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THE IMPACT OF THE JOINT USE OF FALSE AIRCRAFT TARGETS IN A GROUP OF COMBAT UNMANNED AERIAL VEHICLES ON THE RESULTS OF DESTRUCTION

The subject of the paper is the process of joint use of false aircraft targets as part of a group of combat unmanned aerial vehicles to perform tasks to destroy enemy targets. *The purpose* of the paper is to determine the optimal number of false aircraft targets in a group of combat unmanned aerial vehicles to defeat targets with the desired degree of their defeat and acceptable losses of own combat unmanned aerial vehicles. *The scientific task* is to improve the methodology for determining the optimal number of false aircraft targets in a group of combat unmanned aerial vehicles to defeat targets with the desired degree of their defeat and acceptable losses of own combat unmanned aerial vehicles. To achieve the purpose of the research paper, the following tasks were performed: the process of joint use of false aircraft targets as part of a group of combat unmanned aerial vehicles to defeat targets with the desired degree of their defeat has been formalized; a mathematical model for determining the optimal composition of false aircraft targets as part of a group of combat unmanned aerial vehicles to minimize the losses of real aircraft during their tasks has been developed; based on the conditions of a practical example, the functioning of the improved methodology has been tested and the relevant recommendations have been substantiated. *Methods.* The mathematical model uses combinatorics and binomial probability distribution. The following *results* were obtained. An improved methodology is presented, which is multifunctional, since, on the one hand, its use makes it possible to determine the required number of false aircraft targets in a group of combat unmanned aerial vehicles to defeat targets with the desired degree of their defeat and acceptable losses of own combat unmanned aerial vehicles, and on the other hand, to determine the predicted level of losses of real aircraft targets from the group when using a certain number of false aircraft targets. *Conclusions.* The availability of an improved methodology with ready-made calculation formulas will allow predicting possible results of combat use of groups of unmanned aerial vehicles on the basis of initial parameters and substantiate recommendations on their possible composition.

Key words: unmanned aerial vehicle; false aircraft target; fire damage.

Introduction

The tendency of the world's leading military countries to suffer as little losses as possible during the warfare has led to a change in the paradigm of military operations from conducting contact actions of ground forces to long-range remote destruction of opposing groups of troops (forces). Such operations are characterized by a combination of reconnaissance actions of automated reconnaissance complexes and fire actions of long-range weapons of destruction of various bases to the full depth of the operational structure of the enemy's group of troops, where the ground group usually plays the final role in the capture of certain objects, borders and positions [1].

At the same time, the rapid development of the world aviation industry has led to the fact that since the second half of the 20th century, almost none of the military operations of the troops have been carried out

without the use of unmanned aircraft systems for various purposes, including combat aircraft. If in the early 50s of the 20th century, the number of unmanned aerial vehicles (UAVs) during combat operations was counted in single units, then during current operations they are counted in thousands, and of different purposes, classes and types. This is due to a number of factors, the main of which are the following: the possibility of reconnaissance and simultaneous destruction of targets in the depth of the enemy's operational structure with the help of UAVs; the possibility of destroying enemy targets with greater accuracy; the ability to redirect UAVs in flight in case of loss of relevance or impossibility of fire damage to a pre-designated target, which is impossible for tactical missiles, shells; increasing the survivability of UAV operators compared to the survivability of manned aircraft crews and others [2, 3].

This trend has led to the adoption of programs for the development of unmanned aircraft systems in the

world's leading military countries and the rapid arming of their own armed forces with them [4].

The use of UAVs in modern armed conflicts has shown their high combat effectiveness, especially for achieving air and fire superiority over the enemy. A recent striking example is the use of UAVs in Nagorno-Karabakh. It was the UAV air strikes that made it possible to achieve tactical success in this armed conflict and avoid significant losses on the part of the Azerbaijani army. At the same time, the presence of Soviet-made air defense systems (ADS) in the units of Armenia, designed mainly to combat manned combat aircraft, did not provide an adequate degree of cover for their troops from air strikes [5].

