УДК 682.964 DOI: 10.54858/dndia.2022-18-1

O.V. Kharchenko, L.M. Artushin, O.A. Kononov

State Research Institute of Aviation, Kyiv

PROSPECTS FOR THE JOINT USE OF UNMANNED AERIAL VEHICLES

In the article, the development of methods of combat use of unmanned aerial vehicles (UAVs) from the point of view of cause and effect processes in the system "UAVs - means of enemy air defense - purposes of combat mission" is considered by the authors. The main factors of development and changes in the methods of combat use of UAVs are analyzed. The basic patterns and connections of the process of development of methods of joint use of UAVs, the area of conditions for the expedient use of groups of UAVs are highlighted. The scientific problem of the stochastic synthesis of the automated control system for the group application of UAVs, as one of the problems of modern control theory and technical cybernetics, is substantiated and formalized. The question of the possibility of reducing the task of stochastic synthesis of the automated control system for the group application of UAVs to the set of control optimization tasks in linear (linearized) systems according to quadratic criteria is considered.

Keywords: *unmanned aerial vehicles, joint use of unmanned aerial vehicles, group use of unmanned aerial vehicles, probability of fulfilling the combat mission, means of enemy air defense, control.*

.

Introduction

Description of the issue. The ability to perform a wide range of combat missions in the depths of enemy territory, which well protected by air defense systems, without the threat of losing one's own flight personnel, is the main advantage of the military use of UAVs. Their combined use is a means of increasing the likelihood of successful completion of assigned tasks.

This possibility is described by the probability of a stream of independent (unrelated) events: let p - this is the probability of an event that one UAV will be hit by air defense means, then the probability of an event that all n UAVs will be destroyed together will be p^n and P - the probability of an event that at least one UAV will be able to complete the mission will be (when abstracting from taking into account the influence of other factors):

$$P = 1 - p^n. \quad (1)$$

For $p < 1$ and $n \to \infty$ the condition $P >> p^n$ will always be satisfied. That theoretically makes it possible to achieve the required predetermined probability of performing combat missions under counteractions by increasing the number of jointly operating UAVs (Fig. 1).

The dependence $P(p,n)$ shows that $n \geq \log_p\left(1 - P^*\right)$ unmanned aerial vehicles are required to achieve a given probability of completing the assigned task P^* under counteraction conditions p.

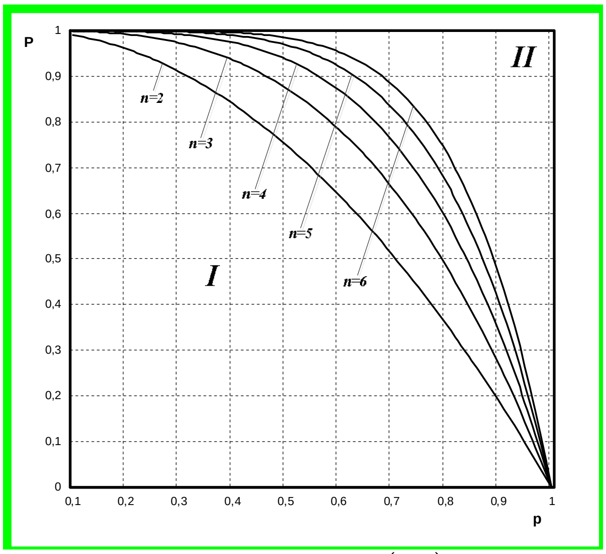

Fig. 1. Dependence $P(p,n)$.

Source: [12].

This confirms the significant potential for the joint use of UAVs, when it is possible to ensure practically guaranteed fulfillment of the assigned combat missions in the face of severe enemy opposition $(p > 0{,}7)$ without losing one's flight crew due to a relatively small increasing in the number of active vehicles.

The ability to carry out with a high probability of successful remote selective strikes against enemy targets protected by air defense makes it possible to consider the joint use of UAVs as a promising type of high-precision weapon.

The level of the modern technological base fundamentally makes it possible to implement the idea of joint combat use of a large number of UAVs. There are all the necessary technical capabilities for its effective implementation: unmanned platforms, means of communication, transmission, receipt and processing of information.

