Impact of the Air Flow Formed by the Movement of a High Speed Train on Solid Particles of the Earth's Surface

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Abstract: in this paper, we consider the problem of particle entrainment by air flow as the speed of a high-speed train increases. We have obtained solutions to the problem in the case when the particles in the section have the shape of a trapezoid.

Keywords: density, movement, high-speed train, solid particles, air flow.

Due to the movement of a high-speed train, some air flow is formed. The air flow rate in the presence of solid particles on the earth's surface enables us to formulate the problem of airflow on particle lying on a rough land surface that affects the velocity distribution of air particles given the diversity of the earth's surface [11-15], [20].

In this regard, we consider the problem of the flow of solid particles by the air flow.

Previously, the problem of the formation of air flow in the surrounding region in the absence of solid particles on the earth's surface was considered [4-6], [11-17], [20]

In various areas along which a high-speed train passes, a high-speed air flow is formed, which can tear off particles lying on the earth's surface (for example, the earth's surface) and carry them away in a certain direction.

Since a high-speed train moves at a high speed, we consider the movement to be uniform and straight [7-13], [20]. Therefore, we assume that the movements of the carried away particles will mainly be in the direction of the train. The lateral velocity of the air flow formed by the movement of a high-speed train is considered relatively small.

The resulting movement of air particles during the movement of the train will be potential [1–4], then the speed of air particles is determined by the equality

$$\vec{V} = grad\varphi \qquad (1),$$

where is the speed potential [2].
The continuity equation will be:

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} = 0 \qquad (2),$$

where are the components of the velocity vector of air particles. We introduce a current function that satisfies the continuity equation

$$u = \frac{1}{\rho}\frac{\partial\psi}{\partial y}, \quad v = -\frac{1}{\rho}\frac{\partial\psi}{\partial x} \qquad (3),$$

here $\rho = \begin{cases} \text{const} & M < 0,3 \\ \text{variable} & M \geq 0,3 \end{cases}$, where M is the Mach number.

If the train is moving at the maximum speed $350\frac{km}{h}$ – $400\frac{km}{h}$, the air density is variable $M \geq 0,3$, and at speed $\vec{V} \leq 250\frac{km}{h}$ the air density will be constant, since ρ it can only change by a small amount, i.e. $\rho = \rho_0 + \Delta\rho$, where $\frac{\Delta\rho}{\rho_0} << 1$.

Equality (3) satisfies the continuity equation (2).

Let's introduce a comprehensive potential

$$w(z) = \varphi(x, y) + i\,\psi(x, y),$$

here $z = x + iy$.

From the equalities (1), (3) it follows that the velocity potential $\varphi(x, y)$ – will be an analytical function in the domain G_z where $z = x + iy$,

$$u = \frac{\partial\varphi}{\partial x} = \frac{\partial\psi}{\partial y}, \quad v = \frac{\partial\varphi}{\partial y} = -\frac{\partial\psi}{\partial x} \qquad (4)$$

When a train is moving at subsonic speed, the following method for $M < 0,3$ $\rho = const,\ u = \frac{\partial\varphi}{\partial x} = \frac{\partial\psi}{\partial y}, \quad v = \frac{\partial\varphi}{\partial y} = -\frac{\partial\psi}{\partial x}$ solving jet problems of a compressible liquid was

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proposed for the case when, by first solving the problem for an incompressible liquid (then $\Delta\rho = 0$) $\rho = const$ [4].

In the case of an incompressible fluid, and the function $w(z)$ will be an analytical function in the flow domain G_Z , here $z = x + iy$, where $0 < x < \infty,\ 0 < y < \infty$.

In the problem under consideration, the movement is potential, the air is incompressible when the speed of a high-speed train $V_n \le 250 km/h$, and the Mach number $M < 0{,}3$ [1], [2].

To get a solution, we first determine the speed distribution when the air flow flows around obstacles.

Consider the problem of carrying away solid particles lying on the earth's surface with different configurations formed by the movement of air flows of a high-speed train.

In [3], we consider the problem of the siltation motion of a particle (a single solid body with a diameter d), where it was assumed that the separation velocity vector and separation occurs in the vertical direction.

Below, we consider the problem of carrying away N pieces of solid particles with a density $\rho_ч$ and cross-sections that have the form of isosceles trapezoids in the form of (Fig. 1).

