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DRONES AS THE CRUCIAL ELEMENT FOR AIR DEFENSE BUILDING AGAINST DRONES AND CRUISE MISSILES AT THE REAR AND BATTLEFIELD

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Drones are an effective tool for organizing offensive and defensive actions in modern warfare. The war between Russia and Ukraine has shown that inexpensive drones can cause critical damage to military equipment and civilian objects of high value. As a result, inexpensive drones used for air attacks have become an effective tool for inflicting very large economic losses on the enemy. They also create a great psychological impact on the population, which leads to significant physiological exhaustion. Such losses exceed the cost of the drones themselves by tens, hundreds, and even thousands of times. Indirect losses can reach a cost ratio of even hundreds of thousands of times. Thus, today a new extremely effective combat weapon has appeared on the battlefield. Today, the problem of developing new technical systems for shooting down aerial drones has arisen. Existing air or ground-based systems of various levels (aircraft, helicopters, cannons, surface-to-air missiles, machine guns, etc.) are focused on shooting down fundamentally different air military platforms, such as aircraft, helicopters, cruise missiles, etc. Therefore, these technical systems have a high cost and are too economically unprofitable for shooting down not only manned but even autonomous drones. Therefore, the use of existing platforms to shoot down air drones quickly economically exhausts defenders. The purpose of the article is to develop approaches (designs) for the functioning of an air defense system using special drones both for rear defense and on the battlefield. In this case, it is proposed to use both existing drones and technical platforms, and promising directions for the development of new drones and platforms for air defense are described. A description of existing strike drones and the design of protection systems against them are given. It is proposed to create a new class of drones – drone hunters – to destroy enemy drones. Some platforms for destroying enemy drones are described in detail. A hierarchically organized system for organizing the protection of the country's territory from enemy drones using hunter drones with various structural details is developed. A system for organizing protection from enemy drones on the battlefield is briefly described. A concept for a universal organization of a hierarchically echeloned organization of air defense against enemy drones is formed. It is emphasized that many drone defense platforms can be effective against cruise and/or ballistic missiles. The results obtained in the article form a new approach to developing strategic programs for the development of drones in the conditions of modern warfare.

Keywords*:* attacking drone, hunter drone, air defense, organization, development.

Introduction

Drones are an effective tool for organizing offensive and defensive actions in modern warfare. Drones are divided into reusable drones (for example, reconnaissance drones) and disposable ones (let's call them “kamikaze drones”). The war between Russia and Ukraine has shown that inexpensive drones can cause critical damage to military equipment and civilian objects of high value. As a result, inexpensive drones used for air attacks have become effective in inflicting very large economic losses on the enemy. They also create a great psychological impact on the population, which leads to significant physiological exhaustion. Such losses exceed the drones' cost by tens, hundreds, and even thousands of times. Indirect losses can reach a cost ratio of even hundreds of thousands of times. Moreover, the use of drones to attack the rear structure also has a distinct negative psychological and physiological impact on the population (for example, due to the need to stay in shelters and bomb shelters for a long time, and sometimes several times a night). In addition, during the day it leads to long interruptions in the work process.

As a result, drones have completely changed the nature of warfare today. World War I, thanks to machine guns and cannons, led to the so-called “positional stalemate.” World War II removed tanks and airplanes from the battlefield, which shifted the war to an offensive mode. Russia’s war with Ukraine became a “drone war,” and again led the war to a “positional stalemate.”

This happened because the use of drones made it possible to eliminate the “fog of war”. Now the battlefield becomes completely open to the enemy, and military reinforcements begin to be attacked by drones already a few dozen kilometers from the front line. As a result, there is a need to use a large number of massing means, fighters move and fight in small groups or alone. The concentration of soldiers and equipment for the offensive becomes impossible.

Existing air or ground-based systems of various levels (aircraft, helicopters, cannons, surface-to-air missiles, machine guns, etc.) are focused on shooting down fundamentally different air military platforms, such as aircraft, helicopters, cruise missiles, etc. Therefore, these technical systems have a high cost and are too economically

unprofitable for shooting down not only manned but even autonomous drones. Therefore, the use of existing platforms to shoot down air drones quickly economically exhausts defenders.

Thus, there is a need to consider the possibility of using drones as an element of air defense against drones. This requires a fundamental change in the organization of air defense systems for both the rear and the front line (they must be different). It is also necessary to develop new types of drones (primarily their general design) and to carry out the significant modifications to existing drones. Some approaches to this are described in [1,2].

