

## TRANSPORT SYSTEMS

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### THE METHOD OF TAKEOFF AND LANDING UAV WITH HELP SPRINGBOARD

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**Abstract**—*The work presents new method takeoff and landing for the unmanned aerial vehicles with help special form of springboard. The calculation of constructive parameters of unmanned aerial vehicle at their application with springboard is carried. The constructive peculiarities of such springboard are analyzed also.*

**Index Terms**—Unmanned aerial vehicle; take-off; landing; springboard; acceleration, velocity, length of fuselage.

#### I. INTRODUCTION

The development new methods for reducing of runway length are important for most modern types of unmanned aerial vehicle (UAV). As the reducing of runway length will expand the applicability of UAV and decrease the cost of carriage of goods.

All these methods can be divided on three classes: 1) for takeoff only; 2) for landing only; 3) for takeoff and landing.

Currently there are series of methods for the UAV takeoff with short runway or without it. Let us consider some of them in detail.

##### *The UAV takeoff from an airship*

In this takeoff method, the plane (or UAV) is lifted to air by help of airship with a device for fixing and detaching it [1]. Then the plane is dumped into free fall with running engines from such a height, that its speed allows to provide flight with climb at the end of fall at the safe distance from the land. Before drop the aircraft is accelerated to a speed sufficient to maintain of stable position in the fall.

The use of this method allows make takeoff of without airfield runways, reduces noise and fuel consumption. Disadvantages of method include the fact that for its implementation requires the development and operation of a special type of airships.

##### *Take off from the aircraft*

It is known and long is used takeoff of the UAV from aircraft in direction of its movement. Rather recently method of UAV takeoff from the aircraft against direction of its movement was implemented in practice [2]. The advantage of such tactic is that a significant portion of space in the rear hemisphere of aircraft will be reached faster at UAV takeoff from

the aircraft against direction of movement. Assume that the aircraft moves along the given trajectory and suddenly there is a need to deliver the specified cargo with help of UAV to a definite point in space behind of aircraft.

At takeoff of UAV from aircraft in the direction of its movement, it should make a turn with the highest possible overload and move along trajectory large length. At takeoff of UAV with aircraft against direction of its movement, path traversed is significantly shorter and time of flight-less. This method of takeoff is advisable to apply when a time to reach specified object has a decisive influence for performance of task.

In both takeoff methods its landing back on the carrier is a sophisticated task.

##### *Take off with help of pyrocharge*

There are many types of installations, which allow realizing this method. Here will consider one of them [3]. Tilt-and-takeoff installation (TTOI), includes cantilevered the steel structure with guides, which is connected with hinged pivot tower.

The essence of the TTOI is that it is provided the starter with one-time pyrocharge, which is designed to accelerate the aircraft (or UAV) along the guides with a kink. While an engine of aircraft is on also. On Fig. 1 is shown schematically the proposed TTOI. For takeoff the plane is set to the starter and the takeoff acceleration of starter with plane is made by help of double traction – with the pyrocharge and engine of plane.

With such acceleration, separation speed of the aircraft from the starter will be higher than speed necessary for takeoff with runway and takeoff will be carried at a large angle in relation to the horizon.

This installation includes a base with a rotary tower 1 (Fig. 1), console 2, which can unfold relatively tower 1 and guides. The guides include over-clocking section 3 and braking section 4. Along the guides during of takeoff, starter 5 accelerates plane by one-time pyrocharge.

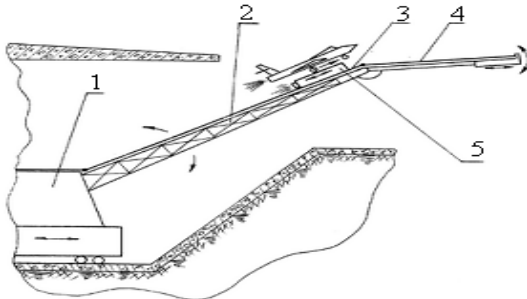


Fig. 1. Tilt-and-takeoff installation (side view)

This installation can be used at distributed disposition in shelters of separate divisions. With help of this installation it possible to make take off only, but for landing of UAV requires other installation.

Among methods, which provide the UAV takeoff and landing without runway, we'll separate one.

*Aircraft (or UAV) with vertical takeoff and landing (TOL) by help of mechanisms for deflecting the jet of engine or of whole engine [4].*

Unfortunately, series of factors, for example, high fuel consumption on vertical flight modes, the overall construction complexity and high cost of vertical TOL, destruction of coatings runways due to hot gas exhaust from engines, – severely restrict the use of UAVs with vertical takeoff and landing.

