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Evaluation of the effectiveness of the protection of troops from unmanned aerial vehicles by the forces and means of engineering support

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Abstract. The relevance of the study is due to the high level of troop losses from enemy unmanned aerial vehicles during hostilities and the need to increase the level of their protection by engineering support forces and means, by implementing a set of engineering measures to fortify military facilities and camouflage them with service camouflage kits. In this regard, this article is aimed at identifying the factors that in modern conditions most affect the effectiveness of the engineering protection of military facilities and taking these factors into account when developing a methodical approach to evaluating the effectiveness of the protection of troops from unmanned aerial vehicles by the forces and means of engineering support , the use of which will make it possible to obtain more correct evaluation results and, based on them, to develop effective practical recommendations for improving the protection of troops from unmanned aerial vehicles during hostilities. To solve this problem, the method of mathematical modeling was used, which allows describing the complex process of engineering protection of military facilities in the language of mathematics and obtaining results for the further development of the above recommendations. The article presents a structural and logical diagram of a methodological approach to assessing the effectiveness of troop protection against unmanned aerial vehicles by engineering support forces and means, describes the stages of assessment, basic initial data, partial and generalized performance indicators, criteria and conditions for assessment. The materials of the article are of practical value for command-and-control bodies that, when planning the use of troops, perform calculations to determine the required amount of engineering measures to increase the survivability of troops during hostilities and reduce their losses from unmanned aerial vehicles.

Keywords: unmanned aerial vehicles, engineering support, military facilities.

Introduction

The analysis of the Russian-Ukrainian war shows that the enemy is increasingly using unmanned aerial vehicles (UAVs) to defeat our troops to reduce their combat capability and gain an advantage on the battlefield (Zaluzhnyi, Moisiuk, Shaptala, 2022). Since the beginning of the full-scale invasion of Ukraine by Russian troops, the Armed Forces of Ukraine (hereinafter - the AFU) have gained some experience in protecting their facilities from UAVs, by hiding them in field fortifications and camouflaging them with service camouflage kits (Office of the President of Ukraine, 2022). However, the losses of our troops from enemy UAVs during hostilities are still high, especially in areas where troops are stationed for a long time and where the enemy conducts targeted UAV strikes (Zaluzhnyi, Moisiuk, Shaptala, 2022). This is a problem that directly affects the survivability of our troops during hostilities and the fulfilment of their combat missions. To solve this problem, it is necessary to develop recommendations for increasing the protection of troops from UAVs by engineering support forces and means, by sheltering their facilities in field fortifications

and camouflaging them with service camouflage kits. This task requires, first, the development of a methodological approach to assessing the effectiveness of troop protection against UAVs by engineering support forces and means, which will be used to develop the above recommendations.

Methodological Framework

The analysis of modern armed conflicts shows that the warring parties widely use UAVs to destroy enemy targets. The greatest success in protecting troops from UAVs has been achieved by the armies of the United States, Turkey, France, and Israel, whose troops have been directly involved in hostilities in the Middle East and Africa (Tkachenko and Danik 2002). The armies of these countries, along with traditional measures to protect troops from UAVs by air defence systems, effectively use support forces and means, in particular, electronic warfare forces and means to suppress the electronic reconnaissance and guidance systems of the ground and airborne components of UAVs with radio interference, engineering support forces and means to carry out engineering measures for fortification equipment (hereinafter - FE) and engineering measures for camouflage, both individual troops and areas of their concentration, as well as chemical, biological, radiation and nuclear protection forces and means to conceal troops' objects by means of aerosol camouflage. Engineering support forces and means have gained particular importance in the implementation of measures to protect troops from UAVs, but the practice of their use shows that they imperfectly combine existing methods and techniques of engineering protection, which significantly reduces their effectiveness (Romanchenko, Zahorka, Butenko, Deinega, 2011). The experience gained in the engineering protection of troops from UAVs in the Russian-Ukrainian war suggests that by implementing measures to protect troops from the effects of military operations and camouflaging troops with service camouflage kits, the effectiveness of protecting troops from UAVs can increase by 1.5-2 times (Voloshchenko, Kushnirenko, Chernykh, 2020), (Kotsiuruba, Datsenko, Dachkovsky, Cherevko, Androshchuk, Tsybizov, Kryvtsun, 2021).

