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R. Zhyvotovskyi[1], Yu. Gorobets[2], O. Momit[3]

[1] Central research Institute of weapons and military equipment of armed forces of Ukraine, Kyiv, Ukraine
[2] National defense University of Ukraine named after Ivan Chernyakhovsky, Kyiv, Ukraine
[3] Military unit A 2393, Odessa, Ukraine

INDICATORS AND CRITERIA OF EFFICIENCY EVALUATION OF SAFETY AVIATION COMPLEXES APPLICATION

Military conflicts of the late XX – early XXI centuries are characterized by the use of a large number of new weapons, which allowed the enemies to distance themselves as far as possible from the direct collision with each other. Unmanned aviation complexes, which during the military conflicts proved their ability to conduct air reconnaissance, damage objects and perform other combat support tasks, became one of the newest examples of weapons on the battlefield. The possibility of successfully solving of various tasks with the help of unmanned aviation complexes was demonstrated during the military conflicts in the Middle East (1982-2008), the Balkans (1999), Afghanistan (2001-2008) and the Caucasus (1994-2008). Nowadays, there is a large number of diverse literature about using unmanned aerial systems during armed conflicts over the past decades. However, the only approach to assessing the effectiveness of using unmanned aviation complexes of special purpose in known sources has not been developed. In this article, the authors proposed indicators and criteria for assessing the effectiveness of using unmanned aviation complexes of special purpose. During the research authors were using the basic provisions of the theory of complex technical systems; method of expert assessments; the method of analysis of hierarchies, methods of multidimensional comparative, general scientific and structural-functional analysis. The indicators and criteria for evaluating the effectiveness of using of special purpose non-pilot aviation complexes, which were proposed in the article, can be used to evaluate the information obtained with equipment operating in the mode of fixed and continuous shooting of individual areas. The indicators proposed in the article can be used for comparative evaluation of several unmanned aviation complexes of special purpose, that allow to assess the level of technical perfection of unmanned aerial systems and choose the most perfect for the implementation of a specific type of task.

Keywords: unmanned aviation complexes, military conflicts, performance indicators, specifications, intelligence, criteria.

Introduction

The rapid development of the unmanned aerial vehicles (UAV) of various purposes and the variety of their types makes it necessary to assess the effectiveness of their application. The literature offers many indicators (criteria) that will allow to compare the same type of UAV to show their advantages and disadvantages. But they are all ambiguously evaluated by experts, that force researchers to look for more options of practice. Consider one of the options based on the principle of evaluation "productivity-cost-efficiency" at a given level of object identification the of exploration (general idea, definition of type, size, characteristics, etc.) [1-3].

The comparative assessment of the aerial vehicles (AV) is an important practical task. The necessity to compare two or more samples appears: while evaluating their combat properties; while choosing a better sample for any indicator; at the procurement in the arms market and others.

It is necessary to analyze many qualitative indicators or criteria, that have different physical nature (technical data of the aircraft, data of its power plant, onboard equipment, the cost of the sample as a whole or its individual components, design, etc.).

The purpose of this article is to develop indicators and criteria for assessing the effectiveness of an unmanned aeronautical complexes use.

Presentation of main material research

It should be noted immediately that the performance indicators for reconnaissance and striking AV should be significantly different as they evaluate the different qualities of these vehicles, therefore, the partial indicators for them should be different. At the same time, even for the same type of AV, it is not always possible to use the same indicators, because they can vary in flight technical characteristics, the level of equipment, devices of provision. However, in some cases, it is possible to differentiate groups (for example, reconnaissance complexes) by some common features and find common indicators for them, useful for comparative evaluation.

Modern UAV assigns more complex tasks, in particular, observing the battlefield: for the movement of troops and military equipment, observing the identified important objects, adjusting their coordinates, determining the results of the task of strikes against the enemy. In this case, the trajectory of the flight may have a more complex profile (fig. 1): reversals in horizontal and vertical planes, bends, height set and decrease. In this case, the trajectory can be repeatedly intersect. While searching for single targets, the trajectory may have the shape of a loop to fly a given boundary or consist of two parallel lines in the search for a point goal, and etc.