Today we can observe a tendency, which, on the one hand, is characterized by a change in the content of the tasks of unmanned aircraft from performing single reconnaissance and destruction tasks to performing tasks of fire damage to infrastructure and groups of enemy troops by groups of UAVs, and on the other - the development of ways and means of combating UAVs [6-9].

Under such conditions, an urgent task arises in the practice of troops to inflict the necessary degree of damage by UAV strikes on certain enemy targets subject to the presence of a stable air defense system of the opposing group of troops, which will be able to effectively fight UAVs of various purposes, and in maintaining the combat capability of the UAV group in order to perform further combat missions. As it is known, the combat capability of a unit during the performance of a combat mission, including that of a UAV group, is not to prevent 100% of its losses, but also to create such conditions under which the level of its losses will not exceed a certain critical value. Because at this level of losses, the group target (which in this case is a group of UAVs for enemy air defense) will not be destroyed, and therefore will be able to continue to perform combat missions under certain conditions [10].

One of the ways not to exceed such a critical level of losses can be the creation of UAVs made of composite materials, the use of which will allow UAV groups to be undetected by enemy reconnaissance means while performing tasks to reach the target area, effectively defeat targets and return UAVs to their basing areas or perform tasks with acceptable losses caused by the enemy air defense system. However, it is a well-known fact that the development of UAVs requires quite a lot of budget funds and time, which is not always possible. [11].

In contrast, there is a less costly way, namely, the creation of a group of combat UAVs, which includes false UAVs (false aircraft targets), which can be decommissioned, but serviceable UAVs. Under such

conditions, the information about false aircraft targets (FATs) and valid aircraft targets (VATs), which are valid combat UAVs, is displayed in the same way on the corresponding display devices of enemy reconnaissance means. Here lies the possibility of misleading the enemy. Indeed, the person who makes the decision to hit the UAV in flight, based on the results of monitoring the air situation, cannot know for sure whether they are going to hit the FAT or VAT.

This, as well as the objective need to perform a larger volume of enemy fire destruction tasks by UAV groups, leads to the search for ways to substantiate scientific and organizational solutions, the implementation of which will allow achieving the desired degree of target destruction by a group of UAVs at a given loss of its own UAVs. For this purpose, there is a scientific task to determine the optimal number of false UAVs in a group of combat UAVs to defeat certain targets with the desired degree of their defeat and acceptable losses of its own combat UAVs.

1. Analysis of recent research and publications

A significant number of scientific works are devoted to the issues of group use of UAVs and misleading the enemy about their actual use.

For example, in [12], the problems of modeling and planning group flights of UAVs based on neural network structures are considered.

The study of the grouping of UAV fleets with sliding redundancy in order to ensure its reliability is presented in [13].

In [14], an approach to determining the optimal composition of the FAT as part of a mixed aviation group is presented. The approach is based on solving the two-criterion problem of determining the optimal number of FATs, the inclusion of which in the group of VATs will ensure the minimum level of their losses in the raid. Determination of the optimal number of FATs is based on calculations of the pareto-optimal value of their number in a mixed grouping of VATs and FATs. It is worth noting that the choice of the optimal number of FATs is carried out by comparing the obtained values of the probabilities of damage to the VATs (when using the minimum number of FATs). At the same time, a significant disadvantage of this approach is that the difference between the probabilities of damage to different numbers of VATs with the same number of FATs may be insignificant, up to 0.02.

In [15], on the basis of analytical calculations, an assessment of the effectiveness of the use of small aircraft false targets in the performance of tasks to mislead the enemy is given. The calculations confirming

the economic feasibility of using small aircraft false targets during combat operations are also presented.

In the paper [16] formulated an optimization problem of false target jamming based on a counterpart problem of UAV detection, where each false target jamming solution is evaluated according to its adversarial effects on a set of possible UAV detection solutions.

In the paper [17] the authors propose the concept of the airborne counter-UAV platform (consisting of several vehicles) with radar. For the countermeasures, the authors suggest using a small rotorcraft UAV carried by a bigger fixed-wing one.

