DOI 10.31891/2307-5732-2024-333-2-2
УДК 629.7.085

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SYSTEM FOR AUTOMATED CALCULATION OF PARAMETERS OF THE STAGE OF LAUNCHING AN UNMANNED AERIAL VEHICLE FROM A CATAPULT-TYPE LAUNCHER

This analysis focuses on the various stages involved in launching unmanned aerial vehicles (UAV) and highlights the key considerations that must be taken into account during these stages. When launching UAV in rugged terrain without a proper runway, alternative launch mechanisms, such as a catapult-type launcher, must be developed. The use of a catapult launcher offers several advantages, including the ability to launch in confined spaces and a quick preparation time. However, the development of a launcher is a complex process that requires a comprehensive approach, involving sophisticated engineering solutions to calculate launch parameters and the flight path of the UAV. Throughout the launch process, the UAV progresses through different stages, starting from the ignition of the starting engine until it reaches the desired height and speed. It is crucial to consider various parameters that influence the trajectory of the UAV during the launch phase.

The authors determined the influence of the characteristics of the engines and launcher on the trajectory of the UAV and formulated a mathematical model for calculating the speed and coordinates of movement, which have a significant impact on the flight path. A system for automated calculation of the parameters of the first stage of launching a UAV from a catapult-type launcher is proposed, this system will reduce the time for product development, as well as reduce the influence of the human factor, which will lead to a decrease in the error in calculations. To analyze the starting characteristics of the product, a catapult model was chosen, which consists of a guide, a carriage and a UAV with a starting engine.

The influence of the mass of the product, the launch angle and the distribution of external forces acting on the product are taken into account, which leads to the calculation of the initial values for further design. The result of the application of the system is to obtain the parameters of the speed of movement and the position of the flying object in tabular and graphical forms.

Keywords: unmanned aerial vehicles; launchers, classification of launchers for unmanned aerial vehicles, simulation of the launch of an unmanned aerial vehicle, automated calculation system.

БУКОВСЬКА ДІАНА, АНТОНЮК ВІКТОР
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СИСТЕМА АВТОМАТИЗОВАНОГО РОЗРАХУНКУ ПАРАМЕТРІВ ЕТАПУ ЗАПУСКУ БЕЗПІЛОТНОГО ЛІТАЛЬНОГО АППАРАТУ З ПУСКОВОЇ УСТАНОВКИ КАТАПУЛЬТНОГО ТИПУ

Цей аналіз зосереджується на різних етапах запуску безпілотних літальних апаратів (БПЛА) і висвітлює ключові міркування, які необхідно враховувати на цих етапах. При запуску БПЛА на пересіченій місцевості без відповідної злітно-посадкової смуги необхідно розробити альтернативні механізми запуску, наприклад, пускову установку катапультного типу. Використання катапультної пускової установки пропонує кілька переваг, включаючи можливість запуску в обмеженому просторі та швидкий час підготовки. Проте розробка пускової установки – складний процес, який потребує комплексного підходу із залученням складних інженерних рішень для розрахунку параметрів запуску та траєкторії польоту БПЛА. У процесі запуску БПЛА проходить різні етапи, починаючи від запалювання стартового двигуна до досягнення бажаної висоти та швидкості. Дуже важливо враховувати різні параметри, які впливають на траєкторію БПЛА під час фази запуску.

Ключові слова: безпілотні літальні апарати; пускові установки, класифікація пускових установок для безпілотних літальних апаратів, моделювання запуску безпілотного літального апарату, автоматизована система розрахунку

Statement of the problem

The increased demand for the use of unmanned aerial vehicles (UAV) in various fields of activity requires the modernization of finished products and the introduction of new technologies. The focus is on launching UAV in conditions with limited space and without a paved runway. Catapult-type launchers provide the ability to launch UAV from rough terrain or in places with limited space. Such launch benefits do not need to be created an open, flat, paved surface that will serve as a runway.

