ISSN: 0975-766X
CODEN: IJPTFI
Available Online through ***Research Article***
www.ijptonline.com

RESEARCH OF INFLUENCE OF A POINT OF FIXING OF WINGS ON FLIGHT OF THE COMBINED JUMPING-FLYING ROBOT

S.F. Yatsun*, O. G. Loktionova, L. Yu. Vorochayeva
Southwest State University 305040, Kursk, st.50 years of October, 94.

Received on 06-08-2016 *Accepted on 10-09-2016*

Abstract:

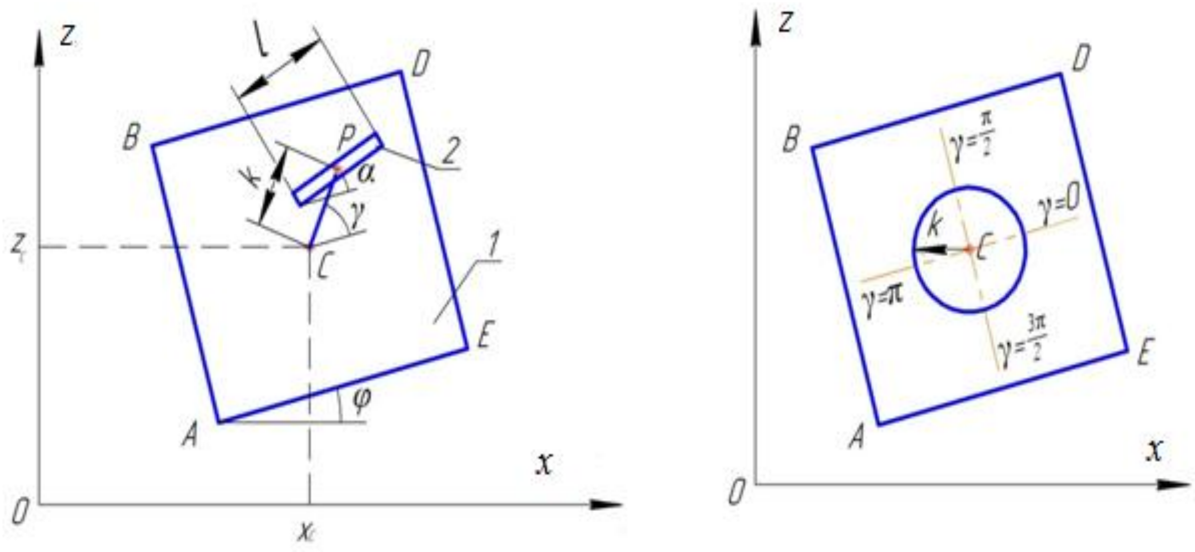
In article the movement of the combined jumping-flying robot is considered during realization of one jump which separation comes from a surface at the expense of the accelerating module which is built in the case, and increase in flying range is provided with disclosure of wings in the top point of a jump. The mathematical model of aerodynamic interaction of wings of the robot with the surrounding environment is developed, special attention is paid to definition of situation on a wing a point of application of the specified aerodynamic force. As a result of numerical modeling influence of provision of a point of fixing of wings on flying range and rotation of the case of the device is established during a jump.

Keywords: the jumping-flying robot, the combined system, passive wings, a point of fixing wing, aerodynamic forces, flight, flying range, flight altitude.

Introduction: Two categories can be distinguished from the robots equipped with wings and intended for movement by air: to one robots with the waving wings, and the other - with passive wings. Robots with the waving wings are a flying robots which motion with a separation from the surface occurs due to waves of the wings providing different values of aerodynamic forces at the movement of wings up (forces of resistance of air are small) and down (forces of resistance are big) that allows devices to fly up, land, hang at one height, etc. Robots with passive wings as a rule represent the combined systems for which accelerating modules as the built-in a design [1,2], and stationary, representing catapults [3,4] are necessary for a separation from a surface, and for increase in flying range and smoother landing at a surface - the passive wings which aren't making any relative movements. Article is devoted to a research of the movement of the combined robot which separation (jump) comes from a surface at the expense of the built-in accelerating module, and passive wings reveal in the highest point of a jump and provide flight of the device on bigger distance.