## II. PROBLEM FORMULATION

The method of takeoff and landing with springboard is used on practice [5]. At the same time the effectiveness of this method and devices, which are realized it, may be increased with help of some constructive reworks [6]. It is necessary to investigate operability of the devices that implements it. In particular, it is follows to define the relationship between constructive characteristics of UAV (the length of fuselage, the height of UAV chassis) and springboard dimensions.

## III. BASIC IDEAS OF METHOD

The main idea of proposed method is that:

- 1) change an angle of springboard inclination for various types of UAV;
- 2) change a configuration of springboard for at execution of takeoff and landing;
- 3) use the conveyor belt, both sides of which have different friction coefficients.

The proposed device of TOL based on a springboard includes overpass with easy folding propelled sections, locks, jacks and pillars.

Propelled sections are located on supports as two inclined planes; as surfaces of which are the conveyor belts. These planes are interconnected, forming a curved surface of a predetermined radius. The conveyor belts are turned upward the smooth side during UAV takeoff.

The heights of first  $H_1$  and second  $H_2$  inclined planes are set with ratio  $H_1 > H_2$  and before takeoff UAV is located on the horizontal site, which is attached to the first inclined plane.

Also, during landing of UAV the conveyor belt is turned upward by other side, with larger friction coefficient, and both inclined planes are connected in a straight line and form a hill for UAV, which lands.

Example of constructive scheme device 1 for UAV landing mode is shown in Fig. 2, where: propelled sections 2, the lock 3, supports 5, control panel 6, by command of which jacks 4 build a conveyor belt 7 in a straight line, and shafts 8 of conveyor allow to achieve a desired geometry of the springboard. In this case the conveyor belt 7 is turned side upward 9, with larger friction coefficient, to reduce the length of run of UAV 10, and horizontal site 12 is turned upward using the hinge post 11.

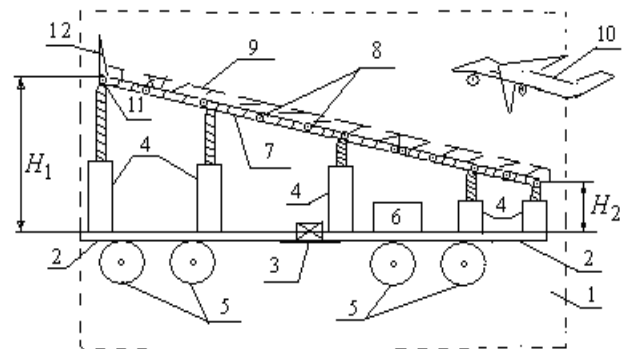


Fig. 2. Constructive scheme of device for UAV landing

Example of constructive scheme of device 1 for UAV takeoff mode is shown in Fig. 3, where: propelled sections 2, the lock 3, the supports 5, control panel 6, on command of which jacks 4 build a conveyor belt 7, as two inclined planes with shafts 8, and surfaces of conveyor belts, are turned upward the smooth side 13. Before takeoff UAV 10 is located on the horizontal site 12, which is attached to the first inclined plane and can be rotated using the hinge post 11.

It should be noted that kinematic parameters of UAV at endpoint of springboard are the initial data for calculation of trajectory of its movement after takeoff [5].

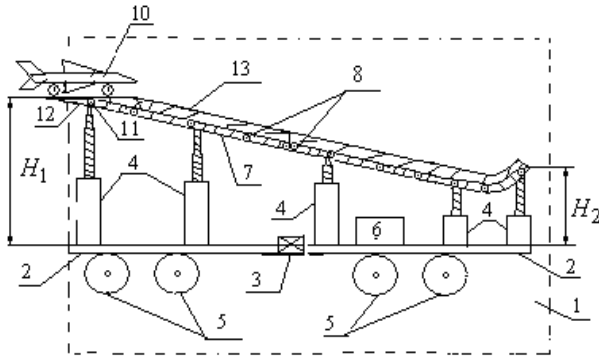


Fig. 3. Constructive scheme of device for UAV takeoff

The effect from using of springboard may be estimated on basis calculations, in which do not take into account the action of friction forces and drag forces air. On the UAV, at moving on springboard, act the force of thrust engine and constant force  $G \cdot \sin \theta_{sp}$  or  $G \cdot \sin \theta_{sp1}$ , where  $G$  is weight of UAV,  $\theta_{sp}$ ,  $\theta_{sp1}$  are angles of inclination 1-st and 2-st inclined planes of springboard (Fig. 4). In this case, at moving on 1-st inclined plane, the acceleration owing to springboard is equal  $\Delta j_{ss} = g \cdot \sin \theta_{sp}$ , where  $g$  is acceleration of free fall, or is equal minus  $g \cdot \sin \theta_{sp1}$ , at moving on 2-st inclined plane.