Results and Discussions

Since the beginning of the full-scale invasion of Ukraine by Russian troops, partial tasks have been solved to protect military facilities from UAVs and to develop a comprehensive methodological apparatus for a comprehensive assessment of the effectiveness of the protection measures that were being implemented at that time. Methodological recommendations on this issue were developed by specialized research units of research institutions of the Ministry of Defence of Ukraine and the Armed Forces of Ukraine. These recommendations set out the general principles and approaches to assessing the effectiveness of troop protection measures against UAVs, considering the peculiarities of troop damage in modern operations (combat actions), identify the main patterns of emergence and development of positive and negative impact factors, and analyse the state of the main components of the system of comprehensive troop protection created in Ukraine and the Armed Forces of Ukraine. Tkachenko and Danik (2002) describe the methodological apparatus for assessing the effectiveness of measures to protect troops from UAVs by air defence and electronic warfare forces and means. Voloshchenko, Kushnirenko, Chernykh (2020) and Kotsiuruba, Datsenko et al. (2021) provide methods for calculating the stability of the coating of field fortifications to protect troops from hinged fire. However, currently, the sources of information known to the author do not contain a methodological apparatus (method, methodological approach) for assessing the effectiveness of protecting troops from UAVs by engineering support forces and means. In developing a methodological approach to assessing the effectiveness of troop protection against UAVs by engineering support forces and means, certain provisions of probability theory (Wentzel, 1972), engineering support modelling methods (Yurkov, 1990), as well as a methodology for assessing the survivability of point military objects in the event of targeted attack and a comprehensive methodology for assessing the effectiveness of camouflage measures to conceal and imitate military objects (Yurkov, 1990) were used. As a criterion for assessing the

effectiveness of troop protection against UAVs by engineering support forces and means, the average degree of troop protection against UAVs ($k_{ІП}^{зах.В}$) was chosen, which is achieved by engineering support forces and means by performing the required amount of engineering work on the FE of military objects and their masking with time sheets camouflage kits. The adopted performance indicator, its thresholds and conditions for evaluation are shown in Figure 1.

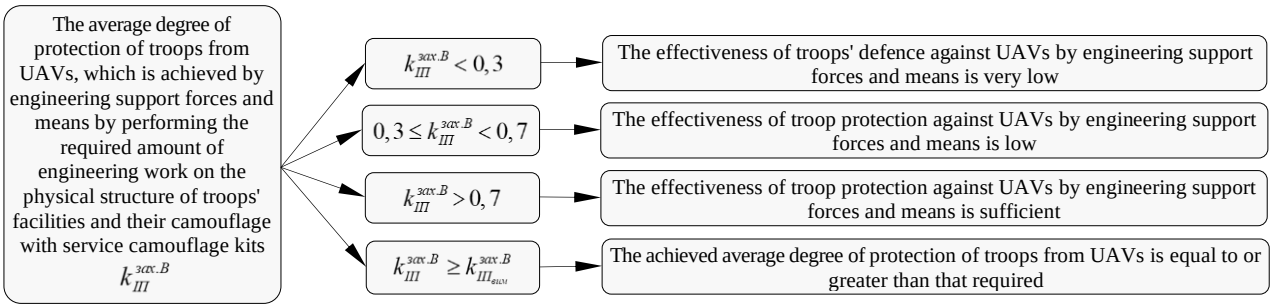


Figure 1. The adopted performance indicator, its thresholds and conditions for assessing the effectiveness of troop protection against UAVs by engineering support forces and means (option)

The structural and logical diagram of the methodological approach is shown in Figure 2.

According to Fig. 2, the effectiveness of protecting troops from UAVs by engineering support forces and means is carried out in the following stages.

At stage 1, the initial data is generated.

At stage 2, indicators, criteria, and conditions are selected to assess the effectiveness of troop protection against UAVs by engineering support forces and means.

At stage 3, the selected indicators are calculated and the effectiveness of troop protection against UAVs by engineering support forces and means is assessed.