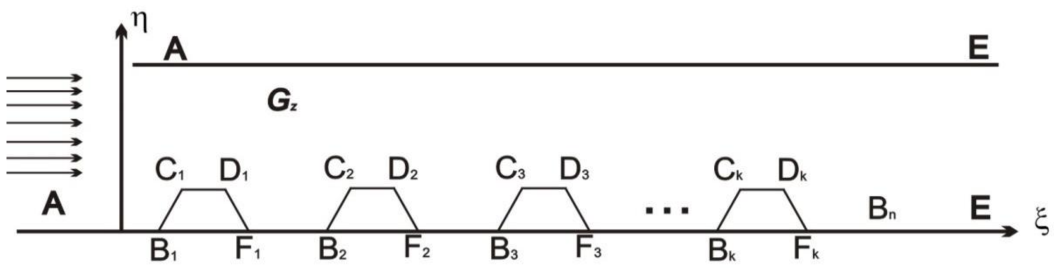

Fig. 1.

Let the distance between the particles be equal to l_k , the total length L, which is equal to $L = \sum l_k + l_k F_k$,

the thickness of the air stream is much less than the height of solid particles h located on the earth's surface G_Z , where $z = x + iy$.

The flow area is G_Z bounded (Fig. 1) from below by straight-line solid segments and the earth's surface, as well as from above by a free surface whose shape AE is unknown.

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We first determine the hydrodynamic force of the air particles on the particles of bodies. to do this, we solve the problem of air flow over a rough surface.

We introduce the upper half-plane, denoting it by G_0, $\zeta = \xi + i\eta$ (Fig. 2). Consider the conformal mapping of the flow region to the G_Z region G_0 – upper half-plane. The actual axis of the area G_0 corresponds to the boundary of the flow area G_z along which the velocity is $V_0 = const$.

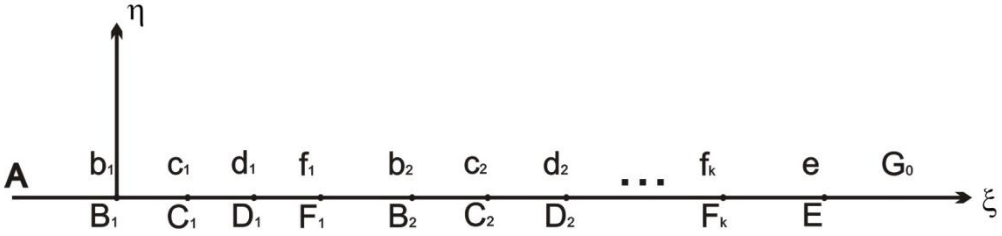

Fig. 2.

Let's assume that solid particles located on the earth's surface have the form of bodies whose cross-section is a trapezoid (Fig. 1). The air flow formed by the movement of a high-speed train flows around solid particles that have the shape of a trapezoid, located on a horizontal surface at a uniform distance from each other.

The flow domain is a region bounded by straight segments (Fig. 2) for the solution, consider the canonical region of the upper half-plane G_0, where $\zeta = \xi + i\eta$, $\eta \geq 0, \ -\infty < \xi < e.$

Given that the flow is flat, we introduce a potential analytical Zhukovsky function

$$\omega(\xi) = \ln\frac{V_0}{V} + i\theta \quad (5)$$

Here V_0 – is the speed on the free surface AE of air particles formed by the movement of high-speed trains, $\bar{V} = u - iv$ –conjugate of complex velocity, V – the speed module, θ –the angle of the vector , u, v –components of the velocity vector in the flow region G_z .

The continuous flow of particle systems located on the earth's surface is considered. From equality (4) we will have the following boundary conditions:

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$$\left.\begin{array}{l}
\text{along } AB_1 : \eta = 0,\ -\infty < \xi < 0 \ \ \operatorname{Im}\omega = 0; \\
\text{along } B_1C_1 : \eta = 0,\ 0 < \xi < c_1 \ \ \operatorname{Im}\omega = \beta_1; \\
\text{along } C_1D_1 : \eta = 0,\ c_1 < \xi < d_1 \ \ \operatorname{Im}\omega = 0; \\
\text{along } D_1F_1 : \eta = 0,\ d_1 < \xi < f_1 \ \ \operatorname{Im}\omega = \pi - \beta_1; \\
\text{along } B_nC_n : \eta = 0,\ 0 < \xi < c_n \ \ \operatorname{Im}\omega = \beta_n; \\
\text{along } C_nD_n : \eta = 0,\ c_n < \xi < d_n \ \ \operatorname{Im}\omega = 0; \\
\text{along } D_nF_n : \eta = 0,\ d_n < \xi < f_n \ \ \operatorname{Im}\omega = \pi - \beta_k;
\end{array}\right\}$$

$$\begin{array}{l}
\text{along } F_kB_k : \eta = 0,\ f_k < \xi < b_k \ \ \operatorname{Im}\omega = 0; \\
\text{along } F_kE : \eta = 0,\ f_k < \xi < e \ \ \operatorname{Im}\omega = 0.
\end{array}$$