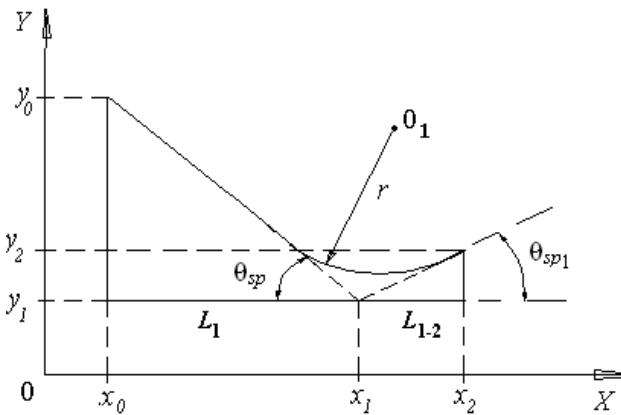


Fig. 4. Proposed scheme of springboard for UAV takeoff

The total acceleration at moving on springboard will be  $j_{x1} = j_{av} + g \cdot \sin \theta_{sp}$  on 1-st inclined plane and  $j_{x2} = j_{av} - g \cdot \sin \theta_{sp1}$  on 2-st inclined plane, where  $j_{av}$  is an acceleration of UAV due to the thrust.

So far as  $g \cdot \sin \theta_{sp}$  constant value then total motion of UAV will be uniformly accelerated and velocity in the end of 1-st inclined plane ( $V_1$ ) equals  $V_1^2 = 2j_{x1}\Delta_1y$ , where  $\Delta_1y = (y_0 - y_1) = L_1 \cdot \sin \theta_{sp}$  is height of 1-st inclined plane and velocity in the end of 2-st inclined plane ( $V_2$ ) -  $V_2^2 = V_1^2 - 2j_{x2}\Delta_2y$ , where  $\Delta_2y = (y_2 - y_1)$  is height of 2-st inclined plane.

Let at moving on 1-st inclined plane of springboard the thrust of UAV engines provides constant acceleration  $g \cdot \sin \theta_{sp}$ .

In this case takeoff velocity after passing of 1-st inclined plane ( $V_{tosp}$ ) equals

$$V_{tosp} = 2\sqrt{gL_1 \sin \theta_{sp}}$$

In Table 1 is showing the comparison of takeoff velocities values: 1) at using of springboard at angle  $\theta_{sp} = 30$  deg. ( $V_{tosp}$ ); 2) at the takeoff run with horizontal runway the same length  $L_1$  (velocity  $V_{tohr}$ ).

TABLE 1

COMPARISON OF TAKEOFF VELOCITIES VALUES AT THRUST OF ENGINES  $G \cdot \sin \theta_{sp}$

| $L_1, m$        | 10    | 15    | 20    | 30    |
|-----------------|-------|-------|-------|-------|
| $V_{tosp}, m/s$ | 14.01 | 17.16 | 19.81 | 24.26 |
| $V_{tohr}, m/s$ | 9.9   | 12.13 | 14.01 | 17.16 |

The effect from using of springboard is decreased at increasing the thrust of engines. The ratio velocities values  $k_1 = V_{tosp} / V_{tohr}$  in dependence from parameter  $n = j_{av} / \Delta j_{ss}$  is shown in Fig. 5 at the length  $L_1 = 10$  m and the angle  $\theta_{sp} = 30$  deg.

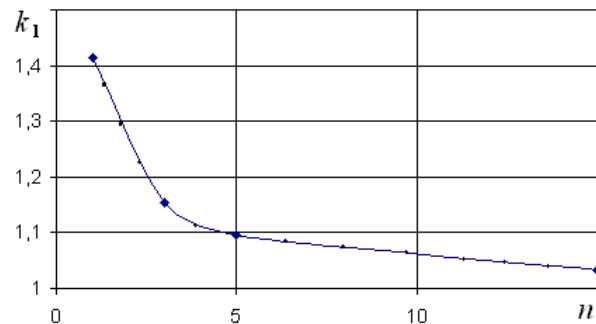


Fig. 5. The dependence of ratio velocities  $k_1$  from value  $n$

But effect from using of springboard isn't only in decreasing of takeoff distance and also in receiving more favorable conditions for continue of flight at the end of springboard with comparison to horizontal runway.