For this purpose, in 3.1, the number of troop objects that will be FE by forces and means of engineering support for the time determined by the commander (commander) is determined, *units*:

$$N_{ФО}^{ОВ} = M_{ФО_{ОВ}}^{ІП} \cdot (1 - \beta_{зм}) \cdot T^{ФО} \cdot k_{ФО}^{ум}, \quad (1)$$

where $M_{ФО_{ОВ}}^{ІП}$ is the capabilities of engineering support forces and means for the FE of military facilities, *units/hour* (Ivan Cherniakhovskyi National Defence University of Ukraine, 2015); $\beta_{зм} = 0,3...0,4$ is the norms of irrecoverable losses of engineering equipment for the FE (Order of the Armed Forces of Ukraine, 2023); $T^{ФО}$ is the time determined by the commander (commander) for the FE of military facilities, *hour*; $k_{ФО}^{ум}$ is the average coefficient of FE conditions (Tables 1-3) (Ivan Cherniakhovskyi National Defence University of Ukraine, 2015).

Table 1: Coefficient of soils and methods of their development, $k_{гр}$

Methods of soil development	Soil			
	Lightweight	**Medium**	**Solid**	**Rocky**
Manually and by means of mechanization	1,1-1,2	1,0	0,6-0,7	0,2-0,3
Manually and with explosives	0,7			0,3-0,55
Manually, by means of mechanization and explosives	0,75			0,55
By means of mechanization and explosives	0,8			0,7