In addition, many optical systems on modern UAV have variable fields of view: a wide field of view is used to search the contour of the intended target, also the angle of field view decreases and repeat enter on the target was performed for the more precise recognition. In this case, the width of the viewing band B decreases, the viewing area is also reduced.

In the future, under the area of intelligence, we will understand $S_{eq} = BVt$. Since we do not interested in physical space, it is determined in flight in the general case

$$S = S_{eq} = BVt. \quad (1)$$

If you represent the viewing angle of the camera in the form of a spotlight, so S will be the trace of this spotlight on the earth's surface while performing any reconnaissance maneuver. Such a "spotlight" should "light" while looking for any purpose: point, linear, plane, leaving behind a trace in the form of an equivalent area. In this case, the value of B can change (for example, while performing repetitions on a target) and it should be taken into consideration while calculating the area.

Reconnaissance flights are usually carried out by scanning the terrain at a certain altitude in the given lane and the given depth. To simplify the problem we will consider the flight of the constant aerial vehicles (with the constant speed).

The height of the flight was determined by the capabilities of the reconnaissance equipment, the characteristics of the aircraft itself, and also depends on the possible aerial vehicles to the enemy air defense, meteorological conditions, and etc. At the same time, one of the main requirements to altitude is the exclusion of damage to the UAV by simple devices: artillery and weapons and anti-aircraft missile systems.

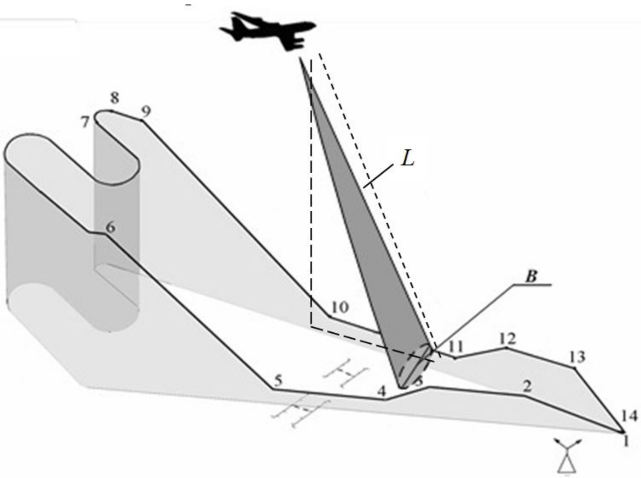

Fig. 1. Spatial flight trajectory while searching for a target

The bandwidth of the seizure *of* the terrain B is determined by the angle of the field of the camera view 2β and the flight altitude H:

$$B = 2H tg\beta \approx H(2\beta). \quad (2)$$

In addition, successful photography depends on the resolution of the equipment, the illumination of the target, its reflecting properties, radiation diffusion, and etc. Obviously, with the increase in the distance of the optical system lens from the target and the increase in field of view, the level of detail of the shooting decreases.

The main task of comparative analysis is to select a better sample from some set of alternatives. Therefore, the primary task of the analysis is to determine the indicators for the comparative assessment.

Proceeding from the above, the quality indicators of the reconnaissance UAV should take into consideration [1-8]:

- flight characteristics of the aerial vehicles, its maneuverability;
- feature of taking off and landing;
- parameters of the intelligence equipment (fields of view and inspection, providing the necessary resolution on the ground, etc.);
- types and data of weapons (for striking complexes);
- operational characteristics (durations of different types of preparations, time of coagulation and deployment of the complex, etc.);
- the cost of the complex;
- the efficiency of the task.

Based on the objectives, you can outline the effectiveness of combat use. According to the authors, indicators in the first approximation can be used the following.