Despite this, the authors have no information about the adoption of UAV joint use complexes. So far, developments in this direction are at the level of experimental research projects (for example, the GREMLINS project [1]) and attempts to jointly use several single-controlled UAVs.

There is an obvious discrepancy between the potential benefits of the joint use of UAVs, the possibilities of modern technologies and the practical results achieved in this direction.

A clear understanding of the reasons for this discrepancy is an important competitive advantage, the methodological basis for the rational allocation of resources in truly promising and important areas in the field of unmanned aircraft.

Analysis of recent research and publications. The study of publications on the joint use of UAVs shows that the vast majority of research is devoted to how to implement joint applications of UAVs (a fairly complete English-language bibliography is given in [2…4], a Russian-language one in [5…7], the last significant publications in this direction are presented in the references of the article [8]).

Consideration of the reasons why the potential for the joint use of UAVs is currently not actually used, as a rule, is not in the circle of interests of the authors and is practically absent.

The purpose of the article. Therefore, the goal of the authors of the article was to eliminate this gap and present the results of their own research on the prospects for the implementation of the joint use of UAVs, focusing on basic cause-and-effect relationships, basic patterns and still unsolved problems.

Presentation of the main material

Let us consider the development of methods for using UAVs within the framework of the system "UAVs - air defense systems - purpose of use" and the coordinates: P - the achieved probability of completing the assigned mission; S - the expended resources (Fig. 2).

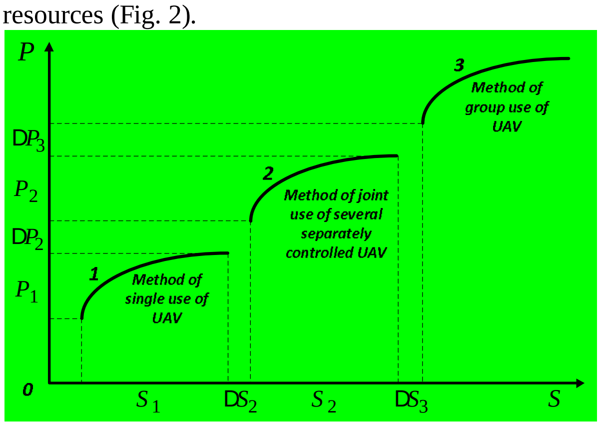

Fig. 2. Scheme of the development of UAV application methods.
Developed by the authors.

The scheme shown in Figure 2 is rather conditional, but it accurately reflects the main connections and patterns of development of UAV application methods.

Historically, the first and easiest way to use UAVs is a single use.

The advantage of a single use of UAVs is that it becomes possible with a high probability to complete the assigned tasks in the face of enemy opposition with relatively low resource costs.

At the same time, the success of the combat mission is determined both by the functionality of the UAV, the composition of the equipment, the flight performance, the skill of remote control, and the capabilities of the enemy's air defense systems, the level of their use.

In the case of a single use, the probability of completing the assigned task P is determined by the probability of hitting the UAV by enemy air defense systems and cannot be more than $(1-p)$, that is: $P \le 1-p$.

Improving the design of vehicles, on-board and ground equipment, and tactics of use make it possible to increase in the probability of performing combat missions P_1 at the expense of resource costs S_1 (Fig. 2).

The possibilities of this method of application have not yet been fully exhausted. New technologies make it possible to create more efficient devices for solving assigned tasks, but this method of application has a fundamental limitation - the probability of completing the set combat mission in it is provided only by one specific UAV and therefore limited.

The presence of a fundamental limitation is an incentive for the development of a more complex method of application - the joint use of several separately controlled UAVs.

To implement this method of application, additional resources ΔS_2 are required, but it becomes possible to increase the probability of performing combat missions when countering enemy air defenses ΔP_2 (Fig. 2).

In contrast to a single use, in this case, the probability will be determined not only by the capabilities of the UAV, but also by their number in accordance with relation (1). This determines the main feature of this method of application: the loss of one (or several) UAVs does not mean the failure of the task, as in the case of a single application.

Improvement of the constructive and technological level of the UAV, control and tactics of use will allow for this method to provide an increase in the probability of fulfilling the assigned tasks by an amount P_2 due to the necessary resource costs S_2 (Fig. 2).