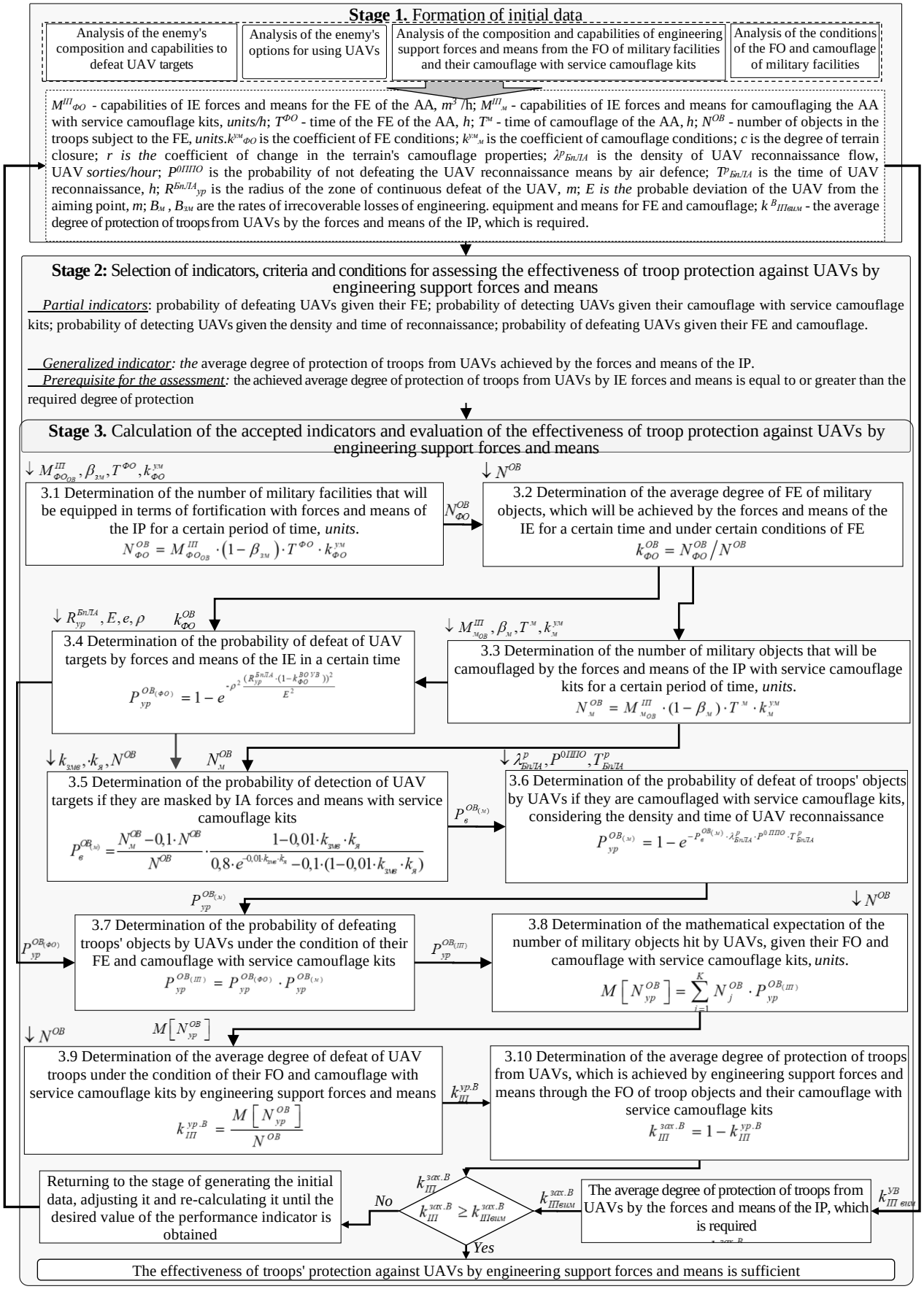


Figure 2. Flowchart of the methodological approach to assessing the effectiveness of troop protection against UAVs by engineering support forces and means

Table 2: Time of day coefficient, k_o

Time of day		
Day	**Evening (morning)**	**Night**
1	0,85	0,7

Table 3: Air temperature coefficient in the contaminated area, k_t

Air temperature, $^{\circ}C$	**- 20**	**- 10**	**0**	**+10**	**+ 20**	**+ 30**
k_t	0,8	0,75	0,7	0,6	0,5	0,1

Section 3.2 determines the average degree of FO of troop objects that will be achieved by engineering support forces and means within the time specified by the commander (commander):

$$k_{ФО}^{OB} = N_{ФО}^{OB} / N^{OB}, \quad (2)$$

where $N_{ФО}^{OB}$ is the number of troops' objects that will be FE by forces and means of engineering support within the time specified by the commander (commander), *units*; N^{OB} is the total number of troops' objects for FE, *units*.

In 3.3, the number of troop objects to be camouflaged by engineering support forces and means with service camouflage kits within the time specified by the commander (commander) is determined, *units*:

$$N_{м}^{OB} = M_{м_{OB}}^{ІП} \cdot (1-\beta_{м}) \cdot T^{м} \cdot k_{м}^{ум}, \quad (3)$$

where $M_{м_{OB}}^{ІП}$ - capabilities of engineering support forces and means for camouflage with service camouflage kits, *units/hour* (Ivan Cherniakhovskyi National Defence University of Ukraine, 2015); $\beta_{м} = 0,1...0,3$ - norms of irrecoverable losses of service camouflage kits (Order of the Armed Forces of Ukraine, 2023); $T^{м}$ - time determined by the commander (commander) for camouflaging troops, *hours*; $k_{ФО}^{ум}$ - average coefficient of conditions for camouflaging troops with service camouflage kits (Tables 2-4) (Ivan Cherniakhovskyi National Defence University of Ukraine, 2015).

Table 4. Terrain camouflage coefficient by months of the year and type of forest plantations, $k_л$

Forest type	**Values by month of the year**											
	1	2	3	4	5	6	7	8	9	10	11	12
Coniferous	1	1	1	1	1	1	1	1	1	1	1	1
Deciduous	0,5	0,5	0,6	0,8	0,9	1	1	1	0,9	0,8	0,5	0,5
Mixed	0,75	0,75	0,8	0,9	0,95	1	1	1	0,95	0,9	0,75	0,75

Experience has shown that the radius of the UAV's area of destruction decreases significantly with the growth of the average degree of military objectives FE (Fig. 3).

That is why the mathematical dependence used in (Methodology for assessing the survivability of point military objects under targeted attack, 1990) to determine the probability of defeating military objects in the event of a targeted attack is supplemented by the indicator $k_{ФО}^{OB}$ (2), the growth of which reduces the radius of total destruction of UAVs and, accordingly, the probability of defeating these military objects in the event of their FE:

$$P_{ур}^{OB_{(ФО)}} = 1 - e^{-\rho^2 \frac{(R_{ур}^{БпЛА} \cdot (1-k_{ФО}^{ВО УВ}))^2}{E^2}}, \quad (4)$$

