

Movement of a corpuscle in the air in conditions of wind and movement of the unit

The purpose. To develop high-precision procedure of approximate integration of equations of movement of material corpuscle launched into the air in conditions of wind and movement of the unit.

Methods. Approximation is used in equations of members $V_0^{N-1}V_{ox}$, $V_0^{N-1}V_0^y$ and $V_0^{N-1}V_0^z$ by polynomials of 3rd, 4th and so on etc. degree in the time t . The first values of quotients of these polynomials are calculated using the equations of zero approximation which are brought in the article. The subsequent values can be gained by iteration, i.e. integration of the equations with these polynomials with their fixed clarification by averaging previous values and values which were received after integration of V_x , V_y , and V_z , up to their coincidence.

Results. The developed multiple-purpose procedure enables to receive practically any accuracy of calculation of parameters of movement of a corpuscle on the taken segment of its movement in conditions of wind and movement of the unit.

Conclusions. This procedure is simple enough, can compete to procedure of calculation executed by means of numerical methods, can be applied in determination of accuracy of such calculations and in integration of other equations which are not integrated in elementary functions.

Key words: equation, zero approximation, approximation, methods of iteration, averaging, clarification, comparison, coincidence.

Actuality of the question. The movement of fertilizers in the conditions of wind and motion of the unit occurs almost always. However, solutions in the quadratures of such equations were obtained without taking into account the wind and the motion of the aggregate [2, 9]. The dependence of the movement of the material particles thrown into free air in the conditions of wind and motion of the unit is necessary to determine in such conditions the width of grabbing of fertilizer, plant protection products, watering of plants, etc. [10]. Therefore, these studies are relevant.

Analysis of recent research and publications. All known studies on these issues are more focused on obtaining differential equations of this motion and do not relate to the solutions of these equations in quadratures. Therefore, the development of methods for their solutions is needed both for the theory and for the practice of such processes. Such equations and their solutions are given in [1 - 7, 9, 10], and their analysis is presented in [10]. In general, these equations do not integrate into elementary functions, therefore their use has certain difficulties.

The purpose of research. Develop a high-precision technique for the approximate integration of particle motion equations under given conditions and give an example.

Research methodology. Approximation is applied in the equations of the members of the $V_0^{N-1}V_{ox}$, $V_0^{N-1}V_{oy}$ and $V_0^{N-1}V_{oz}$ polynomials of the 3rd, 4th, etc. power in time t . The first values of the coefficients of these polynomials are found from the equations of zero approximation, which are given in the article, and the following - by iteration, that is, the integration of equations with these polynomials with their refinement every

time through the averaging of the previous and obtained after the integration of the values V_x , V_y and V_z to their coincidence.

Research results. Let the unit move along the OX axis at a speed V_A (m / s). A spinner with height h (m/s) at an angle γ to a horizontal field ejects a particle with a velocity V_F (m / s) relative to itself whose vector on a horizontal projection is directed at an angle α to its longitudinal axis. At an angle θ to the direction of movement of the unit winds at a velocity V_B (m / s) (figure). Then, in a fixed coordinate system XYZ, the velocity of the particle along its

axes will be equal to:

$$V_x = V_A + V_u \cos \gamma \cos \alpha; \quad V_y = V_u \cos \gamma \sin \alpha; \quad V_z = V_u \sin \gamma$$

and its absolute velocity V in this coordinate system will be equal to:

$$V = \sqrt{V_x^2 + V_y^2 + V_z^2} .$$

The components of the wind speed on these axes will be equal to:

$$V_{BX} = V_B \cos \theta; \quad V_{BY} = V_B \sin \theta; \quad V_{BZ} = 0 ,$$

and the velocity of particle flux in air will be equal to:

$$V_{OX} = V_x \pm V_{BX}; \quad V_{OY} = V_y \mp V_{BY}; \quad V_{OZ} = V_z .$$

In paired signs "+" corresponds to the motion of the component of the wind on the axis against the motion of the particle on it, and the sign "-" - in its motion. Then the absolute particle velocity relative to the air will be:

$$V_o = \sqrt{(V_x \pm V_{BX})^2 + (V_y \mp V_{BY})^2 + V_z^2} ,$$

and the equations of motion of the particle along the X, Y, Z axes take the form:

$$\begin{aligned} \dot{V}_x &= \dot{V}_{ox} = -\frac{g}{\omega_0^N} V_0^{N-1} V_{ox}; \\ \dot{V}_y &= \dot{V}_{oy} = -\frac{g}{\omega_0^N} V_0^{N-1} V_{oy}; \\ \dot{V}_z &= \dot{V}_{oz} = -g - \frac{g}{\omega_0^N} V_0^{N-1} V_{oz}, \end{aligned} \quad (1)$$

where $N = 1.0; 1.2; 1.5; 2.0$ - depending on the mode of flow of particles in air [9];