The ability to use several UAVs together makes it possible to specialize the devices in certain functions (communications, electronic countermeasures, reconnaissance, strike functions), use devices - "false targets”, and significantly expand tactical methods of use.

It is worth noting that in this method of application, counteracting enemy air defense systems is not a priority, the main effect is expected to be obtained from an increase in the number of jointly used devices.

In turn, the further development of countermeasures (such as anti-aircraft shells with a programmable detonation time [9], powerful microwave means of destroying UAVs in flight [10]) will limit the effectiveness of the joint use of several separately controlled UAVs.

In addition, the individual control of each device by the operator complicates the coordination of their interaction in terms of achieving the goal. The psycho-physiological capabilities of the operators do not allow them to control their vehicles, taking into account all the processes of the dynamics of the functioning of other vehicles and the ground situation. Increasing the number of devices used simultaneously will quickly translate this effect into a significant problem.

The potential of the method of joint use of several separately controlled UAVs has not yet been fully exploited. But the intensive improvement of countermeasures determines the need to move to the next most difficult implementation method of use - the group use of UAVs.

The main difference between the group use is that the functioning of all devices of the group is clearly coordinated with each other for the best performance of the mission.

The group use of UAVs is the most common method of application. A group can be made up of devices different in terms of flight performance, functional purpose. They can move along their own trajectories, they can form a battle formation (when the movement of “slave” devices is determined by specified intervals, excesses and distances relative to “leading vehicles”) or several battle formations. In many cases, the term “swarm of UAV” is understood precisely as the method of their group use.

In addition, the general battle formations described in [11] (“спільні бойові порядки”) also refer to the group use of UAVs. So, this once again confirms that the method of group use is quite general.

A feature of the group use of UAVs is that for the operator the entire group is a single object of control, and the direct control of the movement and coordination of the functioning of the vehicles with respect to the common purpose of the application is carried out by automation. For generating control signals automation must take into account the current phase state of the devices, all information about the ground situation, flight performance and functional specialization of each device of the group.

Such an organization of application has qualitatively difference from previous methods. They has the control was carried out directly by the operators, and the functions of automatic systems were limited only to the stabilization of the specified flight modes.

The high level of perfection of the control system in this method of application implies additional expenditure of resources ΔS_3 for the implementation of the UAV group application complex. It is expected that this will help to obtain a qualitative increase in the probability of completing the assigned missions ΔP_3 (Fig. 2).

The group control system must perform three main functions:

to translate operator commands for the group into instructions for the operation of each individual device;

to form the control of each device as a function of all available information (the current phase state of all devices, previous states, ground and air conditions, a priori information, enemy actions, and so on);

to transmit all information coming from the vehicles to the ground control station for the operator to make appropriate decisions.

This will allow the group to:

promptly redistribute the functions of the lost devices among the remaining ones to effectively complete the mission;

effectively counter enemy air defense systems, implement “smart” countermeasures, promptly reveal “weak points” and shortcomings of the air defense organization and use them.

In this method of application, as well as in the joint use of several separately controlled UAVs, the loss of one (even several) vehicles is not the reason for the failure of the mission. However, in case of group application, the increase in the probability of fulfilling the assigned tasks will be ensured not by increasing the number of jointly operating vehicles, but due to the possibility of interaction between different UAVs, a clear coordination of their functioning, and the possibility of effective counteraction to enemy air defense systems.

It becomes possible to fully reveal the potential of using specialized devices in group application. The interaction of UAVs with different functional orientations in a single information field makes it possible the best use of their technical capabilities.

All this makes it possible to obtain the effect from the use of a group more than the effect from the separate use of the same number of devices, that is, the dependence $P(p,n)$ for the group use of UAVs can be represented as

$$P = 1 - p^n + \Delta P , \tag{2}$$

where ΔP – an increase in probability due to the coordinated “group” actions of the vehicles used.

The graphical interpretation of this dependence in coordinates $P(p)$ is that the probability of completing the assigned task for group application should be higher than the probability for other methods of application. So, it has been in the area II (Fig. 1.) for a wide range of application conditions.

It is worth noting that the condition

$$P > 1 - p^n \qquad (3)$$

can be considered as a sufficient condition for the effectiveness of the group use of UAVs, along with the necessary condition given in [12, 13].