The article [18] is dedicated to the recognizing the UAV from its surroundings. The authors propose a novel method for detecting and tracking UAVs.

The analysis of publications shows the lack of works on the creation of mixed UAV groups as part of VATs and FATs. Along with that, the creation of such UAV groups is an extremely relevant, challenging and multidimensional task, which currently remains unresolved.

However, with certain generalizations, the analyzed approaches can be accepted for consideration for their further development and solving the scientific problem stated in the paper.

Taking this into account, **the purpose of the paper** is to improve the methodology for determining the optimal number of FATs in a group of combat UAVs to defeat certain targets with the desired degree of their defeat and acceptable losses of own combat UAVs, as well as to substantiate the relevant recommendations.

2. Models and method

According to [19], the effectiveness of defeating single and group targets depends on many factors, among which the number of projectile hits to the target is decisive. The effectiveness of defeating single and group targets can be characterized by:

1. Probability of hitting the target

$$P = 1 - (1 - p)^N, \quad (1)$$

where p is the probability of hitting the target with one shot;

N is the number of accurate shots on target.

This formula is used provided that the probability of hitting the target with each shot remains unchanged.

$$P = 1 - \prod_{i=1}^N (1 - p_i). \quad (2)$$

Formula (2) is used provided that the probability of hitting the target from shot to shot varies and is equal to p_i .

2. Mathematical expectation of defeating a group target

$$M = P \cdot n_{st}, \quad (3)$$

where n_{st} is the number of single targets within the group target.

Analysis of the above formulas suggests the need to assign the appropriate number of projectiles, the hit of which on the target (group or single one) will lead to its defeat with the appropriate degree. This indicates that if we consider a combat UAV as a carrier of a certain number of projectiles, then in order to defeat the relevant important target with the required efficiency, it is necessary to assign a certain number of combat UAVs, which will form a group of combat UAVs.

It is obvious that all important enemy targets will be covered by its air defense systems. As it is known, the UAV task is divided into the following conditional stages: UAV take-off, reaching the task area, performing the task in the designated area, returning the UAV to the designated area. Accordingly, when performing a UAV task to defeat enemy targets, the UAV group will enter the range of its detection means and with a corresponding probability can be detected and destroyed by enemy air defense systems [20].

The analysis of the tactical and technical characteristics of modern air defense systems of the military enemy of Ukraine shows that the probability of defeating UAVs (P_{ads}) in flight can reach 0.3...0.8 [2].

It is obvious that to perform the task of defeating an important enemy target, it may be decided to use a group consisting of a certain number of combat UAVs. At the same time, to cover its important targets from air attack, the enemy can have such a number of the same type of air defense systems, the use of which allows simultaneously defeating all detected valid combat UAVs from the group. Therefore, it can be logically concluded that in order to perform the task, there is a need to ensure the survivability of a certain number of UAVs from the UAV group. The probability of completing the task in this case can be represented as a formula

$$P(CT) = P(\text{destroyed} \leq k_{IVAT}), \quad (4)$$

where k_{IVAT} is the value of acceptable combat losses of VATs.

It should be noted that while conducting airspace reconnaissance, the enemy can detect some UAVs (VATs and FATs) in the raid in one case, and all of them in another. It is possible to obtain different mathematical models and simulation results for different variants of the scientific problem statement. In this scientific work it is proposed to consider the most typical variant – the first variant of the problem.

The enemy's air defense systems n_{ads} is taken to defeat targets from the group of strike UAVs ($n_{VAT} + n_{FAT}$). Therefore, enemy's air defense systems n_{ads} will attack a certain number of targets n_{VAT} from the group of UAVs.