Obviously, for receiving of advantages that the springboard provides for takeoff, namely: positive angles of pitch and tilt of speed vector to the horizon, setpoint of the initial flight height  $H_1 = y_0$ , - is necessary to expend energy to raise UAV to this height.

It should be noted that transition between 1-st inclined plane and 2-st inclined plane must be smooth for avoidance of impact at motion. On Fig. 4 is shown the example of such transition with help of part cir-

cle's radius  $r$ . But, in every case, the transition part of springboard restricts length of fuselage at takeoff.

Increasing of circle radius from  $r_1$  to  $r_2$  allows increase maximum possible length of fuselage and is defined the minimum possible angle  $\theta_{sp2}$  (Fig. 6).

Constructive scheme of springboard at negative angles  $\theta_{sp2}$  may be used in case of UAV landing.

Let us suppose that the curvilinear segment of springboard presents a cylindrical surface with constant radius [5] and its height is restricted up the value owing  $H_{sp}=(y_2-y_1)$  to constructional considerations (Fig. 7). So, we can calculate

$$AO_1 = r \cdot \cos \theta_{sp2}, B1 = r, \text{ and } H_{sp} = r - r \cdot \cos \theta_{sp2}.$$

So, we can find relation between values ( $r$ ), high ( $H_{sp}$ ) and final angle of springboard ( $\theta_{sp2}$ ):

$$R = H_{sp} / (1 - \cos \theta_{sp2}). \tag{1}$$

The calculation of radius for curvilinear segment with two inclined planes may be reduced to formula (1). In this case it is necessary at system coordinates "XOY" (see Fig. 4) implement a turn of springboard

on the angle  $\arctg\left(\frac{y_1 - y_0}{x_1 - x_0}\right)$  counterclockwise.

If  $r$  –radius of circle, then the maximum possible length of fuselage is defined in dependence from values of  $L_1, L_{1-2}$  and angles  $\theta_{sp}, \theta_{sp1}$

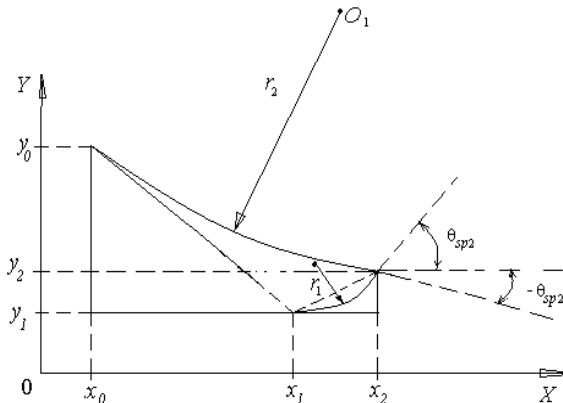


Fig. 6. The scheme of springboard with minimum possible angle  $\theta_{sp2}$

But, these four values define one integrated parameter the length of chord ( $L_{ch}$ ), which is equal distance 1-2 (Fig. 7) or the angle of sector ( $\varphi_s$ ), wherein contains this chord.

Obviously, that the angle of sector may change from  $\varphi_s = \theta_{sp1}$  (for positive values an angle  $\theta_{sp1}$ ) to

$$\varphi_s = 2 \theta_{sp1}, \tag{2}$$

as at this case, and the length of chord is calculated by equation

$$L_{ch} = 2r \sin\left(\frac{\theta_{sp2}}{2}\right) = 2r \sin(\theta_{sp1}). \tag{3}$$

So, the maximum possible length of fuselage  $L_f$  must not exceeds the value  $L_{ch}$ , if the height of UAV chasis  $H_{ch} = CD$ . At decreasing of the meaning  $H_{ch}$  the value  $L_f$  is decreased and at increasing – contrariwise. In real-life the length of fuselage  $L_f$  must be letter, than a meaning  $H_{ch}$ , in the first place, owing to its vibration at moving on springboard.

