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SIMULATION OF THE SYSTEM FOR CALCULATING THE SUPPLY NEEDS OF SUBDIVISIONS WHITH OF UNMANNED AERIAL VEHICLES

Бєляков Р. О., Гриценок К. М., Гулій В. С., Кубік С. І. Моделювання системи розрахунку потреб підрозділів із забезпечення безпілотними літальними апаратами.

Досвід ведення бойових дій на сході України, а після повномасштабного вторгнення російської федерації 24 лютого 2022 року – на всій території, показав, що бойове застосування безпілотних літальних апаратів (БпЛА) може призвести не тільки до тактичних успіхів, але й оперативно-тактичних та стратегічних. Разом з тим узагальнення такого досвіду та обробка статистичних даних застосування підрозділами БпЛА постає гіперперспективним напрямком наукової діяльності. Враховуючи динамічність та швидкоплинність воєнних дій, а також потребу адаптації до умов ведення бойових дій, Збройні сили України постійно набувають спроможностей до відбиття наступу переважаючих сил агресора за рахунок комплектування підрозділів озброєнням власне вітчизняного воєнно-промислового комплексу, озброєнням, що постачається партнерами, силами волонтерів та підприємствами національної економіки, постачаючи цивільні зразки БпЛА до силових підрозділів. Таке постачання потребує узагальнення і аргументування з метою рівномірного розподілу відповідно до цільового призначення військових формувань (підрозділів). Враховуючи те, що БпЛА, що застосовуються, часто не є суто військового призначення і класифікуються за дуже широким рядом характеристичних ознак, доцільно виділити ряд принципових ознак для узагальнення досвіду. У роботі виділено чотири такі категорії: за масштабом завдань, що вирішуються; за тривалістю польоту; за радіусом дії; за типом системи керування. Авторами визначено, що ці характеристичні ознаки є визначальними для формування системи забезпечення безпілотними літальними апаратами бойових підрозділів. Відомо, що із активним застосуванням засобів радіоелектронної боротьби противника та недосконалістю технологічного виконання безпілотників, що застосовуються, мають місце затримки виконання польотних завдань, що безпосередньо або напряму можуть знижувати бойовий потенціал бойових юнітів. Метою роботи є моделювання системи розрахунку потреб підрозділів із забезпечення безпілотними літальними апаратами для формування обґрунтованого підходу до розподілу ресурсів збройних формувань різного призначення.

Ключові слова: *безпілотний літальний апарат, аеророзвідка, розвідка.*

R. Bieliakov, K. Hritsenok, V. Huliy, S. Kubik. Simulation of the system for calculating the supply needs of subdivisions with of unmanned aerial vehicle.

The experience of conducting hostilities in the east of Ukraine, and after the full-scale invasion of the russian federation on February 24, 2022 in the entire territory, showed that the combat use of unmanned aerial vehicles (UAVs) can lead not only to tactical successes, but also operational-tactical and strategic ones. At the same time, the generalization of such experience and the processing of statistical data on the use of UAV units appears as a hyper-promising direction of scientific activity. Considering the dynamism and rapidity of military actions, as well as the need to adapt to the conditions of hostilities, the Armed Forces of Ukraine are constantly acquiring the ability to repel the offensive of the overwhelming forces of the aggressor by equipping units with weapons of the domestic military-industrial complex, weapons supplied by partners, volunteer forces and enterprises of the national economy, supplying civil models of UAVs to military units. Such supply requires generalization and reasoning for the purpose of equal distribution in accordance with the purpose of military formations (units). Considering the fact that the UAVs used are often not of purely military purpose and are classified according to a very wide range of characteristic features, it is advisable to highlight a number of principle features to generalize the experience. The work distinguishes four such categories: by the scale of the tasks to be solved; by flight duration; by radius of action; by type of control system. The authors determined that these characteristic features are decisive for the formation of a system of providing combat units with unmanned aerial vehicles. It is known that with the active use of the enemy's radio-electronic warfare and the imperfection of the technological implementation of the drones used, there are delays in the performance of flight tasks, which can directly or indirectly reduce the combat potential of combat units. The purpose of the work is to model the system for calculating the needs of units for the provision of unmanned aerial vehicles for the formation of a reasonable approach to the distribution of resources of armed formations of various purposes.