1. The productivity of W search. According to the big amount of authors, the search performance of the reconnaissance UAV can be quantitatively quantified by the magnitude of the area being revised per unit time [1-8]. The average value of this indicator can be obtained from formula (1), dividing its right and left sides at time t:

$$W = \frac{S}{t} = \frac{BVt}{t} = BV = VH(2\beta), \quad (3)$$

where V is the average flight speed, B is the bandwidth of the camera, t is the time of the reconnaissance. Modern optoelectronic systems (OES) have several angles of view field: narrow, wide, intermediate. Each of them has its value s_1. In addition, the corners of the field of view may be unequal (fig. 2) for the azimuth ($2\beta_1$), and the angle of the place ($2\beta_2$).

As a result, the linear dimensions of objects reproduced by the OES will also be uneven in the direction of B_1 and B_2. By the analogy with formula (2) we will have $B_1 = H_1(2\beta_1)$, $B_2 = H_2(2\beta_2)$. Because usually, the flight altitude H is substantially larger than the linear dimensions of the site, it is possible to take $H_1 \approx H_2 \approx H$. However, at small angles, instead of the height of H_1, it is necessary to take a range.

Given the above, the size of the shooting area

$$s_1 = B_1 B_2 = H^2 (2\beta_1)(2\beta_2). \quad (4)$$

As can be seen from formula (4), s_1 increases with increasing height in proportion to its square, but thus deteriorates the degree of the image detail on the screen of the receiver. At some height, the detail reaches the critical one, after which the observed objects become indistinguishable.

While searching for different objects, there is not using the angle, but the linear resolution d (detail), which allows you to find the kind of the desired target. The less detail d, the clearer the image on the screen. Therefore, for the exploration of small-scale targets, the linear resolution of the OES should be as small as possible (and therefore better). Specialists in the United States have developed detailed requirements that should ensure the identification of typical objects with a certain degree of clarity (table 1).

Table 1 – **Requirements for detailing the typical objects**

Type of an aim	The resolution required for the purpose classification, m				
	Detection	Identification			Technical analysis
		total	accurate	descriptive	
Auto-transport	1,5	0,6	0,3	0,06	0,045
Aircraft	4,5	1,5	1	0,15	0,045
Rocket-artillery devices	1	0,6	0,15	0,05	0,045
Radar stations	3	1	0,3	0,15	0,015
Positions operational-tactical missiles and anti-aircraft missile systems	3	1,5	0,6	0,3	0,045
Ships	8	4,5	0,6	0,3	0,045
Bridges	6	4,5	1,5	1	0,3
Airfieldconstructions	6	4,5	3	0,3	0,15
Military units	6	2	1,2	0,3	0,15
Railway nodes	15 - 30	15	6	1,5	0,15
Transport communications	6 - 9	6	1,8	0,6	0,4
Urban buildings	60	30	3	3	0,75
Terrain relief	-	90	4,5	1,5	0,75

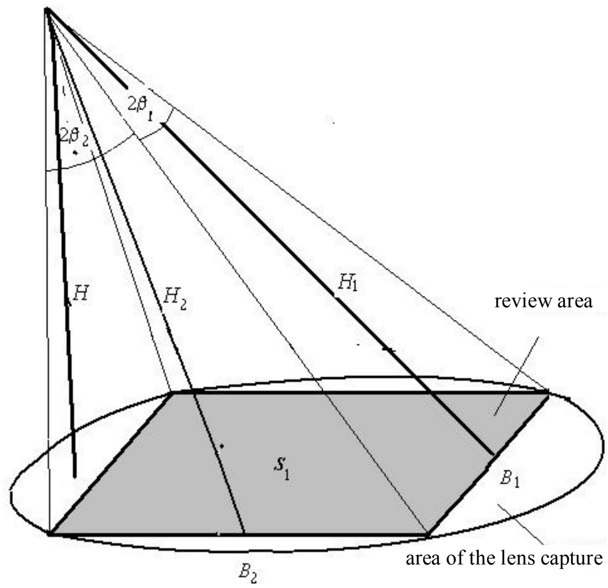

Fig. 2. Scheme of site construction for aim identification

Moreover, the clarity is characterized by five signs [7]:

1. Detection is the localization of the desired target, determining its coordinates.
2. General identification is defining the target class.
3. Accurate identification is defining the type of target within the specified class.
4. Descriptive identification is the identification of the configuration, the size of the target, its constituent parts.
5. Technical analysis of the object is determining the membership, the most probable characteristics, specific features.