An important advantage of such a formulation of the sufficient condition for the effective use of UAV groups is its generality, taking into account only basic fundamental information and energy patterns and abstraction from specific design and technical features, concepts for implementing UAV group application.

Consideration of the method of group use of UAVs within the framework of the development process of the system “UAV - air defense systems - purpose of use” allows us to determine the area of conditions for its expedient use (Fig. 3).

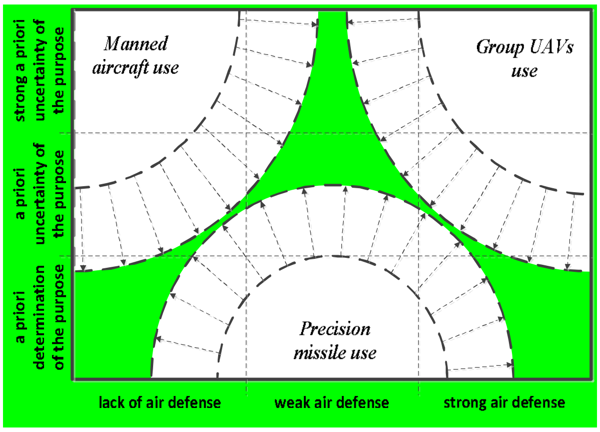

Fig. 3. Scheme of areas of application conditions for UAV groups.
Developed by the authors.

It is advisable to use manned aircraft to perform combat missions under conditions of significant a priori uncertainty, and it is inappropriate use in the face of enemy air defense countermeasures.

It is expedient to use high-precision missile weapons in conditions of complete a priori certainty of the target and inexpedient in conditions of strong a priori uncertainty.

In contrast to them, the group use of UAVs makes it possible to perform combat missions both in the face of opposition from powerful enemy air defenses and in conditions of uncertainty.

Due to the quantitative composition of the UAV group, it can overcome the enemy’s air defense zone, and the possibility of prompt transmission of information from the group’s vehicles to the ground control point fundamentally allows its use in conditions of a priori uncertainty. Not only protected, but also camouflaged, mobile, point objects can be considered as targets.

Therefore, it is advisable to consider the group use of UAVs for conditions of a priori uncertainty of the target and strong opposition from enemy air defense systems (Fig. 3).

Such a distribution of areas of expedient conditions of use shows that the group use of UAVs does not duplicate other types of weapons. Therefore, it can be considered as a new type of high-precision remote-action weapons.

Analysis of the process of development of the system “UAV - air defense systems - purpose of use” allows us to draw the following conclusions:

the ability to perform the assigned missions in the framework of simpler methods of application determines the absence of an urgent need for the implementation of the group use of UAVs;

intensive improvement of air defense systems, the consistent expansion of their capabilities to counter UAVs determine the inevitability of the implementation of group use of UAVs.

In addition to the influence of systemic factors on the development of the method of group use of UAVs, there are also scientific and technical problems, without the solution of which it is impossible to use its potential.

The central place among them is occupied by the problem of synthesis the control system for the group use of UAVs. Its importance is determined by the fact that it is precisely through control that an increase in efficiency should be obtained in comparison with the conscientious use of several separately controlled vehicles.

In general terms, the problem of synthesis a control system for the group use of UAVs can be formulated as follows: for the system “group of UAVs - air defense systems - purpose of use” given by the equations for changing phase states and measurements in the form:

$$\begin{cases} \dot{X}(t) = A(t)\cdot X(t) + B(t)\cdot U(t) + \xi(t) \\ Z(t) = H(t)\cdot X(t) + \eta(t) \end{cases}, \qquad (4)$$

where $X(t)$ - n-dimensional vector of system states, $X(t)\in \Omega_X$; $Z(t)$ - m-dimensional vector of measurements, $Z(t)\in \Omega_Z$; $U(t)$ - r-dimensional control vector, $U(t)\in \Omega_U$; $\xi(t)$ - n-dimensional vector of perturbations of the state of the system, caused by the actions of the enemy, $\xi(t)\in \Omega_\xi$; $\eta(t)$ - r-dimensional vector of measurement violations caused by the actions of the enemy, $\eta(t)\in \Omega_\eta$; $A(t)$ - dynamic matrix of the system with dimension $n \times n$; $B(t)$ - dimension control matrix $n \times r$; $H(t)$ - matrix of observations with dimension $m \times n$; on the time interval of operation $t \in [t_0, t_k]$ it will be necessary to synthesize such a control system $U(t)$ that will be able to provide the maximum probability of achieving the required phase state of the system $X(t)\in\Omega_X^*$ for all possible enemy actions $\xi(t)\in\Omega_\xi$, $\eta(t)\in\Omega_\eta$:

$$U(t)\ :\ \max_{\substack{\xi(t)\in\Omega_\xi\\ \eta(t)\in\Omega_\eta}} P\left(X(t)\in\Omega_X^*\right), \qquad (5)$$

with the fulfillment of the probabilistic condition:

$$P\left(X(t)\in\Omega_X^*\right) > 1-p^n . \qquad (6)$$

In the general case, there are not restrictions on the sets of phase states Ω, the non-stationarity of the dynamic properties of the system is considered, the possibility of changing the dimensions of the vectors of the system (4) over the time interval $t\in[t_0, t_k]$.

Accordingly, the solution of the optimization problem (5) will include:

ensuring that the conditions of complete Kalman observability and controllability are met for the entire range of conditions for applying the group (the symbol $\vdots$ corresponds to the operation of gluing matrices):

$$rank\left[B\ \vdots\ A\cdot B\ \vdots\ A^2\cdot B\ \vdots\ \dots\ \vdots\ A^{n-1}\cdot B\right]=n , \qquad (7)$$

$$rank\left[H^T\ \vdots\ A^T H^T\ \vdots\ \left(A^T\right)^2 H^T\ \vdots\ \dots\ \left(A^T\right)^{n-1} H^T\right]=n ; \qquad (8)$$

structural and parametric synthesis of the control system $U(t)$;

ensuring the probabilistic stability of the resulting solution.

Important features of the synthesis problem (5) are:

the need to consider large dimensions of the vectors $X(t)$, $Z(t)$, $U(t)$, $\xi(t)$, $\eta(t)$, describing the state of the system “UAV group - air defense systems - purpose of use”;

the need to consider the case when, according to measurements from the UAVs, it is necessary to restore the states of not only the devices themselves, but also other components of the system “UAV group - air defense systems - purpose of use”, that is $n >> m$;

the need to synthesize a distributed measurement processing system $Z(t)$, to determine what information should be processed on board the UAV, what information should be transmitted and processed at the ground control point;

the need to ensure complete controllability of the group, both for the operator's commands and for automatic regulators;

the need to synthesize a distributed control system, where part of the functions will be carried out by the ground operator of the group, part by automatic regulators.

The noted features indicate the closeness of the problem of stochastic optimization (5) to the problems of controlling the battle formations of aircraft and the synthesis of human-machine control systems for reusable aerospace systems. Therefore, the best approach to the synthesis of control systems for the group use of UAVs is the use of developments, methodological results obtained in these areas [14…20].

In these works, it is substantiated that problems of the form (5) are not reducible to a set of known (and solved) problems of linear optimization of control, control problems with maximum speed, and optimization problems by quadratic criteria. In turn, this indicates the fundamental impossibility of solving these problems of group management through only technological improvement (increasing the performance of onboard and ground computers, the capabilities of communication and telemetry systems, improving the flight performance of UAVs), without changing the basic methodological approaches to the synthesis of the control system.

Summary

Thus, the analysis of cause-and-effect relationships, basic information and energy patterns of the system “UAV - air defense systems - purpose of use” allows us to draw the following conclusions:

the development of methods for the military use of UAVs is an objective process in which the determining factors are: the need to increase the efficiency of combat missions; expand the capabilities of air defense systems; the technological level, tactical and technical capabilities of UAVs. The impossibility of further increasing the efficiency of the use of UAVs at a certain level of countermeasures in the presence of technological prerequisites (the level of UAV technologies) determines the development of the next most complex method of application;

from the point of view of the control process, the use of single UAVs is the least difficult, the joint use of several separately controlled UAVs is more difficult, and the group use of UAVs is the most difficult. The potential of group use of UAVs makes it possible to perform the tasks of guaranteed remote high-precision engagement of a wide range of targets in the face of severe opposition from enemy air defense systems;

the solution of the problem of stochastic optimization of control of complex non-linear non-stationary multi-dimensional multi-connected distributed systems (5) is of fundamental importance for realizing the potential of group application of UAVs. The irreducibility of stochastic optimization of control of complex nonlinear non-stationary multidimensional multi-connected distributed systems (5) to a set of known (and solved) control optimization problems determines the impossibility of realizing the potential of group application only through the introduction of new technologies.