Description of the robot

We will consider the jumping robot which during a separation from a surface after achievement of the highest point of a jump hovering to a landing due to opening of wings. We will investigate the movement of an object in the vertical O*xz* plane, the jump of the device occurs along an axis O*x* from a surface which this axis belongs (fig. 1).



a b

Fig. 1a - a general view of the robot with a fixed wing, b - the provision of a point of fixing of a wing in the case, 1 - the case, 2 - a wing.

The robot consists of the case, the accelerating module and wings. The device and the principle of operation of the accelerating module are in details described in works [5-7] therefore in this article we won't consider it. The case in the O_{xz} plane has ABDE rectangle form, the center of masses and which center of symmetry coincide and are in the C point.

Position of the case in the vertical plane is defined by three generalized coordinates: projections of x_C, z_C of the center of masses to coordinate axes and an angle of rotation φ counterclockwise concerning an axis O_x. The wing represents a plate length of *l* and width of *b* which thickness is close to zero h→0, at this stage we will consider that the mass of a wing is small in comparison with the mass of the case and accelerating module therefore we won't consider her.

In the plane of a jump we will present a wing in the form of the core fixed in the case in a point *P*, and this point is the center of symmetry of a core.

The point *P* is removed from the center of mass of the case on *k* distance, and the straight line connecting points of *C* and *P* is located at an angle *γ* concerning the party of the *AE* case. The wing is inclined concerning the same party of the case on a corner *α*. Both corners are counted counterclockwise from the party of *AE*.

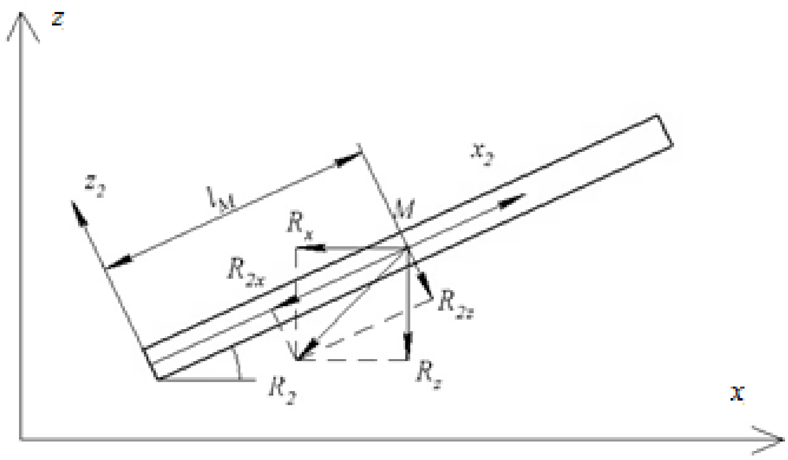
Thus, the point *P* lies on a circle the radius of *k* constructed of the center of mass of the case and at γ=0, γ=π points of *C* and *P* lie on one direct, parallel party of *AE*, and at γ=π/2, γ=3π/2 - on one direct, perpendicular party of *AE*. The point P holds the highest position in the case at γ=π/2, and the lowest - at γ=3π/2.

The purpose of this work is studying of influence on the movement of the robot in flight of an arrangement of a point *P* fixing of a wing in the case - distances of *k* and a corner γ.

Mathematical model of aerodynamic resistance

The mathematical model of movement of the jumping-flying robot during one jump from the moment of its positioning on a surface to a landing is in detail described in works [8-10] therefore we won't provide system of the differential equations describing behavior of an object in this article. Because planning of the robot in case of open wings is caused by action on them aerodynamic forces, we will stop in more detail on model of their interaction with the environment.

During the flight, force of aerodynamic resistance unevenly affect all points of a wing, for simplification of model we will consider that the aerodynamic loading distributed on a wing can be given to one force of *R* applied in some point of a wing of *M* which provision during flight changes. In fig. 2 the scheme of the application of aerodynamic forces to a wing is shown.



The fig. 2. Scheme of the Application of Aerodynamic Forces, acting on a wing.