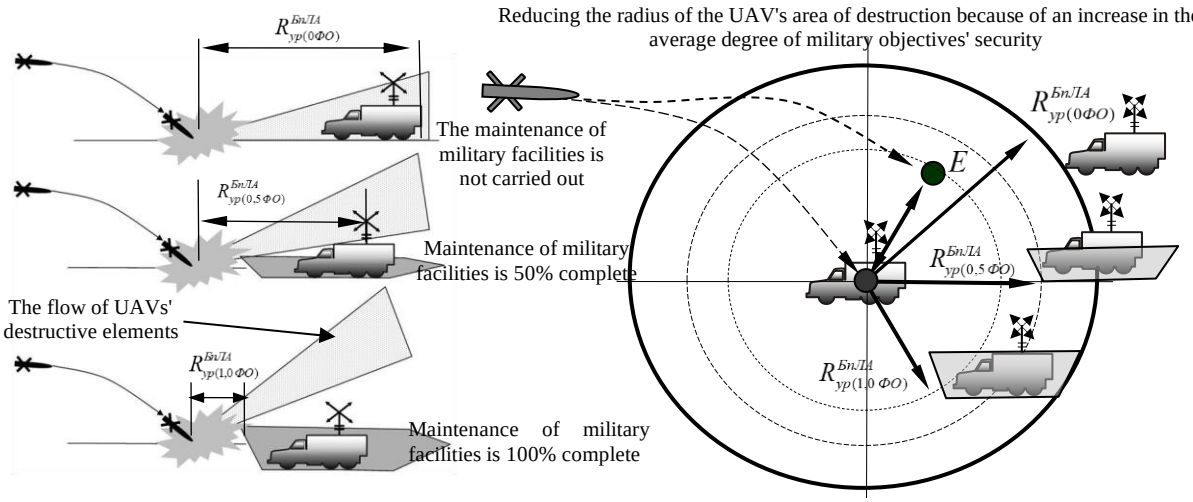


Figure 3. Reducing the radius of the UAV's area of destruction with the growth of the average degree of military objectives FE

where $k_{ФО}^{OB}$ is the average degree of FE of military objects achieved by the forces and means of engineering support; $R_{ур}^{БпЛА}$ is the radius of the UAV's zone of continuous defeat (Technical Report (Shahed-131). Kyiv. 2022.), m; E - probable deviation of the UAV from the aiming point (Technical Report (Shahed-131). Kyiv. 2022), m; $\rho = 0,477$ - Laplace's coefficient.

In 3.5, by analogy with (Comprehensive Methodology, 1993), the probability of detection of troop objects by UAVs is determined if they are camouflaged by engineering support forces and means with service camouflage kits. To obtain more correct results, the mathematical dependence used in (Comprehensive Methodology, 1993) to determine the probability of detection of troop objects by enemy intelligence means is supplemented by the quality coefficients of service camouflage kits $k_{я}$ and changes in the camouflage properties of the terrain $k_{змв}$, which directly depend on the category of camouflage kits, terrain, its forestation, type of forest and vegetation cover, as well as the season, time of day, nature of fog and frequency of cloudy days in the area of military operations:

$$P_{в}^{OB_{(м)}} = \frac{N_{м}^{OB} - 0,1 \cdot N^{OB}}{N^{OB}} \cdot \frac{1 - 0,01 \cdot k_{змв} \cdot k_{я}}{0,8 \cdot e^{-0,01 \cdot k_{змв} \cdot k_{я}} - 0,1 \cdot (1 - 0,01 \cdot k_{змв} \cdot k_{я})}, \quad (5)$$

where $N_{м}^{OB}$ is the number of military objects camouflaged by service camouflage kits, *units*; N^{OB} is the total number of objects in the military that are subject to camouflage, *units*; $k_{я}$ is the quality factor of service camouflage kits (determined by an expert survey); $k_{змв}$ is the average coefficient of change in the camouflage properties of the terrain (Table 5) (Ivan Cherniakhovskyi National Defence University of Ukraine, 2015).

In 3.6, according to the Comprehensive Methodology for Evaluating the Effectiveness of Camouflage Measures for Concealment and Imitation of Military Objects, 1993, the probability of UAVs hitting military objectives is determined if they are camouflaged with service camouflage kits, as well as considering the density of the UAV reconnaissance flow and the probability of not hitting UAVs by air defence systems:

$$P_{ур}^{OB_{(м)}} = 1 - e^{-P_{в}^{OB_{(м)}} \cdot \lambda_{БпЛА}^{р} \cdot P^{0\,ППО} \cdot T_{БпЛА}^{р}}, \quad (6)$$

Table 5. Coefficients of change in the camouflage properties of the terrain, $k_1...k_7$