Here β_i is the angle at the base i –of the isosceles trapezoid, where $i = \overline{1,n}$, $k = \overline{2,n}$.
According to the Kristopher–Schwartz formula, we have:

$$\omega(\xi) = \frac{1}{\pi}\left\{\begin{array}{l} \beta_1 \int_{b_1}^{c_1} \frac{d\xi}{\xi - \zeta} - \beta_1 \int_{d_1}^{f_1} \frac{d\xi}{\xi - \zeta} + \beta_2 \int_{b_2}^{c_2} \frac{d\xi}{\xi - \zeta} - \beta_1 \int_{d_2}^{f_2} \frac{d\xi}{\xi - \zeta} + \\ \ldots + \beta_k \int_{b_k}^{c_k} \frac{d\xi}{\xi - \zeta} - \beta_k \int_{d_k}^{f_k} \frac{d\xi}{\xi - \zeta} \end{array}\right\}$$

From where integrating, we get

$$\omega(\zeta) = \frac{1}{\pi}\left\{\begin{array}{l} \ln\left(\frac{c_1 - \zeta}{b_1 - \zeta}\right)^{\beta_1} - \ln\left(\frac{d_1 - \zeta}{f_1 - \zeta}\right)^{\beta_1} + \ln\left(\frac{c_2 - \zeta}{b_2 - \zeta}\right)^{\beta_2} - \ln\left(\frac{d_2 - \zeta}{f_2 - \zeta}\right)^{\beta_2} + \\ \ldots + \ln\left(\frac{c_k - \zeta}{b_k - \zeta}\right)^{\beta_k} - \ln\left(\frac{d_k - \zeta}{f_k - \zeta}\right)^{\beta_k} \end{array}\right\}$$

or

$$\omega(\zeta) = \frac{1}{\pi}\ln\left(\prod_{i=1}^{k}\left(\frac{c_i - \zeta}{b_i - \zeta}\frac{f_i - \zeta}{d_i - \zeta}\right)^{\beta_i}\right),$$

$$\omega(\zeta) = \frac{1}{\pi}\ln \Im(\zeta),$$

$$V_0 = V_n,\ \bar{V}(\zeta) = \Im(\zeta) V_n \qquad (6),$$

$$dz = \frac{q}{V_n}\frac{d\xi}{\mathrm{I}(\xi)(e - \xi)},$$

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here

$$\Im(\zeta)=\prod_{i=1}^{k}\left(\frac{c_i-\zeta}{b_i-\zeta}\frac{f_i-\zeta}{d_i-\zeta}\right)^{\beta_i},$$

Where q-air flow rate $q = V_n H$, H - flow height.

Using the last equality, we find the horizontal direction of the velocity vector

$$Z(\zeta)=\frac{q}{\pi V_n}\int_0^{\zeta}\frac{d\xi}{(\xi-e)\mathrm{J}(\xi)} \quad (7),$$

$$\left.\begin{aligned} u &= \operatorname{Re}\bar{V} \\ v &= -\operatorname{Im}\bar{V} \end{aligned}\right\},$$

where does the average speed of air particles come from

$$\bar{u}=\frac{q_n}{V_n}\int_0^{e}\frac{\bar{V}(\xi)}{(e-\xi)}d\xi$$

at $0<\xi<\xi_k$, $\bar{u}(\xi)$-average speed.

To solve the problem of the removal of solid particles from the earth's surface, we use the method of linear quadratic action. For this purpose, we use a well-known method for determining the regularity of motion of detached particles [3].

For the K-the trapezoid, we use the solution of the problem of flow of air around a rough surface by entering the shape coefficient C_k defined as follows

$$C_k = 2\beta_k\left[(1+B_k)h_k\right]^{1/2} \quad (8)$$

Here $h_k=\frac{h}{B}$.