The direction for further research. An important direction for further research in the field of joint use of unmanned aerial vehicles is the development of methodological foundations and methods for the synthesis of automated control systems for groups of UAVs, as the most promising way of their joint application.

References

1. DARPA, Dynetics move Gremlins focus to aerial recovery. https://www.janes.com/defence-news/news-detail/darpa-dynetics-move-gremlins-focus-to-aerial-recovery
2. Kozlovski K.R. Robot Motion and Control: monograph, Springer-Verlag Berlin Heidelberg, 2009. – 462 p.
3. Asama H., Fukuda T., Arai T., Endo I. Distributed Autonomous Robotic Systems 2: monograph, Springer Japan, 1996.- 442 p.
4. Tsourdos A., White B., Shanmugavel M. Cooperative Path Planning of Unmanned Aerial Vehicles: monograph, John Wiley & Sons, 2011. – 187 p.
5. Каляев И.А. Модели и алгоритмы коллективного управления в группах роботов / Каляев И.А., Гайдук А.Р., Капустян С.Г. - М.:ФИЗМАТЛИТ, 2009. – 280 с.
6. Абросимов В.К. Групповое движение интеллектуальных летательных аппаратов в антагонистической среде. – М.: Litres, 2017. – 413 с.
7. Моисеев В.С. Групповое применение беспилотных летательных аппаратов: монография. – Казань: Редакционно-издательский центр “Школа”, 2017. – 572 с.
8. Артюшин Л.М. Математична модель побудови бойового порядку спільної авіаційної групи пілотованої та безпілотної авіації / Артюшин Л.М., Лобанов А.А., Коваль В.В.// Сучасні інформаційні технології у сфері безпеки та оборони. – К: НУОУ, 2021. – № 2(41). – С. 23-30.
9. Air Defence Systems by Rheinmetall Defence. https://www.rheinmetall-defence.com/en/rheinmetall_defence/ systems_and_products/ air_defence_systems/index.php.
10. Ryan Boetel. Animated Air Force video shows downing of drones: https://www.stripes.com/branches/air_force/2021-06-09/Animated-Air-Force-video-shows-downing-of-drones-1663512.html.
11. Артюшин Л.М., Герасименко В.В., Коваль В.В. Метод формування спільної авіаційної групи / Артюшин Л.М. // Сучасні інформаційні технології у сфері безпеки та оборони. – К: НУОУ, 2021. - № 1(40). – С. 63-68.
12. Артюшин Л.М., Кононов О.А., Герасименко В.В., Наусенко Б.Ю. Метод вибору варіанта реалізації групового застосування безпілотних літальних апаратів / Кононов О.А. // Сучасні інформаційні технології у сфері безпеки та оборони. – К: НУОУ, 2022. - № 1(43). – С. 48-59.
13. Артюшин Л.М., Кононов О.А., Шморгун Ю.В. Метод формування спільної авіаційної групи / Артюшин Л.М. // Сучасні інформаційні технології у сфері безпеки та оборони. – К: НУОУ, 2019. - № 2(35). – С. 49-54.
14. Artyushin L.M., Solov'ev V.I. Performance monitoring for joint operation by a group of moving objects / Kibernetika i Vychislitel'naya Tekhnika, 1987, 3, – P. 67-70.
15. Artyushin L.M. Problems of controlling the configuration of a mechanical system / Soviet Applied Mechanics, 1987, 23(2), – P. 185-190.
16. Artyushin L.M. Search for optimal laws of variation of the control forces in dynamical system control problems / Soviet Applied Mechanics, 1988, 24(3), – P. 295-300.
17. Artyushin L.M., Malyshenko S.V. Featuers of taking the constraints on control actions into account when solving optimization problems by the inverse dynamics problems method / Journal of automation and information science, 1996, 28(3), – P. 24-27.
18. Харченко А.В., Сивов М.С. Метод реализации принципов автономности и стационарности при синтезе эргатических систем // Киев, научно-методический сборник “Кибернетика и вычислительная техника”, вып. 84. – 1989. – С. 34-46.
19. Харченко А.В., Карнаух В.И., Якубчик А.Ю., Гринь А.К. Об одном подходе к организации адаптивной системы управления ЛА // Киев, научно-методический сборник “Кибернетика и вычислительная техника”, вып. 92, 1991. – С. 24-32.
20. Kharchenko A.V. Organization of an adaptive ergatic system for aircraft control / Cybernetics and Computing technology, number 92, 1991, New York, – P. 21-29.