For example, if the optoelectronic system has a linear detail of d = 4.5 m, then it can be established and this object will be similar to an airplane, at d = 1.5 m it is possible to detect the type of this aircraft, and at d = 1 m to get more accurate information about the aircraft (its affiliation, destination, etc.). Thus, the value of d is determined by the specific task of the intelligence. By analogy with formula (2), it is related to the angular resolution due to the flight height:

$$d = H(2\omega) \text{ or } H = d/(2\omega). \quad (5)$$

The formula shows that at 2ω=const the linear resolution is related to the height proportional to the relationship. As the height increases, it also increases the image on the screen worsens and the object will be indistinguishable. For this reason, the maximum height of intelligence is limited. Consequently, in order to obtain conditional photographs, the flight altitude must be as low as possible. Substituting the value of height from (5) into the formula (4), we obtain an expression for determining the site

$$s_1 = d^2 \cdot (2\beta_1)(2\beta_2)/(2\omega)^2 = d^2 k_{os}, \quad (6)$$

where $$k_{os} = (2\beta_1)(2\beta_2)/(2\omega)^2, \quad (7)$$

k_{os} is the coefficient of the optical system, i.e. its integral characteristic. It combines the viewing angles and the angular resolution of the optical system.

The better resolution (less than 2ω) and the larger viewing angles of the system, the greater the coefficient, and, consequently, the larger area will be removed with a given detail of the object.

Knowing the value of s_1, the total exploration area ΔS and the coefficient of its overlapping k_{overlap}, it is possible to calculate the required amount of information in the number of required images

$$\Delta n = k_{\text{overlap}}\, \Delta S/s_1 = k_{\text{overlap}} BV\Delta t/s_1 = k_{overlap}\Delta t/s_1, \quad (8)$$

and the average speed of the snapshots

$$\dot{n} = \Delta n/\Delta t = k_{overlap} \cdot W/s_1 \,. \quad (9)$$

Obviously, the value of Δn is proportional to the amount of primary information that necessary to be preserved and/or transferred to the ground (to the control point or to another consumer).

2. The cost of UAV. It is accepted to evaluate it on several indicators:

- an initial cost of complex C_0;
- cost of exploitation $C_{\text{operation}}$;
- the cost of the flight hour C_{fh};
- the cost of shooting a plot of area s1 of a given area C_{s1};
- the cost of the reconnaissance flight is the C_{rec}.

Initial cost consists of the cost of developing and manufacturing a glider AV with all onboard systems, the cost of the payload and the cost of the ground part of the C_{ground}, which ensures the operation of the AV:

$$C_0 = C^m_{AV} m_{AV} + C^m_{usl} m_{usl} + C_{ground}, \quad (10)$$

where C^m_{AV} is the cost of 1 kg of the weight of the glider with the equipment, but without the payload, C^m_{usl} is the cost of 1 kg of payload, m_{AV} and m_{usl} is the mass corresponding to the glider and payload.

Cost of operation can be estimated as follows:

$$C_{operation} = C^t_{operation} t_{operation},$$

where $C^t_{operation}$ is an average cost for 1 hour of operation, t_{res} is the flight resource of AV.

If the predicted (statistical) number of combat missions is N, then the actual resource can be estimated approximately as $t_{res}=Nt_{max}$, where t_{max} is the maximum flight duration.