The average velocity of air particles V is determined from the equation:

$$\frac{q_n}{V_n}\int_0^{b_n}\frac{\bar{V}(\xi)d\xi}{L^*},$$

here

$$L^*=\sum_{k=1}^{N}L_k+l_k \quad (9),$$

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where L_k is the length k–of the main trapezoid, l_k the distance between the trapezoids is the C_2^* coefficient of resistance,

$$C_3^* = \frac{L_k}{L_0} C_3,$$

$$L_0 = L_k + P_k \qquad (10),$$

$$\left.\begin{aligned} \mathcal{W}(\xi,\eta) &= V_n \operatorname{Re}[F(\xi)] \\ \mathcal{V}(\xi,\eta) &= V_n \left[\frac{-\operatorname{Im} F(\xi)}{\sqrt{e-\xi}}\right] \end{aligned}\right\} (11),$$

$$\left.\begin{aligned} x(\xi,\eta) &= \operatorname{Re} Z(\xi,\eta) \\ y(\xi,\eta) &= \operatorname{Im} Z(\xi,\eta) \end{aligned}\right\} (12)$$

Equalities (11) and (12) give the distribution of the velocity of air particles in the flow region G_z. To study the issues of entrainment of solid particles from the earth's surface, we use the equation of motion of solid particles as separate particles in the model of siltation motion [1], [2], [3], which allows you to determine the trajectory and patterns of each.

As a coefficient of the form, we will take,

$$C_k^* = B_k (1 + h_k)^{1/2},$$

where $\hat{h}_k$ is the average height of k that particle. Now let's make the equation according to the quadratic law of resistance in the following form: $C_k = C$, – coefficient of the form

$$C_3 = \sqrt{B_k (1 + h_k)} \ (13),$$

$$C_2^{(k)} = C_2^0 \frac{L_k + l_{k_0}}{L_k} \ (14),$$

$$\Phi_0 = \frac{3}{8} \sigma \frac{L_k + l_{k_0}}{L_k + L_{k_0}} \frac{\rho_в}{\rho_ч} \frac{w_0^2}{\sigma g d},$$

Here, $\tilde{u} = \frac{\overline{u}}{w_0}$, $w_0 = w_{кр}$, $\sigma = \frac{\rho_r}{\rho_b}$, ρ_r, $\rho_в$ – the density of solid particles and air particles, d – - the diameter of the particle. For large particles, the hydraulic fineness is determined by equality $w_{кр} = \sqrt{\sigma g d}$.

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The movements of detached particles can be siltation at $\frac{V_*^2}{\sigma g d} \le 1$, where $V_* > 2\frac{m}{s}$.

$$C_2^* = C_2 \frac{L_k}{L_k + l_{k_0}} \tag{15}$$

with the conditions $t = 0$, $x_k(0) = x_k$, $y_k(0) = y_k$, coordinates of the center of gravity of solids or isosceles trapezoids along vertical cross sections.
We assume that the separation of particles occurs at an angle β or vertically, i.e. when $\beta = \frac{\pi}{2}$ Each particle is subjected to hydrodynamic pressure

$$p_k = r_k V_k(x_k, y_k)$$

and power

$$F_k = r_k U_k S_k,$$

where $U_k = \sqrt{u_k^2 + v_k^2}$, a S_k is the cross-sectional area of k – that particle.

$$\begin{cases} C_2 \rho_ч d_ч^3 \dfrac{du_ч}{dt} = \rho_b d_ч^2 C_3 \sqrt{w_ч^2 + \left(u - u_ч\right)^2} \left(u - u_ч\right) \\ C_2 \rho_ч d_ч^3 \dfrac{dw_ч}{dt} = -\rho_b d_ч^2 C_3 \sqrt{w_ч^2 + \left(u - u_ч\right)^2} w_ч - C_2 \rho_ч d_ч^3 g \end{cases} \tag{16}$$

where $\bar{u}$ – is the average velocity of air particles, $u_ч$ – - components of the velocity vector on the axis Ox, w –- components of the velocity vector on the axis Oz.
The speed distribution is defined by the equality

$$u_ч\left(\hat{z}, \tau\right) = V_n \frac{\Phi_0 \hat{u} \tau}{1 + \Phi_0 \hat{u} \tau} \tag{17}$$

$$w_ч\left(\hat{z}, \tau\right) = V_n \frac{1 - \tau - \Phi_0 \hat{u} \frac{\tau^2}{2}}{1 + \Phi_0 \hat{u} \tau} \tag{18}$$

where τ – is the time of particle rise.

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