Надійшла до редколегії 9.12.2022
Схвалена до друку 20.12.2022

Відомості про авторів:

Харченко Олександр Володимирович
доктор технічних наук
професор
головний науковий співробітник
Державного науково-дослідного інституту авіації,
Київ, Україна
https://orcid.org/0000-0002-9972-5233

Артюшин Леонід Михайлович
доктор технічних наук
професор
головний науковий співробітник
Державного науково-дослідного інституту авіації,
Київ, Україна
https://orcid.org/0000-0002-7488-7244

Кононов Олексій Анатолійович
доктор технічних наук
доцент
заступник начальника
Державного науково-дослідного інституту авіації,
Київ, Україна
https://orcid.org/0000-0003-2267-9109

Information about the authors:

Oleksandr Kharchenko
Doctor of Technical Sciences
Professor
Chief Research
of State Research Institute of Aviation,
Kyiv, Ukraine
https://orcid.org/0000-0002-9972-5233

Leonid Artushin
Doctor of Technical Sciences
Professor
Chief Research
of State Research Institute of Aviation,
Kyiv, Ukraine
https://orcid.org/0000-0002-7488-7244

Oleksiy Kononov
Doctor of Technical Sciences
Associate Professor
Deputy Chief
of State Research Institute of Aviation,
Kyiv, Ukraine
https://orcid.org/0000-0003-2267-9109

ПЕРСПЕКТИВИ РЕАЛІЗАЦІЇ СПІЛЬНОГО ЗАСТОСУВАННЯ БЕЗПІЛОТНИХ ЛІТАЛЬНИХ АПАРАТІВ

О.В. Харченко, Л.М. Артюшин, О.А. Кононов

У статті авторами розглянуто розвиток способів бойового застосування безпілотних літальних апаратів з позиції причинно-наслідкових процесів в системі "безпілотні літальні апарати – засоби протиповітряної оборони противника – цілі застосування". Проаналізовано основні чинники розвитку та змін у способах бойового застосування безпілотних літальних апаратів, виділено базові закономірності та зв'язки процесу розвитку способів спільного застосування безпілотних літальних апаратів. Розглянуто спосіб одиночного застосування безпілотних літальних апаратів, спосіб спільного застосування декількох окремо керованих безпілотних літальних апаратів, спосіб групового застосування безпілотних літальних апаратів в рамках розвитку загальної системи "безпілотні літальні апарати – засоби протиповітряної оборони противника – цілі застосування". Визначено області умов доцільного застосування груп безпілотних літальних апаратів як перспективного виду дистанційної високоточної зброї. Обґрунтовано та формалізовано наукову проблему стохастичного синтезу автоматизованої системи управління груповим застосуванням безпілотних літальних апаратів, як одну з проблем сучасної теорії управління та технічної кібернетики. Виділено основні особливості стохастичного синтезу автоматизованої системи управління груповим застосуванням безпілотних літальних апаратів, які відрізняють його від інших завдань синтезу автоматизованих систем управління. Розглянуто питання можливості зведення завдання стохастичного синтезу автоматизованої системи управління груповим застосуванням безпілотних літальних апаратів до сукупності завдань оптимізації управління у лінійних (лінеаризованих) системах за квадратичними критеріями.

Ключові слова: безпілотні літальні апарати, спільне застосування безпілотних літальних апаратів, групове застосування безпілотних літальних апаратів, імовірність виконання бойового завдання, засоби протиповітряної оборони противника, управління.