The total number of cases of acceptance of hitting the VATs by the enemy's air defense systems is determined by the number of combinations

$$P(m_{VAT}, n_{FAT}) = \frac{C_{n_{VAT}}^{m_{VAT}} \cdot C_{n_{FAT}}^{n_{ads} - m_{VAT}}}{C_{n_{VAT} + n_{FAT}}^{n_{ads}}} = \frac{n_{VAT}! \cdot n_{FAT}! \cdot n_{ads}! (n_{VAT} + n_{FAT} - n_{ads})!}{m_{VAT}! \cdot (n_{VAT} - m_{VAT})! \cdot (n_{ads} - m_{VAT})! \cdot (n_{FAT} - n_{ads} + m_{VAT})! \cdot (n_{VAT} + n_{FAT})!}, \quad (5)$$

where n_{VAT} is number of UAVs (VATs) as part of the combat UAV group;

n_{ads} is the number of the enemy's air defense systems;

n_{FAT} is the number of FATs as part of the combat UAV group;

$$P(l_{VAT}, m_{VAT}) = C_{m_{VAT}}^{l_{VAT}} \cdot P_{ADS}^{l_{VAT}} \cdot (l_{VAT} - P_{ADS})^{m_{VAT} - l_{VAT}} = \frac{m_{VAT}!}{l_{VAT}! (m_{VAT} - l_{VAT})!} \cdot P_{ADS}^{l_{VAT}} \cdot (l_{VAT} - P_{ADS})^{m_{VAT} - l_{VAT}}, \quad (6)$$

where l_{VAT} is the number of defeated VATs from the set of those VATs and FATs that were detected by the enemy and taken for destruction.

$$P(l_{VAT}, k_{VAT}) = \sum_{m_{VAT}=l}^{n_{VAT}} \left(\frac{C_{n_{VAT}}^{m_{VAT}} \cdot C_{k_{VAT}}^{n_{ads} - m_{VAT}}}{C_{n_{VAT} + k_{VAT}}^{n_{ads}}} \right) \cdot C_{m_{VAT}}^{l_{VAT}} \cdot P_{ADS}^{l_{VAT}} \cdot (l_{VAT} - P_{ADS})^{m_{VAT} - l_{VAT}} = \sum_{m_{VAT}=l}^{n_{VAT}} \left(\frac{n_{VAT}! \cdot k_{VAT}! \cdot n_{ads}! (n_{VAT} + k_{VAT} - n_{ads})!}{m_{VAT}! \cdot (n_{VAT} - m_{VAT})! \cdot (n_{ads} - m_{VAT})! \cdot (k_{VAT} - n_{ads} + m_{VAT})! \cdot (n_{VAT} + k_{VAT})!} \right) \times \left(\frac{m_{VAT}!}{l_{VAT}! (m_{VAT} - l_{VAT})!} \cdot P_{ADS}^{l_{VAT}} \cdot (l_{VAT} - P_{ADS})^{m_{VAT} - l_{VAT}} \right), \quad (7)$$

where k_{VAT} is the number of destroyed VATs from the number of VATs that were detected and taken for destruction by the enemy.

The probability of not exceeding the acceptable number of combat UAVs during the performance of the task by the group can be determined by the formula

$$P(k_{IVAT}, k_{VAT}) = \sum_{l_{VAT}}^{k_{IVAT}} P(l_{VAT}, k_{VAT}). \quad (8)$$

Thus, the probability of completing the task by a group of UAVs using the formula (4) and (8) can be represented as follows

$C_{n_{VAT} + n_{FAT}}^{n_{ads}}$. The number of favorable cases in which the enemy's air defense systems n_{ads} will hit the VATs can be represented as $C_{n_{VAT}}^{m_{VAT}} \cdot C_{n_{FAT}}^{n_{ads} - m_{VAT}}$.

In this case, the probability of acceptance to the defeat of a certain number VATs can be determined using the following formula [16].

m_{VAT} is number of UAVs detected by the enemy from the group of combat UAVs.