ω - particle speed, m / s. The solution of the equations of type (1) is given in [9]. It is based on techniques of the iteration method [8]. It first finds an approximate solution, obtained, for example, by the method of superposition. With its help, on the taken interval t , which is split into 3, 4, etc. the same intervals, the values of $V_0^{N-1} V_{ox}$, $V_0^{N-1} V_{oy}$, $V_0^{N-1} V_{oz}$, in which the approximating polynomials of the 3rd, 4th, etc. are found, are found at their points. degree from t . If these polynomials give the values V_x , V_y , V_z greater than the actual ones, after integrating them into (1), these values will decrease, and if smaller, they will increase. By averaging each preceding and derived values of these velocities at the points taken and specifying these polynomials, we automatically move to their exact values. The latter accelerates the coincidence of results and prevents the instability of solutions. Substituting in (1) the values of variables, we have a system of equations, which, in the absence of the motion of the unit and the wind passes into the equation of ballistics. For zero approximation we assume that in this case, V_0 in (1) changes as well as without taking into account the forces of its weight. Then for the quadratic, most used law, or particle resistance ($N=2$):

$$\dot{V}_0 = -\frac{g}{\omega_0^2} V_0^2, \text{ що дає: } V_0 = \frac{V_{0n}\omega_0^2}{gV_{0n}t + \omega_0^2}, \quad (2)$$

where V_{0n} - initial value V_0 , m / c. After substitution (2) in (1) we have:

$$\begin{aligned} \dot{V}_x &= \dot{V}_{0x} = -\frac{gV_{0n}}{gV_{0n}t + \omega_0^2} V_{0x}; \\ \dot{V}_y &= \dot{V}_{0y} - \frac{gV_{0n}}{gV_{0n}t + \omega_0^2} V_{0y}; \\ \dot{V}_z &= \dot{V}_{0z} - g - \frac{gV_{0n}}{gV_{0n}t + \omega_0^2} V_z. \end{aligned} \quad (3)$$

With superposition (1) integrate and give [9]:

$$\begin{aligned} V_{0x} &= (V_x \pm V_{0x}) = \frac{V_{0xn}\omega_0^2}{gV_{0n}t + \omega_0^2}; \\ V_{0y} &= (V_y \mp V_{0y}) = \frac{V_{0yn}\omega_0^2}{gV_{0n}t + \omega_0^2}; \\ V_z &= -gt + \frac{V_{0zn}\omega_0^2}{gV_{0n}t + \omega_0^2}, \end{aligned} \quad (4)$$

where V_{0xn} , V_{0yn} , V_{0zn} are the initial velocities V_{0x} , V_{0y} , V_{0z} , m / s, of which:

$$\begin{aligned} X &= X_n \mp V_{0x}t + \frac{V_{0xn}\omega_0^2}{gV_{0n}} \ln\left[\frac{gV_{0n}t}{\omega_0^2} + 1\right]; \\ Y &= Y_n \pm V_{0y}t + \frac{V_{0yn}\omega_0^2}{gV_{0n}} \ln\left[\frac{gV_{0n}t}{\omega_0^2} + 1\right]; \\ Z &= Z_n - \frac{gt^2}{2} + \frac{V_{0zn}\omega_0^2}{gV_{0n}} \ln\left[\frac{gV_{0n}t}{\omega_0^2} + 1\right], \end{aligned} \quad (5)$$

where $V_{0zn} = V_{zn}$.