Analysis of recent sources

The catapult-type launcher must be mobile, have minimal weight and size characteristics to ensure portability and speed up preparation for the launch of the UAV. The main requirements for a launcher are that it must operate in a variety of climates, be safe for the operator, and be easy to exploit (with low maintenance, resulting in rapid operator training). Another important condition in the design of the installation is the adjustable launch angle for different types of UAV and weather conditions [1].

In order to take into account the critical requirements for the design of catapult-type launchers, their varieties are analyzed:

– launcher with a starting engine;
– pneumatic launcher;
– with a spring mechanism;
– electromagnetic launcher.

Analysis of literature sources has shown that a catapult-type launcher with a starting engine is used to launch

UAV weighing up to 50 kg and is relatively cheap compared to other types [2].

Pneumatic launchers are used to launch light and medium UAV, the main disadvantages are their cost and overall dimensions, which creates problems during transportation [3, 4].

The use catapult launcher with a spring mechanism requires highly qualified specialists, which increases the time for personnel training [5, 6].

The electromagnetic launcher is characterized by increased complexity in design and manufacture, as well as high cost [2].

Since the launcher with a starting engine meets all the basic requirements, it was chosen for the development of a system for automated calculation of the parameters of the first stage of launching a UAV from a catapult-type installation.

The trajectory of the UAV in space is determined by the distribution of external forces acting on the flying object. To successfully launch the UAV, you need to balance the product. An object is in a state of dynamic balance when the sum of all acting forces is zero. At launch, the UAV goes through three stages of launch, each of which requires the calculation of the center of mass of the product. To calculate the center of mass of the product during the start process, you need to know such parameters as: speed, product coordinates and launch angle [7].

The launcher with a starting engine selected for research consists of a guide on which a carriage is placed, which serves to mount the UAV and the starting engine. The carriage ensures the movement of the product along the guide during the start-up process.

During launch, the UAV goes through three main stages of launch: movement along the guide, movement after leaving the guide, flight after resetting the starting engine (Fig. 1).

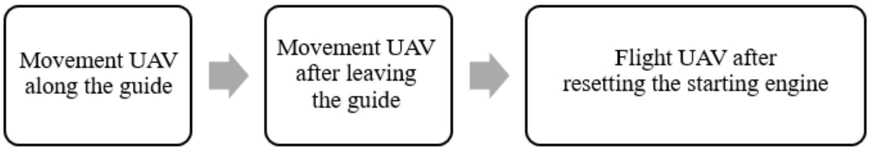

Fig. 1. Three main stages of start-up

At the first stage of launch, the movement of the UAV along the guide begins under the influence of the thrust force of the starting and propulsion engines. At the second stage of launch, after leaving the guide, the operation of the engines continues, the UAV gains height sufficient to continue the flight. At the third stage of start-up, after gaining the set height, the carriage with the starting engine is reset and movement continues under the force of the propulsion engine.

The purpose of the work is: to study the first stage of launching a UAV from a catapult-type launcher and to develop a system for automated calculation of parameters that describe the movement of the center of mass of the product at the first stage of launching a UAV from a catapult-type launcher.

Statement of the main material

After analyzing the literature, it was determined that the launcher with a starting engine has a number of advantages over other varieties and requires further research and calculation. Since the product must be balanced during the start-up process, it is necessary to analyze the distribution of external forces, as well as the location of the center of mass of the product in the start-up process.

Consider a catapult-type launcher with a guide length $l_н$, which has an angle of inclination to the ground $\alpha_н$. A UAV is placed on the rail, which is fixed to the carriage with yokes. The carriage ensures smooth and continuous movement of the product along the guide.

Figure 2 shows a schematic representation of a catapult with a UAV mounted on it, as well as the distribution of forces acting on the product, the center of mass of the equipped UAV, and the starting coordinate system. Axis y_{cm} passes through the center of mass of the product, x_{cm} placed parallel to the ground. At the point of attachment of the UAV arise frictional forces (F_1, F_2) and the forces of the normal ground reaction (N_1, N_2). The distance from the beginning of the guide to the first pair of yokes is marked $l_б$.