In turn, the probability of defeating the VAT during the infliction of damage by enemy air defense means on a group of detected combat UAVs can be determined by the formula [19]

Thus, the probability of destruction of a certain number of detected UAVs during a group strike by the enemy air defense against a group of combat UAVs consisting of VATs and FATs will be as follows

$$P(CT) = P(k_{IVAT}, k_{VAT}) = \sum_{l_{VAT}}^{k_{IVAT}} P(l_{VAT}, k_{VAT}) \quad (9)$$

3. Case study and calculation results

To reconnoiter and destroy the enemy artillery battery, it was decided to use a group of 9 combat UAVs. At the same time, it was decided that possible losses of combat UAVs during the mission should not exceed 3 ($k_{IVAT} = 3$).

Taking into account the importance of the artillery battery, the enemy took measures to provide its cover from air strikes in such a way that the allocated number of air defense means is able to simultaneously hit 6 UAV targets. Analysis of the tactical and technical characteristics of modern enemy's air defense systems, the variety of ways to perform UAV tasks, made it possible to take, in the conditions of the study, the value of the statistical probability of UAV defeat by enemy air defense systems, which lies in the range from 0.3 to 0.5 ($P_{ADS} = 0.3 \dots 0.5$).

Under such conditions, a question arose: with what number of FATs as part of the combat UAV group it will be able to perform the task.

The solution of this problem was carried out using the proposed mathematical model. Since the value of the statistical probability of UAV defeat by enemy air defenses was within the appropriate limits, the task was solved twice: using the upper and lower limits of the values.

Based on the results of the calculations, the corresponding graphs were built, which are presented in Fig. 1-5.

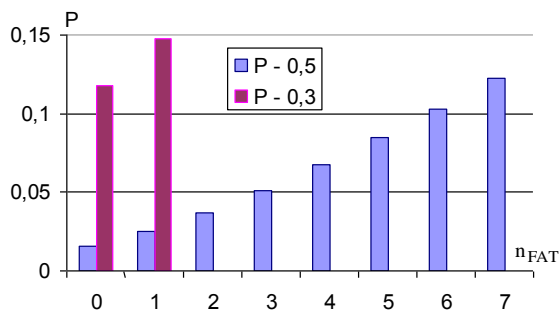


Fig. 1. Probability of destruction of 0 UAVs:
1 – at $P_{ADS} = 0.5$; 2 – at $P_{ADS} = 0.3$

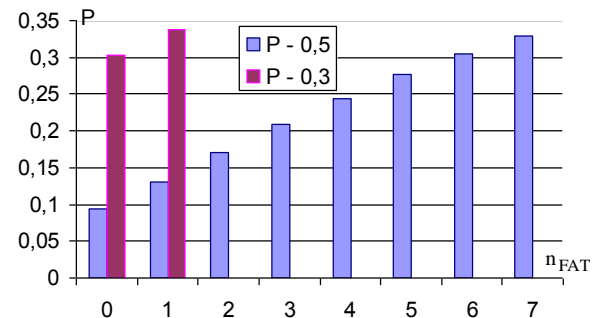


Fig. 2. Probability of destruction of 1 UAV:
1 – at $P_{ADS} = 0.5$; 2 – at $P_{ADS} = 0.3$

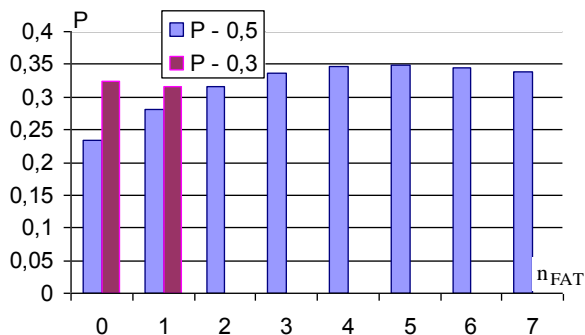


Fig. 3. Probability of destruction of 2 UAVs:
1 – at $P_{ADS} = 0.5$; 2 – at $P_{ADS} = 0.3$