With these assumptions, the total cost of a complex can be estimated in the form of an amount

$$C_{UAV} = C_0 + C_{operation}. \quad (11)$$

One of the most important indicators for the comparative estimation of UAV is the cost of the flight hour. It can be estimated from the sum of the initial cost, the maximum flight time t_{max} and multiplicity of application is the number of takeoffs N:

$$C_{fh} = \frac{C_0}{t_{max} N} + C^t_{operation}. \quad (12)$$

The denominator in this formula defines the flight of the AV for the intended lifetime. We will now determine the cost of the UAV flight. If the probability of fulfilling the task with taking into consideration all possible operating factors (performance of equipment, radio indication, overcoming the enemy's air defense, the possibility of destruction of anti-aircraft devices or aircraft of the enemy, etc.) is equal to p_{enemy}, then the cost of such a flight will be estimated by the magnitude

$$C_{enemy} = C_{s1} * n / p_{enemy}. \quad (13)$$

The value of C_{s1} can be determined by the flight time and the cost of the flight hour. Indeed, while shooting a site s_1 (fig. 2) AV passes the path $B_2= =H_2(2\beta_2).=V\Delta t_1$. Hence the time of the passage of this site

$$\Delta t_1 = H_2(2\beta_2)/V, \quad (14)$$

then $$C_{s1} = C_{fh}\Delta t_1 = C_{fh} \cdot H_2(2\beta_2)/V. \quad (15)$$

Obviously, this indicator will be one of the most significant. It responds to a specific question: what resources should be spent to identify a specific target (for example tank, aircraft, etc.) that can be located on a site $s_1 = d^2 k_{OES}$, where d is the linear resolution of the OES.

3. Efficiency. The success of intelligence depends, basically, on the obtaining time information and its quality. As you know, the total flight time of the reconnaissance UAV consists of the execution time of individual stages: preparation of the UV before departure; flight to the exploration zone; conducting own intelligence; processing and storage of data (if necessary); data transmission to the control point; processing and data transmission to the consumer.

The value of t characterizes the efficiency of obtaining information from the intelligence officer. In some cases, time t can be no less important than the cost of the complex. Time of passage to the intelligence zone can be roughly calculated as $t_{zone} = L/V + (2...3)$, where L is the separation of the exploration zone from the start point, V is the flight speed. It can be selected depending on the task: either maximum or cruising. 2 ... 3 min is an amendment to the time for the acceleration of the AV and set of altitudes for intelligence conducting. The time for conducting intelligence t_{int} can be determined in two ways:

– for the purpose of the route and flight profile by conduction of engineering-navigational calculation;

– at the task of the area exploration by the formula (3) $t_{int} = S/W$. If the intelligence conduct with the overlapping terrain, then the result will be multiplied by the overlap factor.

In the case of an arbitrary flight, the time of intelligence is determined by the fuel reserve $t_{int} = m_{fint}/q_ч$, where m_{fint} is the supply of fuel for performing intelligence (with the exception of all regulated residues), q_h is the hourly fuel consumption.

The usual time of information processing repeatedly exceeds the time of its receipt with the necessary detail, and the obtained data have to be saved if their transfer from the board to the ground in real time does not have time to be processed. On the first intelligence UAV, the information was stored on the board drives and processed after the flight. Naturally, the operational value of such an intelligence left much to be desired.

If during the performance of the reconnaissance flight the task was not viewing a certain area, but to identify targets for some other features, then the total area can be calculated as $S = ns1$ in a certain zone.

Conclusions

Thus, the criterion of cost C_{s1} will be the same for both discrete and panoramic images.

The proposed indicators W, C_{s1} and t correspond to the categories "productivity - cost - efficiency". They can be used to evaluate information obtained using equipment that works in a mode of fixed, continuous shooting of individual areas. These indicators can be used to benchmark several intelligence systems.

The direction of further research should be considered the development of a mathematical model of the functioning of unmanned aviation complexes under counteraction conditions.