The value the hight of UAV chasis is defined from formula:

$$H_{ch} = r(1 - \sqrt{1 - \sin^2(\theta_{sp1})}) = r(1 - \cos \theta_{sp1}). \tag{4}$$

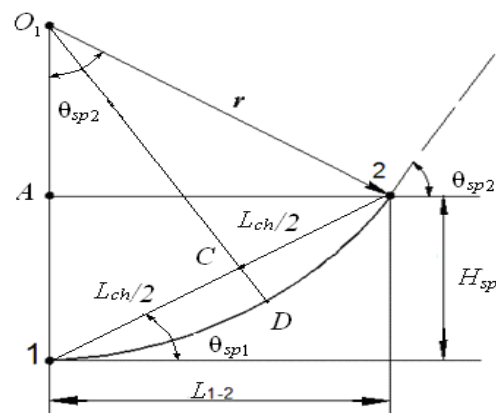


Fig. 7. The scheme of springboard with curvilinear segment

From analysis formulas (1) and (4) follows that if the angle  $\theta_{sp2} = \theta_{sp1}$ , then the value  $H_{ch}$  is equal to height of springboard.

Let estimate the springboard dimensions, if the length of fuselage  $L_f$  is equal 5 m (for example, this is the dimension of UAV "Heavenly patrol").

The dependences a value radius  $r$  and an angle  $\theta_{sp1}$  from parameter  $L_{ch}$  for various heights  $H_{sp}$  are shown in Figs 8 and 9.

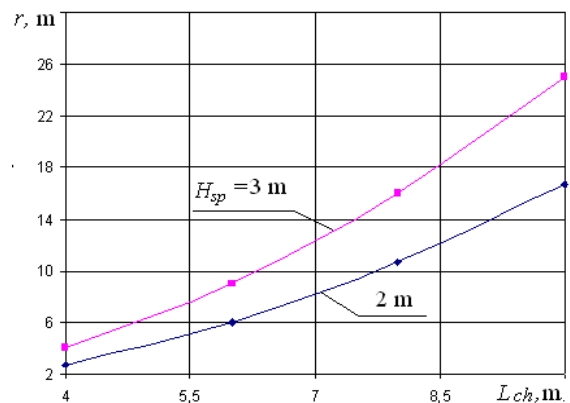


Fig. 8. The dependence a value radius  $r$  from parameter  $L_{ch}$

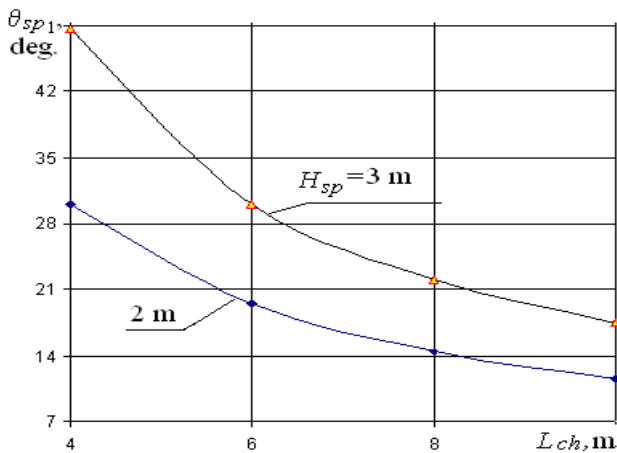


Fig. 9. The dependence an angle  $\theta_{sp1}$  from parameter  $L_{ch}$

CONCLUSION

In the article is proposed the method of takeoff and landing UAV with help springboard. The construction of springboard for assigned task is designed. The calculation of constructive parameters of UAV at their application with springboard was carried with help of formulas (1) – (4).

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**М. Ф. Тупіцин, Б. І. Дмитренко, А. А. Зіганшин, І. О. Степаненко.** Метод зльоту і посадки БПЛА за допомогою трампліну  
 Розглянуто новий метод зльоту та посадки безпілотних літальних апаратів за допомогою спеціальної форми трампліну. Виконано розрахунок конструктивних параметрів безпілотних літальних апаратів у разі застосування трампліну. Також проаналізовано конструктивні особливості такого трампліну.

**Ключові слова:** безпілотний літальний апарат; зліт; посадка; трамплін; прискорення; швидкість; довжина фюзеляжу.

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**Н. Ф. Тупіцин, Б. И. Дмитренко, А. А. Зіганшин, И. А. Степаненко. Метод взлета и посадки БПЛА при помощи трамплина**

Рассмотрен новый метод взлета и посадки беспилотных летательных аппаратов с помощью специальной формы трамплина. Выполнен расчет конструктивных параметров беспилотных летательных аппаратов в случае применения трамплина. Также проанализированы конструктивные особенности такого трамплина.

**Ключевые слова:** беспилотный летательный аппарат; взлет; посадка; трамплин; ускорение; скорость; длина фюзеляжа.

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