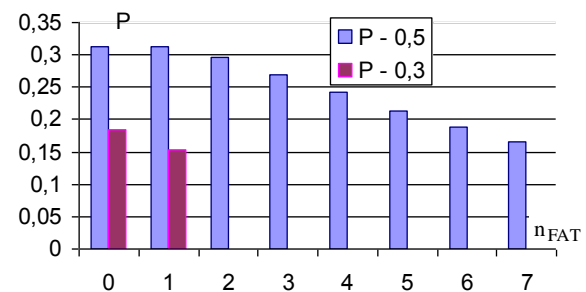


Fig. 4. Probability of destruction of 3 UAV:
1 – at $P_{ADS} = 0.5$; 2 – at $P_{ADS} = 0.3$

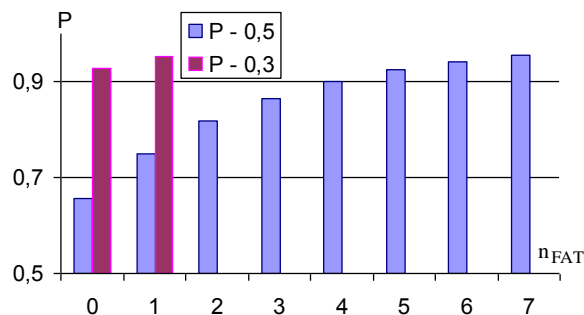


Fig. 5. Probability of destroying no more than 3 UAVs in a raid: 1 – at $P_{ADS} = 0.5$; 2 – at $P_{ADS} = 0.3$

Figure 1 analysis shows that at $P_{ADS} = 0.3$ and at $P_{ADS} = 0.5$ it is practically impossible to complete a combat mission without combat losses of the VATs. Because the probability that no one VATs will be tripled is less than the value of the confidence probability 0.95.

Figures 2-4 shows that at $P_{ADS} = 0.3$ and at $P_{ADS} = 0.5$ the task cannot be completed with losses of 1, 2 та 3 VATs. Because full probability of defeat 1, 2 and 3 VATs from the group of UAVs is also less than the value of the confidence probability 0.95 for any number (1, 2, 3) of VATs.

The results of the analysis of figure 5 show that at:

$P_{ADS} = 0.3$ no more than 3 VATs using 1 FAT will be affected, since the probability of such an event will be equal to the confidence probability value of 0.95;

$P_{ADS} = 0.5$ no more than 3 VATs using 7 FATs will be affected, since the probability of such an event will be equal to the confidence probability value of 0.95.

The results obtained mean that under the accepted conditions of the task and at $P_{ADS} = 0.3$ it is necessary to include 1 FAT in the VAT group, and at $P_{ADS} = 0.5$ it is necessary to include 7 FATs.

With this number of FATs, the losses of combat UAVs in the group with a confidence level of 0.95 will not exceed 3 units. From the calculations we can also confirm the recommendation, namely: before carrying out fire destruction of important targets, first of all, it is necessary to suppress the activity of enemy air defense systems that cover them.

Conclusions

Thus, the scientific paper presents an improved methodology for determining the optimal number of FATs in a group of combat UAVs to defeat certain targets with the desired degree of their defeat and acceptable losses of own combat UAVs. This methodology is based on the theory of combinatorics and binomial distribution of a random variable. In addition, on the basis of this methodology, a case study was solved and the relevant recommendations were substantiated.

The process of determining the optimal number of FATs in a group of combat UAVs is modeled in three stages. At the first stage, using the theory of combinatorics, the possible number of detected VATs in a group of combat UAVs is determined, provided that a certain number of FATs is used. At the second stage, the probability of defeat by enemy air defense means of the

detected (according to the results of the first stage of modeling) number of VATs is determined. At the third stage, according to the suitability criterion, the number of FATs is determined, the inclusion of which in the group of combat UAVs will allow not to exceed the permissible level of losses of VATs in the group.

The presented model is multifunctional, since, on the one hand, its use allows determining the required number of FATs in a group of combat UAVs to ensure its survivability, and on the other hand, to determine the predicted level of losses of VATs from the group when using a certain number of FATs.

The given example of input data is taken from real combat experience, and the results obtained indicate the possibility of using the presented mathematical model in practice.

