow behind a high-drag body.

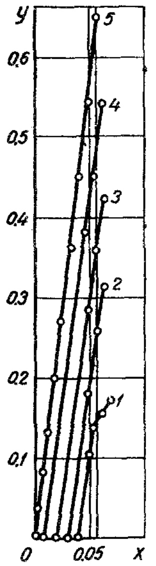


Fig. 3. Calculated trajectories of particles entering inclined barrier from various slot sections: 1) X = = 0; 2) 0.0247 m; 3) 0.0331; 4) 0.0419; 5) 0.05.

The following conclusions can be drawn from the experiments:

1) Gas flow behind a complex barrier of the type in question is jet flow with turbulent counterflow jets; the cores of the forward and reverse jets are rather sharply expressed.

2) The presence of a transverse gas-velocity component is found.

3) The change in gas velocity within a region of three-fourths of the sloth width (from the side wall) is small. With sufficient practical accuracy, in this region we can let W = const, and the ratio of the longitudinal and transverse velocities $W_Y/W_X = 5.65$, where $W_Y = 0.70W\Gamma$.

Now that we have the flow pattern, we can make a sample calculation of the trajectory of a particle moving in a gas stream behind an inclined barrier in a chamber with B = 0.185 m and E − $a$ = 0.12 m.

From the experimental data, we find the mean values of the dimensionless velocity components for various chamber cross sections:

| 0 | 0.05 | 0.10 | 0.15 | 0.20 | 0.25 |
|---|---|---|---|---|---|
| 0.816 | 0.906 | 0.871 | 0.868 | 0.876 | 0.844 |

Over the entire height of the jet, $m_Y = 0.860$ and $m_X = 0.152$.

The maximum longitudinal velocity $W_{Y max} = 2.3$ m/sec, and the "soaring" velocity of the particle $W_s = 7.8$ m/sec.

The gas-velocity projections onto the coordinates axes are:

$$W_Y = m_Y W_{Y\max} = 10.6 \text{ m/sec},$$

$$W_X = m_X W_{Y\max} = 1.875 \text{ m/sec}.$$

Let us make successive calculations for the values on the right sides of Eqs. (16), (17), (18), and (19) for a number of values of the independent variable. The obtained functions $V_X = f(\tau)$ and $V_Y = f(\tau)$ are shown in Fig. 2.

The particle trajectory is constructed from points by plotting the displacements on the axes. The calculated trajectories of a particle entering behind an inclined barrier from various slot sections is shown in Fig. 3.

The results are in good agreement with visual examination of particle trajectories by high-speed filming.

NOTATION

B is the width of the chamber, m; $a$ is the slot width, m; $\Gamma = a/B$ is the channel geometry simplex; $f$ is the mid-cross-sectional area of a particle, $m^2$; m is the particle mass, kg; $m_0$ is the liquid mass in particle volume, kg; W is the air velocity at total apparatus cross-section, m/sec; $W_X$, $W_Y$ are the velocity projections onto the coordinate axes, m/sec; $W_T$ is the circular gas flow velocity, m/sec; $m_Y = W_Y/W_{Y max}$, $m_X = W_X/W_{Y max}$ are the dimensionless projections of gas velocity; V, $V_0$ are the absolute and relative particle velocities, m/sec; U is the dimensionless velocity of mass removal, m/sec; $\tau$ is the time, hr, sec; g is the gravitational acceleration, $m/sec^2$; $\rho$ is the material density, $m^2$/sec; e is the unit vector.

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