In double signs (5) "-" correspond to the motion of a particle against the component of the wind, and "+" - after it. These dependences are sufficient to obtain a zero approximation of fertilizer motion in the ascending segment of the trajectory. At its top point, $V_z = 0$, therefore, from the last equation in (4) we write:

$$\begin{aligned} -gt_{\text{вис}} + \frac{V_{0zn}\omega_0^2}{gV_{0n}t_{\text{вис}} + \omega_0^2} &= 0, \text{ звідки} \\ t_{\text{вис}} &= -\frac{\omega_0^2}{2gV_{0n}} + \frac{\omega_0}{g} \sqrt{\frac{\omega_0^2}{4V_{0n}^2} + \frac{V_{0zn}}{V_{0n}}}, \end{aligned}$$

where $t_{\text{вис}}$ is the time of movement of a particle to the highest point of the trajectory, c. Roughly divide the $t_{\text{вис}}$ at 3 level intervals. For $V_0^N - V_{0x}$ at their points $t_1 = 0$; $t_1 \approx t_{\text{вис}} / 3$; $t_2 = 2t_1$, $t_3 = 3t_1$ we have:

$$\begin{aligned} a_0 + a_1t_1 + a_2t_1^2 + a_3t_1^3 &= V_{01}^N - V_{0x1}; \\ a_0 + 2a_1t_1 + 4a_2t_1^2 + 8a_3t_1^3 &= V_{02}^N - V_{0x2}; \\ a_0 + 3a_1t_1 + 9a_2t_1^2 + 27a_3t_1^3 &= V_{03}^N - V_{0x3}. \end{aligned} \quad (6)$$

The polynomial (11) passes through 4 points of these intervals, in which the value $a_0 = V_{0n}^N - V_{0xn}$ at the starting point, $V_{01}^N - V_{0x1}$, $V_{02}^N - V_{0x2}$, $V_{03}^N - V_{0x3}$ - respectively at the end of the 1st - t_1 , 2nd - t_2 and the 3rd - t_3 intervals. Replacing $V_{01}^N - V_{0x1} - a_0 = b_1$; $V_{02}^N - V_{0x2} - a_0 = b_2$; $V_{03}^N - V_{0x3} - a_0 = b_3$, from (6) we have:

$$\begin{aligned} a_1 t_1 &= (18b_1 + 2b_3 - 9b_2) / 6; \\ a_2 t_1^2 &= (4b_2 - b_3 - 5b_1) / 2; \\ a_3 t_1^3 &= (b_3 + 3b_1 - 3b_2) / 6. \end{aligned}$$

Of these, it is easy to find a_1, a_2, a_3 , but it is more convenient to use $a_1 t_1, a_2 t_1^2, a_3 t_1^3$.

For ${}^1V_0^N - {}^1V_{0y}$ the same: $V_0^N - {}^1V_{0y} = c_0 + c_1 t + c_2 t^2 + c_3 t^3$. Then $c_0 = V_{0n}^{N-1} V_{0yn}$ at the starting point. For $t_1, t_2 = 2t_1; t_3 = 3t_1; V_{01}^N - {}^1V_{0y1} - c_0 = d_1; V_{02}^N - {}^1V_{0y2} - c_0 = d_2; V_{03}^N - {}^1V_{0y3} - c_0 = d_3; = (18d_1 + 2d_3 + 9d_2) / 6;$

$$\begin{aligned} c_2 t_1^2 &= (4d_2 - d_3 - 5d_1) / 2; \\ c_3 t_1^3 &= (d_3 + 3d_1 - 3d_2) / 6. \end{aligned}$$

Similar for $V_0^{N-1} V_{0z}$: $V_0^{N-1} V_{0z} = B_0 + B_1 t + B_2 t^2 + B_3 t^3$. For $t_1, t_2 = 2t_1; t_3 = 3t_1; B_0 = V_{0n}^{N-1} V_{0zn}; V_{01}^{N-1} V_{0z1} - B_0 = j_1; V_{02}^{N-1} V_{0z2} - B_0 = j_2; V_{03}^{N-1} V_{0z3} - B_0 = j_3$. Where:

$$\begin{aligned} B_1 t_1 &= (18j_1 + 2j_3 - 9j_2) / 6; \\ B_2 t_1^2 &= (4j_2 - j_3 - 5j_1) / 2; \\ B_3 t_1^3 &= (j_3 + 3j_1 - 3j_2) / 6. \end{aligned}$$

Then with (5):

$$\begin{aligned} \dot{V}_x &= -\frac{g}{\omega_0^N} (a_0 + a_1 t + a_2 t^2 + a_3 t^3); \\ \dot{V}_y &= -\frac{g}{\omega_0^N} (c_0 + c_1 t + c_2 t^2 + c_3 t^3); \\ \dot{V}_z &= -g - \frac{g}{\omega_0^N} (B_0 + B_1 t + B_2 t^2 + B_3 t^3), \end{aligned}$$