The availability of this model with ready-made calculation formulas will allow, on the basis of the initial parameters, assessing the possible results of the combat use of UAV groups and substantiate recommendations on their possible composition depending on the conditions of the operational and tactical situation.

According to the results of the study, the dependence of the level of losses of a group of combat UAVs during the performance of tasks on enemy fire damage on the number of FATs included in such a group was revealed.

Thus, the availability of this mathematical model and the obtained adequate practical results indicate the achievement of the research objective.

Prospects for further research

Further research in this area may consist in improving the mathematical model, which will take into account the different probabilities of detection and defeat of FATs and VATs in the UAV group.

Contribution of the authors: development of a mathematical model for determining the optimal number of FATs as part of a group of combat UAVs to defeat certain targets with the desired degree of their defeat and acceptable losses of own combat UAVs and analysis of the research results – **Volodymyr Prymireenko**; selection and use of software and hardware tools for modeling and presentation of research results – **Andrii Demianiuk**; review and analysis of information sources, formulation of the purpose and problem of research, formulation of conclusions and prospects for further research in this area – **Roman Shevtsov**; analysis of the capabilities of the enemy's air defense system in terms of the possibility of detecting and destroying FATs and VATs, formalization of this process – **Serhii Basilo**; review of

the conceptual provisions and experience of group use of unmanned aerial vehicles of various types to perform reconnaissance and target destruction tasks, development of the research concept – **Petro Steshenko**.

All authors have read and agreed with the published version of the manuscript.

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ВПЛИВ СПІЛЬНОГО ЗАСТОСУВАННЯ ХИБНИХ АВІАЦІЙНИХ ЦІЛЕЙ У ГРУПІ УДАРНИХ БЕЗПІЛОТНИХ ЛІТАЛЬНИХ АПАРАТІВ НА РЕЗУЛЬТАТИ УРАЖЕННЯ

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Предметом вивчення статті є процес спільного застосування хибних авіаційних цілей у складі групи ударних безпілотних літальних апаратів для виконання завдань щодо ураження об'єктів противника. **Метою** статті є визначення оптимальної кількості хибних авіаційних цілей у складі групи ударних безпілотних літальних апаратів для ураження цілей з потрібним ступенем їх ураження і допустимими втратами своїх ударних безпілотних літальних апаратів. **Науковим завданням** є удосконалення методики визначення оптимальної кількості хибних авіаційних цілей у складі групи ударних безпілотних літальних апаратів для ураження цілей з потрібним ступенем їх ураження і допустимими втратами своїх ударних безпілотних літальних апаратів. Для досягнення мети наукової статті були виконані завдання: формалізовано процес спільного застосування хибних авіаційних цілей у складі групи ударних безпілотних літальних апаратів для ураження цілей з потрібним ступенем їх ураження; розроблено математичну модель визначення оптимального складу хибних авіаційних цілей у складі групи ударних безпілотних літальних апаратів для мінімізації втрат дійсних літальних апаратів під час виконання ними завдань; на основі умов практичного прикладу перевірено функціонування удосконаленої методики та обґрунтовано відповідні рекомендації. **Методи.** В математичній моделі застосовано комбінаторику та біноміальний розподіл імовірності. Отримано такі **результати**. Представлена удосконалена методика, яка є багатофункціональною, оскільки з однієї сторони її використання дає змогу визначати необхідну кількість хибних авіаційних цілей у складі групи ударних безпілотних апаратів для ураження цілей з потрібним ступенем їх ураження і допустимими втратами своїх ударних безпілотних літальних апаратів, а з іншої – визначати прогнозований рівень втрат дійсних авіаційних цілей зі складу групи при використанні певної кількості хибних авіаційних цілей. **Висновки.** Наявність удосконаленої методики з готовими розрахунковими формулами дозволить на основі вихідних параметрів прогнозувати можливі результати бойового застосування груп безпілотних літальних апаратів та обґрунтовувати рекомендації щодо їх можливого складу.

Ключові слова: безпілотний літальний апарат; хибна авіаційна ціль; вогневе ураження.

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