For convenience of modeling we will consider R force in two systems of coordinates: absolute – Oxz and connected with a wing - O2x2z2. Then force of R can be presented in the form of two projections of Rx, axis Rz on axis Ox and Oz, and also in the form of projections of Rx2, Rz2 to axes O2x2 and O2z2

$$\overline{R} = \overline{R}_x + \overline{R}_z = \overline{R}_{x2} + \overline{R}_{z2} \qquad (1)$$

Because thickness of a wing is close to zero h→0, we will consider that Rx2=0, then $\overline{R} = \overline{R}_{z2}$. We will determine the M point provision on a wing as the center of mass of the figure which is the distribution law of aerodynamic force on a wing:

$$R_{z2} = \frac{C_R \rho S_2}{2}(\dot{z}_{M2})^2 = Al^2{}_M + Bl_M + C \qquad (2)$$

where the distance l_M is equal

$$l_M = \frac{(3Al^2 + 4Bl \ + 6C)l}{4Al^2 + 6Bl \ + 12C}, \qquad (3)$$

and coefficients A, B and C are defined as follows:

$$A = \frac{C_R \rho S_2}{2} \cdot \dot{\varphi}^2, \qquad (4)$$

$$B = \frac{C_R \rho S_2}{2} \cdot (2\dot{z}_C \dot{\varphi} \cos(\alpha + \varphi) - 2\dot{x}_C \dot{\varphi} \sin(\alpha + \varphi) + 2\dot{\varphi}^2 (k\cos(\gamma - \alpha) - l/2)) \qquad (5)$$

$$C = \frac{C_R \rho S_2}{2} \cdot [\dot{x}_C^2 \sin^2 \varphi - 2\dot{z}_C \dot{x}_C \sin(\alpha + \varphi)\cos(\alpha + \varphi) + \dot{z}_C^2 \cos^2(\alpha + \varphi) +$$
$$+ \dot{\varphi}(2k\cos(\gamma - \alpha) - l)(\dot{z}_C \cos(\alpha + \varphi) - \dot{x}_C \sin(\alpha + \varphi)) + \dot{\varphi}^2 (k\cos(\gamma - \alpha) - l/2)^2] \qquad (6)$$

The projection of the speed $\dot{z}_{M2}$ of point M on the axis O2z2 written as follows:

$$\dot{z}_{M2} = -\dot{x}_C \sin(\alpha + \varphi) + \dot{z}_C \cos(\alpha + \varphi) + \dot{\varphi} k \cos(\gamma - \alpha) - \dot{\varphi}(l/2 - l_M). \qquad (7)$$

Projections of aerodynamic force to axes of absolute system of coordinates are calculated on formulas:

$$R_x = \frac{C_R \rho S_2}{2} \cdot \dot{z}_{M2} |\dot{z}_{M2}| \cos(\alpha + \varphi), \qquad (8)$$

$$R_z = \frac{C_R \rho S_2}{2} \cdot \dot{z}_{M2} |\dot{z}_{M2}| \sin(\alpha + \varphi), \qquad (9)$$

where ρ - the mass density of air, C_R - dimensionless coefficient of aerodynamic force, S_2- the area of wing along an axis O_{2x2}.

Because disclosure of wings of the robot occurs in the highest point of a jump, aerodynamic forces are defined from conditions:

$$R_x = \begin{cases} R_x, \text{ если } \dot{z}_C < 0 \\ 0, \text{ если } \dot{z}_C \geq 0 \end{cases}, \qquad (10)$$

$$R_z = \begin{cases} R_z, \text{ если } \dot{z}_C < 0 \\ 0, \text{ если } \dot{z}_C \geq 0 \end{cases}. \qquad (11)$$

The system of the differential equations describing the movement of the robot has an appearance

$$B\ddot{q} + K\dot{q}^2 = F, \qquad (12)$$

where q - a vector of the generalized coordinates, B, K - matrixes of coefficients, F-a matrix of the generalized forces.