Which are easy to integrate and give:

$$\begin{aligned} V_x &= V_{xn} - \frac{g}{\omega_0^N} (a_0 + \frac{a_1 t}{2} + \frac{a_2 t^2}{3} + \frac{a_3 t^3}{4}) t; \\ V_y &= V_{yn} - \frac{g}{\omega_0^N} (c_0 + \frac{c_1 t}{2} + \frac{c_2 t^2}{3} + \frac{c_3 t^3}{4}) t; \quad (7) \\ V_z &= V_{zn} - gt - \frac{g}{\omega_0^N} (B_0 + \frac{B_1 t}{2} + \frac{B_2 t^2}{3} + \frac{B_3 t^3}{4}) t. \end{aligned}$$

From (1, 3, 4) we define the following V_{0x}, V_{0y}, V_{0z} and V_0 at the points t_1, t_2, t_3 , which are averaged each time by dividing the sum of the sum from the previous and the obtained values. At the end of the calculations from (5) for $t_k = kt_1$ (in the taken points $k = 1, 2, 3$, and outside them $k = t / t_1$ will be fractional), we have:

$$\begin{aligned} X_k &= X_n + V_{xn} k t_1 - \\ &-\frac{g}{\omega_0^N} \left(\frac{a_0}{2} + \frac{k a_1 t_1}{6} + \frac{k^2 a_2 t_1^2}{12} + \frac{k^3 a_3 t_1^3}{20} \right) k^2 t_1^2; \\ Y_k &= Y_n + V_{yn} k t_1 - \\ &-\frac{g}{\omega_0^N} \left(\frac{c_0}{2} + \frac{k c_1 t_1}{6} + \frac{k^2 c_2 t_1^2}{12} + \frac{k^3 c_3 t_1^3}{20} \right) k^2 t_1^2; \quad (8) \\ Z_k &= Z_n + V_{zn} k t_1 - \frac{g k^2 t_1^2}{2} - \\ &-\frac{g}{\omega_0^N} \left(\frac{c_0}{2} + \frac{k c_1 t_1}{6} + \frac{k^2 c_2 t_1^2}{12} + \frac{k^3 c_3 t_1^3}{20} \right) k^2 t_1^2. \end{aligned}$$

For a descending segment of the trajectory in the case of $V_{zn} = 0$, the air resistance force in V_z in (9) will always be equal to zero. Therefore, for this segment of the trajectory, as an output, we receive a quadratic V_z air resistance law throughout the entire site. Then [9] for $|V_z| \leq \omega_0$, $N = 2$, we write:

$$\dot{V}_z = -g + \frac{g}{\omega_0^2} V_z^2, \text{ що рівнозначно:} \\ \left(-\frac{\omega_0^2}{g}\right) \frac{dV_z}{dt} = \omega_0^2 - V_z^2. \quad (9)$$

At $t=0$, $V_z=V_{zn}$ з (14) we get:

$$t = \frac{\omega_0}{2g} \left[\ln \frac{\omega_0 + V_{zn}}{\omega_0 - V_{zn}} - \ln \frac{\omega_0 + V_z}{\omega_0 - V_z} \right]. \quad (10)$$

The values of V_z are negative values, so t in the last expression will always be positive and grow in motion $|V_z|$ to ω_0 . From it we get [9]:

$$V_z = \omega_0 \frac{(\omega_0 + V_{zn}) - (\omega_0 - V_{zn}) \exp\left(\frac{2g}{\omega_0^2} t\right)}{(\omega_0 + V_{zn}) + (\omega_0 - V_{zn}) \exp\left(\frac{2g}{\omega_0^2} t\right)}; \quad (11) \\ Z = Z_n - \frac{\omega_0^2}{2g} \left[\ln \frac{(\omega_0^2 - V_{zn}^2)}{(\omega_0^2 - V_z^2)} \right].$$

With growth $|V_z|$ the fraction increases by logarithm, and Z decreases. If from (1) we define V_{zk} at $Z_k = 0$ and substitute it in the expression t , we can determine the time of the $t_{\text{нис}}$ of the motion of the particle before falling to the surface of the field.