Let's consider the simulation of the UAV movement at the first stage of launch, when the UAV moves along the guide. As the material point of the variable mass, we take $m(t)$ [8].

The purpose of the study is to describe the movement of the UAV in the vertical plane of flight at a time using the speed parameters $V(t)$, incline angle $\alpha_н$. and coordinates$x(t)$, $y(t)$.

During the flight, the starting engine operates, which means that the mass of the product will be variable in time, which can be described by the formula:

$$m(t) = m + m_{сд} - \mu t; \quad t\epsilon[0,\tau], \tag{1}$$

where m – UAV weight (kg), $m_{сд}$ – mass of the starting engine with a charge (kg), μ – mass charge combustion rate (kg/s), τ – operating time of the starting engine (s).

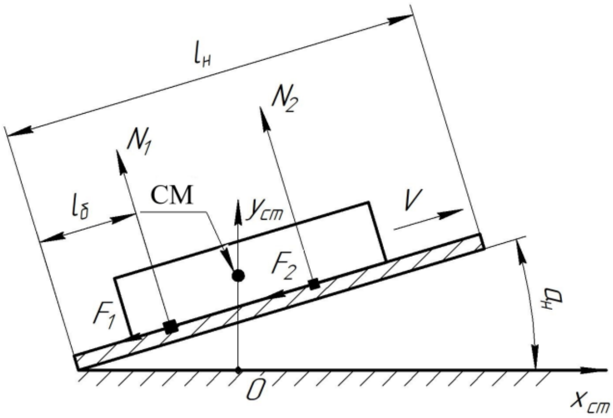

Fig. 2. Launch coordinate system of UAV launch:
CM – Center of Mass; y_{cm}– axis of the center of mass; F_1, F_2 – frictional forces (N); N_1, N_2 – normal ground response (N); V – speed (m/s); $l_н$ – guide length (m); $l_б$- the distance from the beginning of the guide to the first pair of yokes (m)

At the first stage of launch, the movement of the UAV can be described by a system of differential equations of the form:

$$\dot{V} \; = \frac{P_{мд} + P_{сд} \cos \alpha_н - F_{тр} - X(\alpha_н, M \;\; , y \;\;)}{m(t)} - g sin\alpha_н;$$
$$\dot{L} \;\; = V \;\; ;$$
$$\dot{x} \;\; = V \;\; cos\alpha_н; \quad (2)$$
$$\dot{y} \;\; = V \;\; sin\alpha_н; \;\; t\epsilon[0,\tau],$$

where $P_{мд}$– the value of the thrust force of the propulsion engine (N), $P_{сд}$– the value of the thrust force of the starting engine (N), $F_{тр} = F_{тр}(t)$ – the total value of the friction force of the yokes at the moment of time t (N), $X(\alpha_н, M \;\; , y \;\;)$ – the force of the UAV's frontal resistance at zero angle of attack, which moves at a speed of V at height y, $M \;\; = V/\alpha$ – Mach number, $L \;\; = L \;\; (t)$ – the distance traveled by the UAV along the guide at a time t (m), τ – operating time of the starting engine (s).

To calculate the total value of the friction force of the yokes, we use the formula:

$$F_{тр}(t) = k(P_{мд} + P_{сд} \sin \alpha_н - m(t) g sin\alpha_н), \quad (3)$$

where k – coefficient of friction of sliding yokes along the UAV guide.

The system of equations (2) is integrated on the time interval $[0, \tau]$ under initial conditions:

$$V(0) = 0; L(0) = 0; x(0) = 0; y(0) = y_{цм}, \quad (4)$$

where $y_{цм}$ –the height of the CM UAV at the initial placement on the guide..

Time τ (completion of the first stage of start-up) is determined from the equation:

$$L(t) = l, \quad (5)$$

where $l = l_н - l_б$ – the distance that the UAV must travel along the guide to the second stage of launch.