$$q = \begin{pmatrix} x_C \\ z_C \\ \varphi \end{pmatrix}, \quad B = \begin{pmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{pmatrix}, \quad K = \begin{pmatrix} K_{11} & K_{12} & K_{13} \\ K_{21} & K_{22} & K_{23} \\ K_{31} & K_{32} & K_{33} \end{pmatrix}, \quad F = \begin{pmatrix} F_{11} \\ F_{21} \\ F_{31} \end{pmatrix} \qquad (13)$$

Simulation of flight of the robot

The results of simulation of flight of the combined jumping-flying robot received by the numerical method are given in fig. 3-5. Within the research the provision of a point P fixing of a wing in the casing changed in case of an angle variation γ from 0 to 2π with a variable step $\Delta\gamma=\pi/12$, $\Delta\gamma=\pi/6$ in case of invariable value of radius of k.

In fig. 3 paths of movement of center of mass of casing in case of layout of a point are shown P in different quadrants (and - the I quadrant, - the II quadrant, in - the III quadrant, one or IV a quadrant).

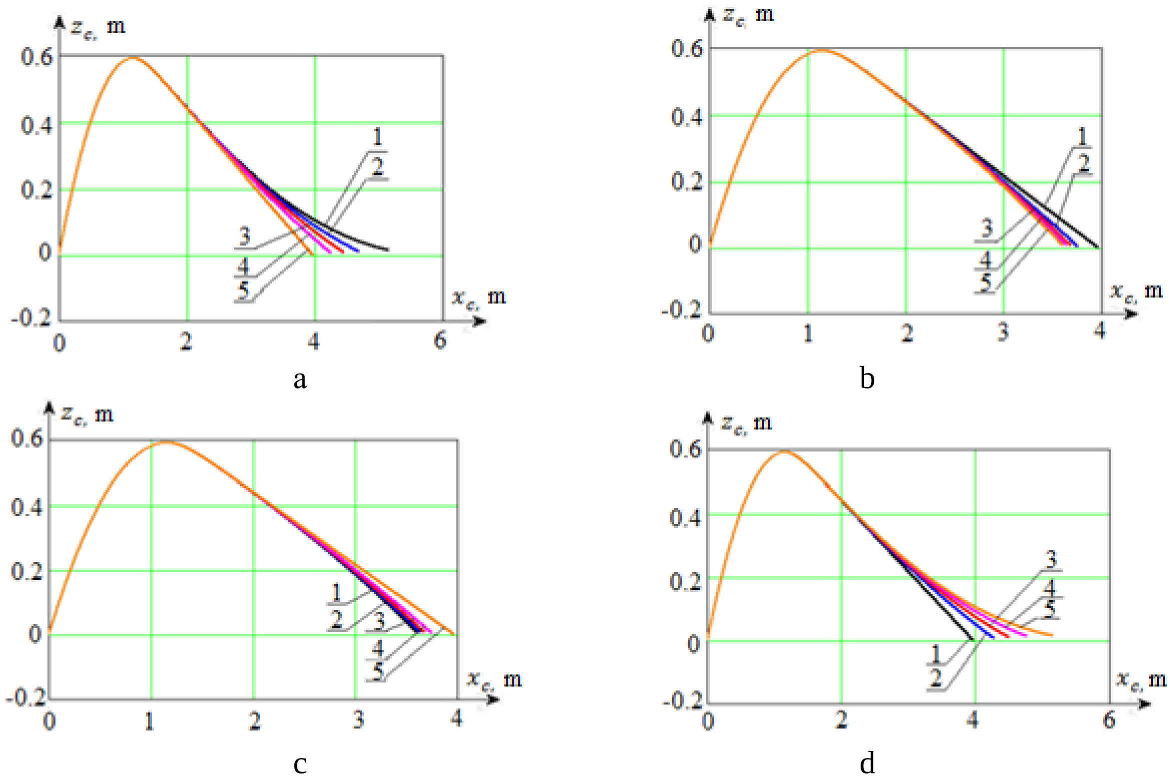
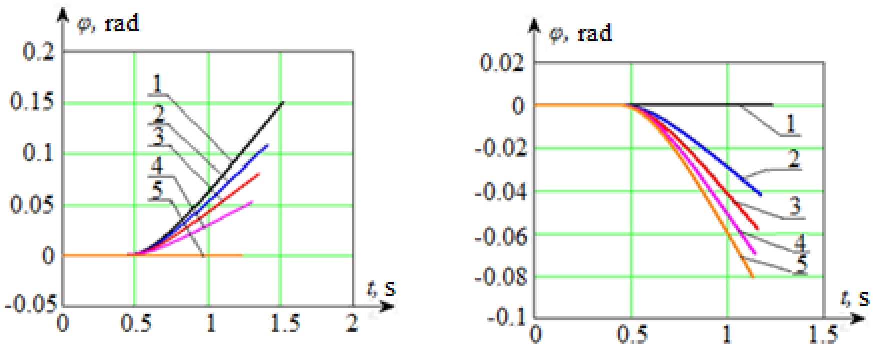


