Simulation modeling of the soil flow movement process in the air, supplied by a ground gun while extinguishing a forest fire

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Abstract. The article presents a technological scheme of the operation process of a soil-throwing unit, which has a milling-throwing working body and a guiding casing, and a developed simulation model of the process of movement in the air of a directed flow of soil particles supplied by a soil launcher when extinguishing a forest fire. The aim of the study is to assess the influence of soil and air flow parameters on the indicators of its suitability for extinguishing a ground forest fire by using simulation modeling of the process. The study of this work covers the process of flow, which received the necessary impulse from the milling cutters of the soil launcher. The theoretical description of this direction of research is complex, since it considers both the packing of flying particles and individually detached spherical elements that come into contact with air particles, also presented in the form of discrete elements. As a result of modeling the movement of soil in the air, a vertical cut of the system of fragments of soil and air, graphs of dependences on time, the average distance between soil elements and the average resistance force of the air environment were obtained.

1. Introduction
The use of soil for extinguishing forest fires has a high perspective, mainly due to its unlimitedness near the centers of fire. Today, research institutes, universities and firefighting services are developing the topic of eliminating natural fires by throwing soil into the fire zone with special machines [1]. The patent search shows the relevance of the development of techniques for extinguishing fires using soil for forestry [2]. While carrying out research work in order to achieve the maximum efficiency of the soil gun, it is necessary to take into account the process of flight of portions and the rush flow of soil in the air to determine the correct trajectory of movement and the densest directional flow of the supplied soil.

The use of simulation based on discrete elements makes it possible to effectively study various processes and characteristics in the development and creation of ground-throwing equipment [3, 4]. Such an approach to discretizing the environment at the initial stage of designing new units can significantly reduce model errors and comprehensively describe the processes occurring during operation [5, 6]. While developing soil launchers used in forestry to eliminate soil fires, it is necessary to take into account, on the one hand, that it must work with different characteristics of forest soil, and on the other hand, it must ensure the most effective flow of soil supplied to the edge of the fire to stop the advance of the fire front on the forest area [7] (Figure 1). In this case, it is necessary to take into account the structure of the material, to ensure the range and accuracy of the flight of soil particles [8].
The aim of the study is to assess the influence of soil and air flow parameters on the indicators of its suitability for extinguishing a ground forest fire by using simulation modeling of the process of movement in the air of a soil flow supplied by a ground gun to the edge of a forest fire.

2. Material and methods
To simulate the movement of the soil flow from the cutters-throwers along the guiding casings in the air, the particle dynamics method was chosen, which has proven itself well in modeling the process of extinguishing a forest fire, described in [9]. The particle dynamics method uses discretization of the research object and is a mathematically natural method for describing the movement of one medium (crumbly soil) into another (gas) (Figure 2).

The modeling is done in two-dimensional space. The description of the movement of elements is based on Newton's second law [10, 11]. The elastic-viscous forces act between the elements. The soil movement modeling in air is based on the discretization of several media: soil, which received an impulse for flight from milling cutters, and a gaseous medium that comes into contact with the soil. The coefficients of stiffness of interaction and viscous friction for a gas are significantly lower (by 4-6 orders of magnitude) than for solids. In this model, to determine the coefficients, tabular data on the physical properties of the air at a temperature corresponding to the summer period of 300 K (27°C) were used [12, 13].
The developed simulation program in the Delphi development environment is designed to study the nature of the movement of soil fragments in the air [14, 15]. The program allows to describe with high physical adequacy soil fragmentation in flight and aerodynamic processes in the air within the framework of the particle dynamics method. In the text of the program, the geometric and physical parameters of the soil flow and the conditions for conducting a computer experiment can be specified. The program displays a vertical section of the system and graphs of the time dependences of the average distances between fragments and the forces of resistance to soil movement (Figure 3).

At the initial moment of time, the rectangular modeling space \( L_x \times L_z \) is filled with close-packed elements of the same diameter. This close-packed filling is prepared in advance, written to a file and called from it at the beginning of the simulation to reduce machine time.

\[
p_i = \begin{cases} 
1, & \sqrt{(x_i - x_c)^2 + (z_i - z_c)^2} < R_f; \\
2, & F_i < s; \\
otherwise, & 
\end{cases}
\]

where \( p_i \) - is the type of element, which takes the values 1 - soil or 2 - air; \( x_i, z_i \) - coordinates of the element center; \( x_c, z_c \) - initial coordinates of the center of the soil fragment in the approximation of a round shape; \( R_f \) is the radius of the soil fragment; \( F_i \) - successive realizations of a random variable distributed uniformly in the interval 0 ... 1; \( s \) is the parameter of the continuity of the soil fragment.

![Figure 3](image1.png)

**Figure 3.** Interface form for outputting the results of modeling soil movement in the air (vertical cut of a system of soil and air fragments, graphs of time dependences of the average distance between soil elements and the average resistance force of the air environment).

Then, in the original dense packing of elements, the elements are divided into two types: soil and air. The type is determined using the following inequality:

This formula specifies a uniform distribution of soil elements in a circular region with a given degree of continuity \( s \) (through the continuity, the friability parameter can be expressed as \( 1 - s \)). Examples of the initial state of soil with different continuity are shown in Figure 4. More natural is not a constant continuity \( s \) within the soil fragment, but a gradient one: the continuity of the fragment is
higher in the center and decreases towards the edges (Figure 4, l). Such a fragment with a gradient continuity distribution is given by the following inequality:

\[
P_i = \begin{cases} 
1, & \sqrt{(x_i - x_c)^2 + (z_i - z_c)^2} < R_f; \\
F_i < s_1 + \left(s_2 - s_1\right) \frac{\sqrt{(x_i - x_c)^2 + (z_i - z_c)^2}}{R_f}; \\
2, & \text{otherwise},
\end{cases}
\] 

where \(s_1\) and \(s_2\) are the parameters of continuity at the center and at the boundary of the circular region.

![Figure 4](image)

**Figure 4.** Representation in the model of the initial state of the soil flow for cases of different continuity \(s\).

Due to the high level of versatility of the developed model of soil movement in the air, it becomes possible to study the influence of a large number of soil and air flow parameters on the quality indicators of the formation of a directed soil flow, which can be used to create effective ground-throwers for extinguishing forest fires.

3. Conclusions

A simulation model of soil flow movement in air has been developed, which takes into account soil crumbling and allows to determine the flow dispersion by the absolute and angular values of the velocity vector. A computer program has been developed to simulate the movement of soil flow in the air, which allows, on the basis of a series of computer experiments, to establish the influence of the parameters of the flow of soil and air on the indicators of the suitability of the soil flow supplied by
ground-throwing machines to extinguish a ground forest fire.

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