Where:

$$V_{zk} = -\sqrt{\omega_0^2 - (\omega_0^2 - V_{zn}^2) \exp\left(-\frac{2gZ_n}{\omega_0^2}\right)}; \quad (12) \\ t_{\text{нис}} = \frac{\omega_0}{2g} \left[\ln \frac{\omega_0 + V_{zn}}{\omega_0 - V_{zn}} - \ln \frac{\omega_0 + V_{zk}}{\omega_0 - V_{zk}} \right].$$

For $|V_{zn}| \geq \omega_0$ (9) will have solutions, which are given in [9]. On the motion of the particle against the wind on the OX axis it is possible to change the V_x values from positive to negative. At this point, $V_{0x} = V_{ax}$, $V_x = 0$, and the values of t are equal to:

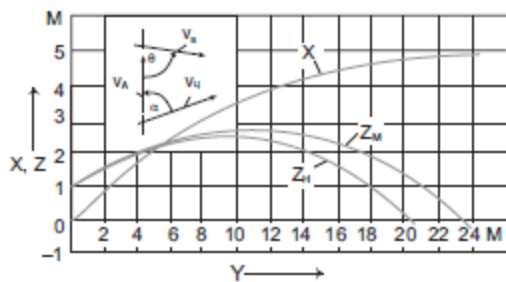
$$t_{3x} = \frac{(V_{0xp} - V_{ax})\omega_0^2}{V_{0p}V_{ax}g}.$$

$$t_{3y} = \frac{(V_{0yp} - V_{ay})\omega_0^2}{V_{0p}V_{ay}g}.$$

Under these same conditions, the OY sign changes the sign and V_y , this occurs at the point:

Example. At the stationary, a scatterer with a height of $h = 1$ m throws fertilizer ($\omega_0 = 8$ m / c) at a velocity $V_0 = 40$ m / s at an angle $\alpha = 70^\circ$ (on a horizontal projection) to its longitudinal axis and at an angle $\gamma = 150$ to the horizon (drawing). During operation, it moves at a speed $V_A = 3$ m / s. At an angle $\theta = 80^\circ$ in the direction of its motion winds at a speed $V_B = 10$ m / s (figure). Find the trajectory of motion of their particles. From (1, 3) we have: $V_{xp} = 16.3$ m / s; $V_{yp} = 36.3$ m / s; $V_{zn} = 10.352$ m / s; $V_{bx} = 1.736$ m / c; $V_{by} = 9.848$ m / s; $V_{bz} = 0$; $V_{0xp} = 18.036$ m / s; $V_{0yp} = 26.452$ m / s; $V_{0zp} = V_{zp} = 10.352$ m / s, $V_{0p} = 33.646$ m / s. Substituting them in (10), we find $t_{\text{VIS}} = 0.3627$ c, divide it into 3 level intervals. Approximately we take $t_1 = 0.14$ with each. Then from (9) for $t_P = 0$; $t_1 = 14$ s, $t_2 = 2t_1$; $t_3 = 3t_1$ we have: $V_{0x1} = 10.475$ m / s; $V_{0x2} = 7.381$ m / s; $V_{0x3} = 5.698$ m / s; $V_{0y1} = 15.336$ m / s; $V_{0y2} = 10.827$ m / s; $V_{0y3} = 8.358$ m / s; $V_{0z1} = 4.638137$ m / s; $V_{0z2} = 1.489$ m / s; $V_{0z3} = -0.85$ m / s; $V_{01} = 19.166$ m / s; $V_{02} = 13.188$ m