Keywords: *unmanned aerial vehicle, aerial reconnaissance, reconnaissance.*

Introduction. Today, unmanned aerial vehicles (UAVs) are an integral part of any advanced army. Although UAVs are a relatively new type of weapon as they stand today, they have already proven their effectiveness and necessity. UAVs for reconnaissance, UAVs for aiming and adjusting artillery, attack UAVs are already successfully used, it is predicted that cargo and medical UAVs will soon be used to evacuate the wounded.

Certain myths, inaccuracies, and unreliable information are always born around a rapidly developing new industry. One of the reasons for this is the lack of a generalized analysis of UAV types and their application options. In addition, the expansion of the model range of unmanned aerial vehicles requires the introduction of classification according to characteristic features. The next, no less important issue is the determination of the required number of UAVs for the successful performance of combat missions.

The purpose of the work is to develop a mathematical model for calculating the required number of UAVs in combat conditions.

Analysis of scientific works of the subject area. Modern classifications are not sufficiently complete, as they do not consider the entire array of types of UAVs that exist today, due to the dynamic development of this technology [1]. In [2], it was determined that the main components of a UAV are: an aerial platform with a special landing system, a power plant, a power source for it, a power supply system, on-board radio electronic equipment (on-board control equipment and electronic elements of the target load). On-board equipment consists of on-board computer or special processors, radio navigation system signal receiver, altimeter, gyrovertical, on-board communication and data transmission system, steering mechanisms. The works [3–5] gives a fairly complete classification based on more than 10 characteristic features. In order to achieve the goal of the work, it is necessary to highlight and reveal four of them in more detail:

1. According to the scope of tasks to be solved:

- tactical; - operational-tactical; - operational-strategic.

2. According to the duration of the flight:

- short duration; - medium duration; - long duration;

3. By radius of action:

- short radius; - small radius; - long flight range; - medium radius; - far radius.

4. By type of control system:

- remotely piloted; - remotely controlled; - automatic; - remotely controlled by the navigation system.

Quadcopters (Fig. 1) have actually supplanted all other types of UAVs in short-range reconnaissance tasks. Modern technologies make it possible to make them quite light and compact, the time of their preparation for flight is reduced to a minimum. In addition, copters are maneuverable and capable of hovering at one point, unlike aircraft-type UAVs (Fig. 2, 3), which must move constantly to maintain stable flight. Today, DJI is the most mass-produced copter in the world.

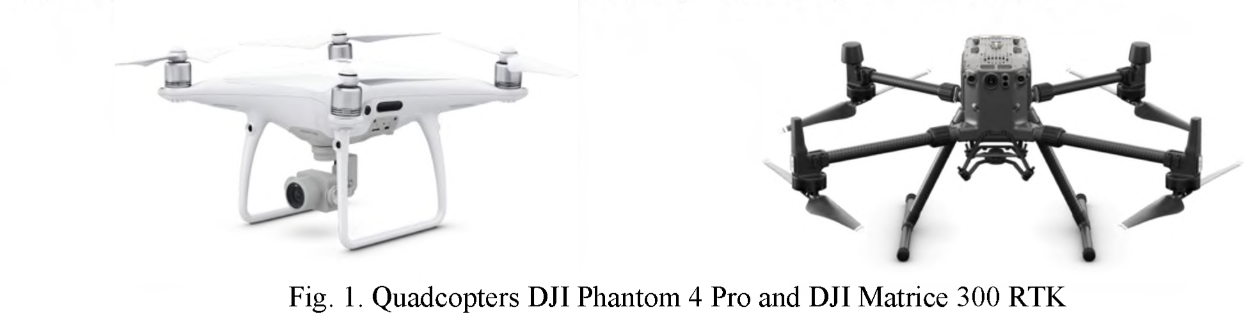

Fig. 1. Quadcopters DJI Phantom 4 Pro and DJI Matrice 300 RTK

Fig. 2. Aero Vironment RQ-20 Puma – UAV with classic aircraft scheme

Fig. 3. Athlon-Avia A1-SM "Fury" - built according to the scheme of a flying wing

Among the disadvantages of copters are a short flight range compared to the aircraft type, a higher noise level, and low autonomy. At this stage of technology development, the flight range of most compact models of copters does not exceed 10 km. Larger models, carrying a large payload, rarely cross the 20-30 km range. Low autonomy refers to the dependence of the automatic flight of copters on the presence of a GPS signal. Modern models for the most part cannot perform autonomous flight only by internal sensors; therefore, in combat conditions (under the conditions of the enemy's electronic warfare means) they are used mostly in manual (semi-automatic) mode.