№ n/a	Name of the coefficients	Meaning.
1.	Terrain coefficient, k_1 (mountainous, rugged, flat)	0,4; 0,7; 1,0
2.	Forest cover, k_2 (small, medium, large)	0,5; 0,8; 1,0
3.	Time of year coefficient, k_3 (winter – spring, summer – fall)	0,75; 1,0
4.	Forest type and vegetation cover factor, k_4 (deciduous, coniferous)	0,5; 1,0
5.	Time of day factor, k_5 (evening – night, morning – day)	0,75; 1,0
6.	Fog Character Coefficient, k_6 (thick, liquid)	0,6; 1,0
7.	Coefficient of the number of cloudy days k_7 (small, large)	0,85; 1,0

where $P_{в}^{ВОУВ_{(м)}}$ is the probability of detecting the objects of the UAV troops if they are camouflaged with service camouflage kits; $\lambda_{БпЛА}^{р}$ is the density of the UAV reconnaissance flow, UAV *sorties/hour*; $P^{0ППО}$ is the probability of not being hit by air defence systems; $T_{БпЛА}^{р}$ is the time of UAV reconnaissance, *hour*.

Section 3.7 determines the probability of defeating troops' objects by UAVs, if they are equipped with FE and camouflage with service camouflage kits:

$$P_{ур}^{ОВ_{(ІП)}} = P_{ур}^{ОВ_{(ФО)}} \cdot P_{ур}^{ОВ_{(м)}}. \quad (7)$$

In 3.8, we calculate the mathematical expectation of the number of military objects that will be hit by UAVs, if they are equipped with FE and camouflage with service camouflage kits, *units*:

$$M\left[N_{ур}^{ОВ}\right] = \sum_{j=1}^{K} N_{j}^{ОВ} \cdot P_{ур}^{ОВ_{(ІП)}}, \quad j = \overline{1,K}. \quad (8)$$

In 3.9, the average degree of defeat of troops by UAVs is determined, provided that the engineering support forces and means carry out a set of engineering measures to protect the physical environment of military facilities and camouflage them with service camouflage kits:

$$k_{ІП}^{ур.В} = \frac{M\left[N_{ур}^{ОВ}\right]}{N^{ОВ}}. \quad (9)$$

Section 3.10 defines the average degree of protection of troops from enemy UAVs, which is achieved by engineering support forces and means by performing the required amount of engineering measures to protect the physical environment of troop objects and their camouflage with service camouflage kits:

$$k_{ІП}^{зах.В} = 1 - k_{ІП}^{ур.В}. \quad (10)$$

The resulting value $k_{ІП}^{зах.В}$ is compared with the value required by $k_{ІП_{вим}}^{зах.В}$. If the accepted condition $k_{ІП}^{зах.В} \geq k_{ІП_{вим}}^{зах.В}$ is met, it is considered that the effectiveness of protecting troops from UAVs by engineering support forces and means is sufficient. If this condition is not met, the algorithm of the proposed methodological approach provides for a return to the stage of generating the initial data, adjusting them by the number of means for FE, camouflage or the time of execution of these

measures, and repeating the calculations until the desired value of the accepted performance indicator is reached.

Conclusion

The peculiarities of the proposed methodological approach are the consideration of the most important indicators for the protection of troops from UAVs, the values of which numerically characterize the main parameters of the combat use of UAVs, as well as the most influential on the effectiveness of engineering protection conditions for the implementation of measures for the protection of troops and camouflage with service camouflage kits (Kotsiuruba, Datsenko, Dachkovsky, Tkach, Holda, Holda, Klontsak, Mykhailova, 2021), (Kosenko, Voloshchenko, Kushnirenko, 2022), (Voloshchenko, Kovbasa, 2020), (Sukhodolia, 2016). Considering these indicators and parameters allows us to obtain more correct assessment results and, on their basis, develop more effective practical recommendations for improving the protection of troops from UAVs by engineering support forces and means. The author believes that his approach to assessing the effectiveness of troop protection against UAVs by engineering support forces and means can be useful for improving the existing methodological apparatus for assessing the effectiveness of troop protection in modern operations (combat operations), as well as for assessing the effectiveness of the use of engineering units designed to increase the survivability of troops. Further research in this area will be aimed at developing a comprehensive methodology for assessing the effectiveness of troop protection against UAVs by engineering support forces and means.

Recommendations

The materials of the article are of practical value for management bodies that, when planning the use of troops, perform calculations to determine the required amount of engineering protection measures to increase the survivability of troops during hostilities and reduce their losses from UAVs.

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