/ s; $V_03 = 10.15$ m / s of zero approximation. Of these: $V_0PV_0HP = a_0 = 606,772$ (Dimensions are omitted); $V_0PV_0YP = c_0 = 890.0$; $V_0PV_0ZP = v_0 = 348.3$; $V_01V_0H1 = 200.764$; $V_02V_0X2 = 97.2$; $V_03V_0X3 = 7.835$; $V_01V_0Y1 = 294, 4856$; $V_02V_0Y2 = 142.786$; $V_03V_0Y3 = 8.4, 8.3.4$; $V_01V_0Z1 = 8.8, 9.3$; $V_02V_0Z2 = 1.9, 6.5$; $V_03V_0Z3 = -8.637$; $b_1 = -406.01$; $b_2 = -509.572$; $b_3 = 548.937$; $d_1 = -595.51$; $d_2 = 747.2$; $d_3 = -805.166$; $j_1 = -259.37$; $j_2 = -328.65$; $j_3 = -356,937$. Based on them: $a_1t_1 = -636.67$; $a_2t_1^2 = 270.35$; $a_3t_1^3 = -39.707$; $c_1t_1 = -934.12$; $c_2t_1^2 = 397.0$; $c_3t_1^3 = -58,355$; $B_1t_1 = -404,135$; $v_2t_1^2 = 169.6$; $3t_1^3 = -24.86$. For $N = 2$ we find: $VX1 = 8.39$; $VX2 = 5.52$; $VX3 = 3.76$; $VY1 = 24.697$; $VY2 = 20.48573$; $VY3 = 17.893$; $VZ1 = 4.7608$; $VZ2 = 2.43$; $VZ3 = 0.882$; $V_0X1 = 10.176$; $V_0X2 = 7.305$; $V_0X3 = 5.546$; $V_0Y1 = 14.849$; $V_0Y2 = 10.63773$; $V_0Y3 = 8.045$; $V_0Z1 = 4.7608$; $V_0Z2 = 2.43$; $V_0Z3 = 0.882$. The averaging gives: $V_0X1 = 10.3255$; $V_0X2 = 7.343$; $V_0X3 = 5.622$; $V_0Y1 = 15.107$; $V_0Y2 = 10.732$; $V_0Y3 = 8.2$; $V_0Z1 = 4.7$; $V_0Z2 = 1.95$; $V_0Z3 = 0.016$. After 3 such approximations we get: $VX1 = 8,53$; $VH2 = 5.72$; $VX3 = 3.9$; $VY1 = 24.793$; $VY2 = 20.783$; $VY3 = 18.13$; $VZ1 = 4.788$; $VZ2 = 2.313$; $VZ3 = 0.449$. To achieve a particle of the upper point of its trajectory, add its travel time $\Delta = = = Z_3 t V / g 0, 449/9, 81 0, 04577$ s, to $t_4 = t_3 + + 0,04577 = 0.4657$ c. In it: $k_4 = t_4 / t_1 = 3.3264$, $VX4 = 3.656$; $VY4 = 17.8$; $VZ4 = 0.02$; $X1 = 1.63$; $X2 = 2.61$; $X3 = 3.247$; $X4 = 3.45$; $Y1 = 4.143$; $Y2 = 7.297$; $Y3 = 10.0$; $Y4 = 10.817$; $Z1 = 1.993$; $Z2 = 2.505$; $Z3 = 2.67$; $Z4 = 2.677$, which is the starting point for the downlink of the trajectory. Then from (10, 17) for falling on the soil $V_{IK} = -6.0$ m / c;



Graphic dependences of $X(Y)$ and $Z(Y)$ with the screen saver of the vectors V_A, V_V, V_C (Z_M - according to the method, Z_N - in the zero approximation)

$t_{NIZ} = 0,793$ c, roughly divide t into 3 levels of the area by 0,3 s each. By making 3 approximations, we get: $VX1 = 1.96776$; $VX2 = 1.0141$; $VX3 = 0, 3 1 2 3$; $VY1 = 1 5, 2 9 9$; $VY2 = 1 3, 8 7 7$; $VY3 = 13.877$; $VY3 = 12.8158$; $VZ1 = -2.481$; $VZ2 = -4.35$; $VZ3 = -5.781$; $X1 = 4.402$; $X2 = 4.702$; $X3 = 4.995$; $Y1 = 15.738$; $Y2 = 20.1$; $Y3 = 24.09$; $Z1 = 2.3995$; $Z2 = 1.25$; $Z3 = 0.28$. By these values, we construct graphs of motion of a particle (figure). It is seen from them how the lateral wind bends the particle motion path from the OX axis and significantly increases the distance of the particle along the OY axis compared to that obtained in [9].

Conclusions

The main operations for the derivation of the equations of motion of a material particle, thrown into free air in the conditions of wind and motion of the unit, is the alternate definition of the components of the V_x, V_y, V_z of the absolute velocity of the particle V along the axes of the fixed coordinate system XYZ ; the components of V_{Bx}, V_{By}, V_{Bz} wind speed V_B on these axes and the components V_{Ox}, V_{Oy}, V_{Oz} relative velocity V_O of the motion of the particle relative to the air in these axes. After this, the equation of motion of a particle in such conditions becomes the form:

$$\dot{V}_X = \dot{V}_{OX} = -\frac{g}{\omega_0^N} V_0^{N-1} V_{OX};$$

$$\dot{V}_Y = \dot{V}_{OY} = -\frac{g}{\omega_0^N} V_0^{N-1} V_{OY};$$

$$\dot{V}_Z = \dot{V}_{OZ} = -g - \frac{g}{\omega_0^N} V_0^{N-1} V_{OZ},$$

which are analytically identical to the equations of the ballistics [9] and are solved identically to them. The easiest way to solve them is given in this article, as well as in [9].

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