Based on the above formulas for modeling the second stage of launch, we determine the value of $V(t)$, and coordinates $x(t)$, $y(t)$.

To implement the calculation of the values of the mass, the total value of the friction force of the yokes, the coordinates of the location of the UAV in the process of movement and flight speed, the method of automated calculation of the parameters of the first stage of launching a UAV from a catapult-type launcher is used , the algorithm of which is shown in Fig 3.

At the first stage of the program, initial data are entered (guide length, launch angle, UAV weight, type of starting engine, mass of the starting engine with a charge, thrust force value of the main and starting engines, guide and carriage material).

At the second stage of the program, the correctness of the entered data is checked, if there is an error in the input, then the user is prompted to return to the first step.

If the data is entered correctly, are performed calculations speed $V(t)$, and coordinates $x(t)$, $y(t)$ by formulas (1), (2), (3), (4), (5) and output of results in tabular and graphical forms.

The presented system for calculating the parameters of the first stage of launching a UAV from a catapult-type launcher takes into account the main factors that have an impact on the trajectory of the UAV. An important result of the program is the calculation of the parameters that are necessary to continue the study of the second stage of start-up, namely: the speed and coordinates of the product. The use of the proposed system will lead to a decrease in the calculation error, a reduction in the time spent on the design of the UAV.

Conclusions

As a result of the research, three stages of launching unmanned aerial vehicles from a catapult-type launcher have been identified. The stages of UAV movement along the guide installation are analyzed and the distribution of external forces acting on the product is determined, as well as the main parameters necessary for calculating the center of mass of the UAV in the process of movement are determined. The main parameters that affect the movement of the UAV after leaving the guide are determined.

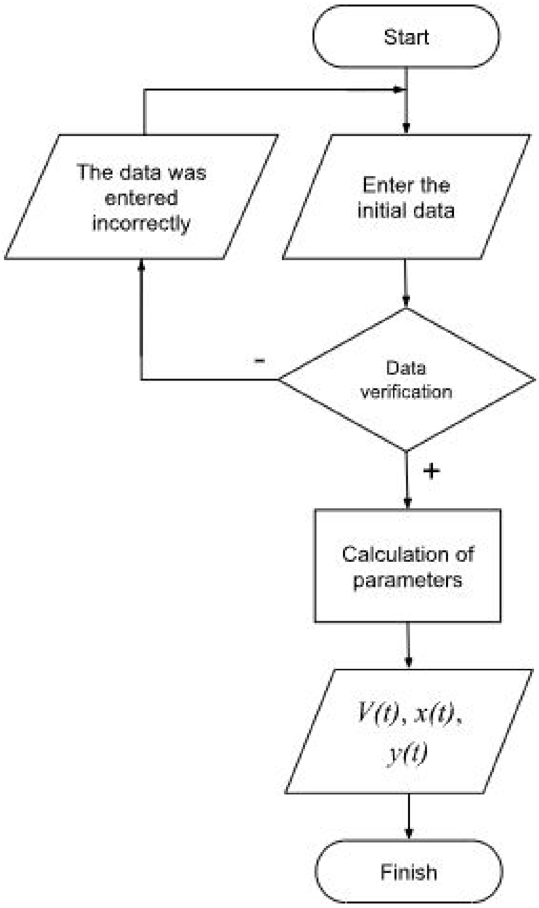

Fig. 3. Algorithm of operation of the system for automated calculation of parameters of the first stage of launching an unmanned aerial vehicle from a catapult-type launcher

Mathematical modeling of the UAV launch process at the first stage of launch has been developed. On the basis of the mathematical model, an algorithm for the operation of the system for automated calculation of the parameters of the first stage of launching a UAV from a catapult-type launcher was created.

The introduction of this system into production will lead to a decrease in the calculation error, as well as reduce the time for the development of new approaches to the launch of UAV, therefore, it is a promising topic for further research.

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