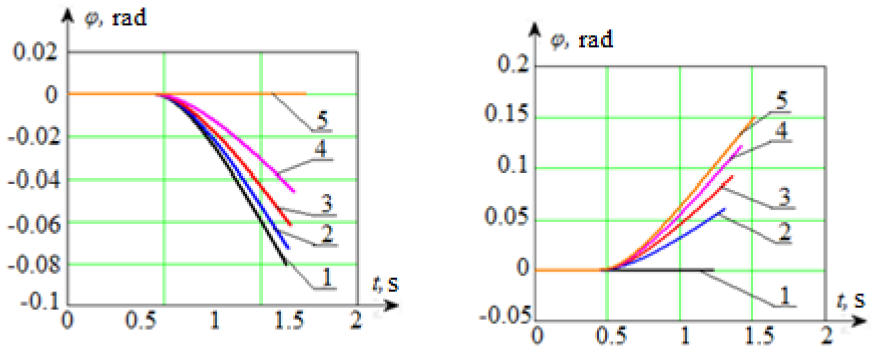
Fig. 3. Schedules of trajectories $z_C(x_C)$:
a - 1 – $\gamma = 0$, 2 – $\gamma = 30^0$, 3 – $\gamma = 45^0$, 4 – $\gamma = 60^0$, 5 – $\gamma = 90^0$,
b -1 – $\gamma = 90^0$, 2 – $\gamma = 120^0$, 3 – $\gamma = 135^0$, 4 – $\gamma = 150^0$, 5 – $\gamma = 180^0$

c - 1 – $\gamma = 180^0$, 2 – $\gamma = 210^0$, 3 – $\gamma = 225^0$, 4 – $\gamma = 240^0$, 5 – $\gamma = 270^0$
d - 1 – $\gamma = 270^0$, 2 – $\gamma = 300^0$, 3 – $\gamma = 315^0$, 4 – $\gamma = 330^0$, 5 – $\gamma = 360^0$

According to the constructed schedules it is visible that in cases when the point *P* is in the first and fourth quadrants, trajectories after passing of the highest point of a jump have an appearance of the smooth curves located bulges down and the greatest distinctions between them are observed at approach to a surface. At an arrangement of points of *C* and *P* on one horizontal relatively the parties of *AE* of the case of a straight line *(γ=0, 2π)* a trajectory curve the most flat, flying range the greatest. In case points of *C* and *P* lie on one vertical relatively the parties of *AE* of the case of a straight line *(γ=π/2, 3π/2),* the flat site of a trajectory is practically absent, and flying range the smallest of received in these quadrants. If the point *P* is located in II and III quadrants, sites of trajectories after opening of wings represent inclined straight lines which tilt angle increases, and flying range decreases at change of a corner *γ* from *π/2* and *3π/2* to *π.* Also according to schedules it is visible that range flights of z_{max} of the robot the greatest at *γ=0 (2π),* and the smallest at *γ=π* (fig. 5, a), and flight altitude of z_{max} is identical irrespective of value *γ* (fig. 5, b). We will note that the type of trajectories of the movement of the center of masses and value of flying range are identical concerning an axis of the symmetry formed by diameter of a circle 2*k* at *γ*=0. Fig. 4 illustrates change of an angle of rotation of the case during flight also at an arrangement of a point *P* in each of four quadrants. According to schedules it is visible that in cases when *γ=π/2, 3π/2*, rotation of the case during flight doesn't happen, *φ*=0. In all other cases the case at a lead of the robot from a surface turns, and when finding a point *P* in Ii IV quadrants rotation happens counterclockwise and if the point *P* is in II and III quadrants, then the case turns clockwise. In addition it is possible to draw a conclusion on what before achievement by the robot of the highest point of a jump of rotation of the case in flight doesn't occur, so disclosure of wings leads to emergence of a rotary component of the movement. This results from the fact that at the opened wings there are forces of aerodynamic resistance which line of action don't pass through the center of mass of the case (except for cases when *γ=π/2, 3π/2*), thereby generating the moment due to which action the case in flight turns.