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Рецензент: д-р техн. наук, проф. М. А. Павленко,
Харківський національний університет Повітряних Сил імені Івана Кожедуба, Харків
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Показники та критерії оцінювання ефективності застосування безпілотних авіаційних комплексів

Р. М. Животовський, Ю. О. Горобець, О. С. Момiт

Воєнні конфлікти кінця XX – початку XXI ст. характеризуються застосуванням великої кількості нового озброєння, яке дозволило ворогуючим сторонам максимально дистанціюватися від безпосереднього зіткнення один з одним. Одними із новітніх зразків озброєння на полі бою стали безпілотні авіаційні комплекси, які під час воєнних конфліктів довели свою здатність щодо ведення повітряної розвідки, ураження об'єктів та виконання інших завдань бойового забезпечення. Можливість успішного вирішення різноманітних завдань за допомогою безпілотних авіаційних комплексів продемонстровано під час воєнних конфліктів на Близькому Сході (1982–2008), Балканах (1999), в Афганістані (2001–2008) та на Кавказі (1994–2008). На сьогоднішній час існує велика кількість різноманітної літератури про способи застосування безпілотних авіаційних комплексів під час збройних конфліктів останніх десятиріч. Проте єдиного підходу з оцінювання ефективності застосування безпілотних авіаційних комплексів спеціального призначення в відомих джерелах не розроблено. В зазначеній статті авторами запропонований показники та критерії оцінки ефективності застосування безпілотних авіаційних комплексів спеціального призначення. В ході зазначеного дослідження авторами використані основні положення теорії складних технічних систем; метод експертних оцінок; метод аналізу ієрархій, методів багатовимірного порівняльного, загальнонаукового та структурно-функціонального аналізу. Запропоновані в роботі показники та критерії оцінки ефективності застосування безпілотних авіаційних комплексів спеціального призначення можуть бути використані для оцінки інформації, одержуваної за допомогою апаратури, що працює у режимі як фіксованої, так безперервної зйомки окремих ділянок місцевості. Запропоновані в статті показники можуть бути використані для порівняльної оцінки декількох безпілотних авіаційних комплексів спеціального призначення, що дозволяють провести оцінку рівня технічної досконалості безпілотних авіаційних комплексів та обрати найбільш досконалі для виконання конкретного типу завдань.

Ключові слова: безпілотні авіаційні комплекси, воєнні конфлікти, показники оцінки ефективності, технічні характеристики, розвідка, критерії.

Показатели и критерии оценки эффективности применения беспилотных авиационных комплексов

Р. Н. Животовский, Ю. А. Горобец, А. С. Момит

Военные конфликты конца XX - начала XXI в. характеризуются применением большого количества нового вооружения, которое позволило враждующим сторонам максимально дистанцироваться от непосредственного соприкосновения друг с другом. Одним из новейших образцов вооружения на поле боя стали беспилотные авиационные комплексы, которые во время военных конфликтов доказали свою способность по ведению воздушной разведки, поражения объектов и выполнения других задач боевого обеспечения. Возможность успешного решения различных задач с помощью беспилотных авиационных комплексов продемонстрировано во время военных конфликтов на Ближнем Востоке (1982-2008), Балканах (1999), в Афганистане (2001-2008) и на Кавказе (1994-2008). На сегодняшнее время существует большое количество разнообразной литературы о способах применения беспилотных авиационных комплексов во время вооруженных конфликтов последних десятилетий. Однако единого подхода по оценке эффективности применения беспилотных авиационных комплексов специального назначения в известных источниках не разработано. В указанной статье авторами предложены показатели и критерии оценки эффективности применения беспилотных авиационных комплексов специального назначения. В ходе указанного исследования авторами использованы основные положения теории сложных технических систем; метод экспертных оценок; метод анализа иерархий, методы многомерного сравнительного, общенаучного и структурно-функционального анализа. Предложенные в работе показатели и критерии оценки эффективности применения беспилотных авиационных комплексов специального назначения могут быть использованы для оценки информации, получаемой с помощью аппаратуры, работающей в режиме как фиксированной, так непрерывной съемки отдельных участков местности. Предложенные в статье показатели могут быть использованы для сравнительной оценки нескольких беспилотных авиационных комплексов специального назначения, позволяющие провести оценку уровня технического совершенства беспилотных авиационных комплексов и выбрать наиболее совершенные для выполнения конкретного типа задач.

Ключевые слова: беспилотные авиационные комплексы, военные конфликты, показатели оценки эффективности, технические характеристики, разведка, критерии.