Aircraft-type UAVs are mostly used at distances of hundreds and thousands of kilometers. In addition, today a large number of winged UAVs use liquid fuel as an energy carrier, while the vast majority of copters are electric.

VTOL (Vertical Take-off and Landing) UAVs are created in order to combine the advantages of aircraft and helicopter types – vertical takeoff and landing with a long flight range. Theoretically, it also allows reducing the time of preparation of the complex due to the absence of means for launching. However, a combination of advantages is impossible without a combination of disadvantages. As a rule, the engines used for takeoff are not used in cruise mode, that is, they actually take the mass of the payload in the aircraft version. In addition, they create additional resistance, which negatively affects the flight range. Thus, the advantages of VTOL are fully used only where there is not enough space for take-off "like an airplane" and at the same time a long flight range is required. In other cases, it is more appropriate to use conventional schemes.

Fig. 4. VTOL UAV Lockheed-Martin “Stalker VXE30”

Fig. 5. UAV Bayraktar TB2

Thus, taking into account the peculiarities of the structure, purpose of UAVs, and the constant expansion of the model range of the presented means, the task of calculating the necessary number of UAVs for the purpose of successfully conducting combat operations of a specific unit arises, which is not covered in open sources and formally described in doctrinal and other departmental guidance documents.

In addition, the analysis of the experience of conducting hostilities shows that the need to provide UAVs for combat units in the conditions of the dynamics and rapidity of armed confrontation is constantly growing.

Presenting main material.

Today, the scope of application of UAVs is constantly expanding, in particular in the areas of aerial reconnaissance and reconnaissance and/or fire damage to the enemy. They are gradually replacing the need for traditional correctors, and this issue is particularly acute in certain units up to and including a mechanized battalion (artillery division), during operations in densely populated areas of the area, when miscalculation of fire damage can cost the lives of civilians, which is unacceptable.

The process of using a specific number of unmanned aerial vehicles for the purpose of aerial reconnaissance requires reasoning based on the types and scope of tasks and the characteristics of the UAVs themselves.

To model the system for calculating the needs of units for the supply of unmanned aerial vehicles, we will use systems of mass service with failures, since they most fully describe all possible cases in the conditions of military operations.

In order to formalize the process of providing needs for the use of unmanned aerial vehicles, it is necessary to define the initial data.

Initial data:

The link of the unit is tactical j_1, operative-tactical j_2, strategic j_3;

Depending on the method of conducting the battle (defense, offensive), the actual size of the application area of the unit with the total area will change S_A, m^2 (position, area, operational zone);

Conditional initial number of drones d of the j-th type;

Flight resource of the unit of the j-th type, H_0, flights;

The average flight mission time will vary depending on the type of UAV missions assigned to the unit of the j-th type (reconnaissance, shock, relay), T_0, sec;

The number of personnel (engineering and technical or flight personnel) participating in the maintenance and control of UAVs.

Limitation: Detachment of personnel to resume maintenance and control of the UAV is unacceptable, and does not affect the unit's combat readiness ratio;

Assumption: The total number of UAVs is limited by the staff of the j-th type unit and cannot be instantly increased or restored.

The technical condition of unmanned aerial vehicles is changing exponentially.

The aim of the research consists in finding the required number d of unmanned aerial vehicles for specific application conditions without reducing the unit's combat readiness ratio.

In the case of conducting aerial reconnaissance by several UAVs, the time for completing one flight task is

$$T_0 = T_p/d \ , \tag{1}$$

where T_p – the average time of completing one flight task, d – total number of UAVs.

In many cases T_p can be roughly defined as the eccentricity of the graph of the observation area (site area), or as the flight time from the area of concentration to the conditional center of this section.

Intensity of flying tasks

$$\mu_p = 1/T_0. \tag{2}$$

The UAV usage rate (the total number of UAVs in the unit) can be determined from the expression

$$\rho_p = \lambda/\mu \ , \tag{3}$$

where λ – the intensity of needs (applications) for reconnaissance/pre-reconnaissance for the entire unit.

In this system, there should be a sufficient number of free UAVs to meet the needs of all fire units, since waiting for a free UAV often leads to a loss of fire superiority on the battlefield and, as a result, to a decrease in the combat potential of its troops (forces).