a b



c d

Fig. 4. Schedule of dependence of an angle of rotation $\varphi(t)$:

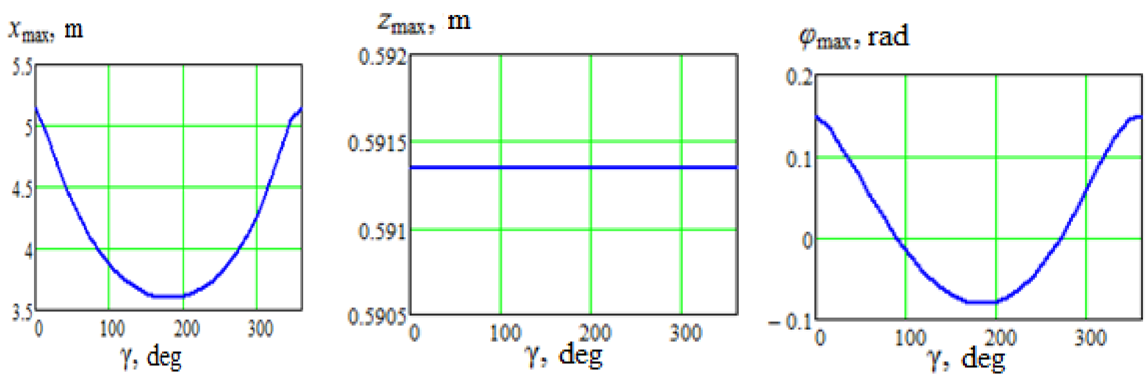
a - 1 – $\gamma = 0$, 2 – $\gamma = 30^0$, 3 – $\gamma = 45^0$, 4 – $\gamma = 60^0$, 5 – $\gamma = 90^0$,

b -1 – $\gamma = 90^0$, 2 – $\gamma = 120^0$, 3 – $\gamma = 135^0$, 4 – $\gamma = 150^0$, 5 – $\gamma = 180^0$

c - 1 – $\gamma = 180^0$, 2 – $\gamma = 210^0$, 3 – $\gamma = 225^0$, 4 – $\gamma = 240^0$, 5 – $\gamma = 270^0$

d - 1 – $\gamma = 270^0$, 2 – $\gamma = 300^0$, 3 – $\gamma = 315^0$, 4 – $\gamma = 330^0$, 5 – $\gamma = 360^0$

We will note that the module | φ_{max} | the greatest value of an angle of rotation of the case of the robot increases in process of removal of a corner γ from $\pi/2$, $3\pi/2$, and these values are symmetric concerning the same axis, as a trajectory of the center of mass of the case (fig. 5, c). Case angles of rotation on and counterclockwise aren't identical (counterclockwise almost twice more), it is caused by the fact that the center of mass of all system is displaced concerning a point *C* at the expense of the accelerating module located in the case to the left.



a b c

Fig. 5 of Graphics of dependences on a corner γ: and - flying range of $x_{max}(\gamma)$, flight altitude of $z_{max}(\gamma)$ and the greatest corner $\varphi_{max}(\gamma)$ turn of the case during flight

Conclusion

In work the combined jumping-flying robot which for a separation from a surface is equipped with the built-in accelerating module is investigated, and for increase in flying range the wings opening in the top point of a jump are passively fixed in his case. The research of influence of an arrangement of a point of fixing of wings in the case on flying range and rotation of the device before achievement of a surface is conducted. The provision of this point was set by some radius which is carried out from the center of mass of the case and a tilt angle of the straight line connecting two earlier specified points. The mathematical model of aerodynamic interaction of wings of the device with air during the flight has been developed for this purpose, and also the model describing behavior of the robot during a jump.

As a result of the carried-out numerical modeling it is established that the greatest flying range is observed at an arrangement of a point of fixing of wings on one horizontal straight line concerning the party of *AE* of the case with the center of masses of the last, during her maximum removal to the right, and minimum - at an arrangement of this point on the same straight line only during her maximum removal to the left. Schedules of trajectories of the movement of the center of mass of the case and the angles of his turn in flight are symmetric to rather earlier specified straight line. Rotation of the case in flight is absent in case the point of fixing of wings and the center of mass of the case lie on one vertical relatively the parties of *AE* of the last of a straight line.

Thanks

The research is executed with financial support of the Russian Federal Property Fund within the scientific project No. 14-08-00581 and, RNF within the scientific project No. 14-39-00008.

References

1. Kovac, M. A miniature jumping robot with self-recovery capabilities / M. Kovac, M. Schlegel, J. Zufferey, D. Floreano, D // Proc. of the IEEE/RSJ International conference on robotics and automation. – Kobe, Japan, 2009. - P. 583–588.
2. Hutter, M. Planar Hopping with a Robotic Leg / M. Hutter, D. Remy, R Siegwart. – Eidgenössische Technische Hochschule Zurich, 2011. – 92 p.
3. Sapognikov S.B. Compact dispersal at the stand for ballistic tests/ S.B. Sapognikov, O.A. Kudriavtsev // Series «Engineering», 2012, № 20, P. 139-143.
4. Zelentsov V.V. Multi-purpose ballistic laboratory: Results and prospects of development / V.V. Zelentsov, A.S. Karneychik, V.S. Vladimirov // Journal of Engineering Science and Innovation, 2013, N. 3. URL: http://engjournal.ru/catalog/machin/ rocket/626.html.
5. Yatsun, S. F. Results of pilot study of characteristics of a jump of the accelerating module of the robot moving with a separation from surface /S. F. Yatsun, O. G. Loktionova, L. Yu. Volkova, A. V. Vorochayev //Reference book. The engineering magazine with the application. 2014. - № S4. - Page 7-12.

6. Yatsun, Page F. Management of height and length of a jump of the robot by his positioning and dispersal / S. F. Yatsun, L. Yu. Volkova// Southwest State University News. Equipment series and technologies. 2012. - № 2. P.1 Page 210-213.
7. Jatsun S. Robotic System Equipped with Catapult / S. Jatsun, O. Loktionova, L. Vorochaeva, A. Vorochaev // Advances in Intelligent Systems and Computing Proceedings of the 24th International Conference on Robotics in Alpe-Adria-Danube Region (RAAD). 2015. P. 173-181.
8. Jatsun, S. Modeling of movement of the planning robot / S. Jatsun, L. Vorochaeva, A. Vorochaev // Advances in Robotics, Mechatronics and Circuits: proceedings of the 18th International Conference on Circuits (CSCC'14) and proceedings of the 2014 International Conference on Mechatronics and Robotics, Structural Analysis (MEROSTA 2014), Santorini Island, Greece, 2014, P. 34-39.
9. Jatsun S.F. Modeling of Jumping Robot Equipped with Wings / S.F. Jatsun, O.G. Loktionova, L.Yu. Vorochaeva, A.V. Vorochaev // 2014 International Conference on Mechanical Engineering, Autornation and Control Systerns, 2014. P. 1-7.
10. Jatsun S.F. Investigation of the influence of the wings and tail in flight of the jumping robot / S.F. Jatsun, O.G. Loktionova, L.Yu. Vorochaeva, A.V. Vorochaev // Applied Mechanics and Materials Vols. 789-790 (2015) pp 621-625.