The probability of such a situation is [14]

$$p = \frac{\rho_p}{d!}\left[\frac{1}{1+\rho+\frac{1}{2!}\rho^2+\cdots+1\frac{1}{d!}\rho^d}\right]. \tag{4}$$

Let's assume that for a certain unit of time for the execution of reconnaissance/pre-reconnaissance tasks, the combat potential will be reduced by L. Also, the operation of one UAV per unit of time leads to a decrease in the resource of the unit – K.

Below the K it is necessary to understand not only operational costs, but also the involvement of personnel (operators) to perform flight tasks for one UAV. The reduction of the flight resource during the operation of all UAVs will be K_d.

Let the failure during the performance of one flight task cause a direct decrease in the combat potential by L_0.

Then the average reduction in combat potential associated with exploitation d UAV and with number of tasks of using UAVs per time T_p and the reduction of combat potential in connection with failures per unit of time $LT_p\lambda$, on average are

$$H = L_0\lambda_p + LT_p\lambda + K_d. \tag{5}$$

In (5) T_p – average time of the average time of completing one flight task, and together with it $LT_p\lambda$ decrease as the number of UAVs in the unit increases d.

But K_d in the same conditions also increases.

Thus, the main feature of calculating the needs of units for the provision of unmanned aerial vehicles UAVs consists in choosing such a value d, in which the criterion of reducing combat potential H will be minimal, that is, that the costs associated with the involvement of personnel and the operation of UAVs and the unproductive maintenance of an excessive number of UAVs and crews (flight crew) will be the least [15].

An important indicator is the average flight task delay time T_F, which is most often associated with the technical delay required to launch the UAV (in particular, the time for landing and take-off) and T_{F_R} – delay associated with the targeted impact of the enemy's radio-electronic warfare during the flight itself.

The sum of the average delay times T_F and performing a flight task (depending on the tasks – aerial reconnaissance or fire damage) T_{FM} is equal to the average time of use of the UAV by the unit

$$T_{SFM} = T_F + T_{F_R} + T_{FM}. \quad (6)$$

Let's establish a relationship between the average number of needs to use the UAV located in the unit and the average time of the flight task. Since for a unit of time in the unit there is a need for execution λ flight tasks, and the average time of the average time of the use of UAVs by the unit – T_{SFM}, then the total duration of use of UAVs by fire units per unit of time is equal to λT_{SFM}. Since in the unit during the conduct of hostilities there may be an average of A requests for the use of UAVs, this value is equal to

$$A = \lambda T_{SFM}. \quad (7)$$

Similarly, the average number of requests for flight tasks for units awaiting execution will be

$$A_S = \lambda T_3. \quad (8)$$

Due to the expenditure of additional resources to reduce the delay time due to the modernization of the fleet of UAVs involved, reduce T_{F_R}, and it is possible to significantly reduce the average time of the flight task T_{FM}. At the same time, the value will also decrease T_{SFM}.

In this case, the criterion for finding the optimal number of UAVs in the unit H the specified additional costs should also be entered.

An indicator of quality

$$K_Q = \lambda\mu/d. \quad (9)$$

UAV utilization ratio (which is the main indicator for predicting the operational load during maintenance and repair by service personnel - operators, especially with a large number of UAVs)

$$K_{QUAV} = A_0/d, \quad (10)$$

where $A_0 = A - A_S$ – the average number of UAV use cases served by the available UAV fleet.

Thus, in its essence, the use of the proposed model is carried out due to the processing of statistical data of the real use of unmanned aerial vehicles with the indication of a specific type of tasks, taking into account the technological capabilities of the UAVs themselves, which is why it becomes possible to calculate their average required number in a specific link (tactical, operational tactical, operational-strategic), which corresponds to the purpose of the study.

Conclusions. Thus, the work considers the classification of existing types of UAVs to determine the defining characteristic features for determining their required number. An analysis of factors that can influence the processes of execution of combat tasks by units was carried out. It was determined that delays in the performance of aerial reconnaissance, reconnaissance, and UAV fire damage tasks can directly reduce the combat potential of units.

The main difficulty in the practical implementation of the model for calculating the needs of units for providing unmanned aerial vehicles is the use of such drones according to the principle of their availability.

The main advantage of using the proposed model it is possible to justify the needs based on the criterion of reducing the combat potential of the combat unit, which in the future provides an opportunity to evenly distribute UAV resources during the planning of fire damage to the enemy.

The direction of further research the collection and generalization of statistical data on the use of UAVs and the approbation of this model using simulation modeling should be considered.

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