The purpose of the article is to develop approaches (designs) for the functioning of an air defense system using special drones both for rear defense and on the battlefield.

Attacking drones

Attacking drones fly, as a rule, at a relatively low speed. So, the Iran/Russian Shahed/Gheran kamikaze drones, which are most often used in the Russian-Ukrainian war, have a speed of up to 180-200 km/h. For other drones, as a rule, their speed is also a few hundred kilometers per hour. This is because they are disposable and therefore it does not make sense to use powerful engines and an advanced system for sudden changes in trajectory, flight control, and navigation. The height of the flight is also a few hundred meters, although they can rise to a height of several kilometers.

Most drones used on the battlefield have the same characteristics (line of contact of the parties and 10-50 kilometers on either side).

Defense systems against drones

Systems of defeating drones.

Aircraft/helicopters with air-to-air guns and/or missiles. As a rule, the missiles were self-guided, similar to those used to counter enemy aircraft. The use of airplanes/helicopters is too economically inefficient. In addition, entire classes of drones cannot be destroyed using such platforms. For example, these are small quadcopter drones that can be: 1) kamikaze drones (often FPV), 2) drones that attack with just one/several grenades or bombs, and 3) reconnaissance drones on the battlefield. They have small sizes and small signatures for identification. In addition, it is very difficult to identify them on the battlefield.

Surface-to-air missiles. These missiles were also designed to target aircraft/helicopters and are therefore cost-ineffective to use. In addition, small drones are again a problem precisely because of their characteristics described above.

Platforms with machine guns/cannons (tracked, wheeled, stationary, etc.). Here, the main problem of protection is that the attacking drones in a very short time are in an area where they can be identified, aimed, and fired effectively. Again, these platforms were targeted against aircraft/helicopters, and are therefore not cost-ineffective for shooting down very cheap drones.

Platforms of electronic warfare against drones (“anti-drone guns”, for example). They are aimed directly at countering drones. However, they can counter mainly drones that are controlled by the enemy using radio communication channels. At the same time, in some cases, their drones may have limitations in their use.

Using nets or tapes of various materials that entangle the propeller(s) of drones, causing them to fall to the ground.

Damage by laser radiation. So far, it is expensive, in addition, it requires precise aiming and long enough time to hold the laser beam on small targets (this makes it difficult to destroy drones from the ground). However, recently there was information about the use of lasers to shoot down missiles [3].

(Generally speaking, the main problem in the use of laser weapons arises from the need to obtain an energy flow with high intensity for pumping the working body. This problem can be solved in many ways. For example, with the use of a Magnetohydrodynamic (MHD) generator. For combat conditions, an open-loop MHD generator can be used, which allows for keeping the flow of energy on the order of one to several tens of seconds. The energy of the laser will be enough for the rapid (from 1 to several seconds) destruction of the body of the drone and the cruise/ballistic missile. During the operation of the MHD generator, it is possible to destroy several drones or cruise missiles. Using several MHD generators (and possibly laser systems) it is possible to create a rather dense antiaircraft system. Especially when the MHD-generator + laser system is placed on a moving (flying, wheeled, tracked, water) platform.)

Drone detection/identification systems.

Radar systems have limited use for detecting drones, as they have too small an effective reflective surface. In addition, there are small drones that have too few metal parts. In addition, the radar systems themselves have little resistance against the attack of enemy drones. Defense of such systems requires significant military resources.

Acoustic systems for detecting drones and identifying their position/trajectory can be effectively applied

only to some drones. For example, in Shahed/Gheran, their identification is carried out from the ground using acoustic systems that identify the sound signature of drone engines and propellers (see [4]). For small drones, and even more so on the battlefield, this method will have significant limitations.

Detection/identification of drones by their communication channels with their command center. It can be two-way communication when the drone is controlled by a command center. This can be a one-way communication when the drone is used for enemy position scouting. Passive radar systems can be used here. However, the limitations are that drones and their command center can use narrowly directed radio communication channels.

Visual drone detection systems. There are still quite too few automatic systems for this, and their active development is just beginning. This direction will develop, but the level of its effectiveness still needs to be investigated.

Air defense systems for drones have been implemented.

There are quite too few examples of the implementation of complex systems for the organization of air defense for drones today. As a rule, separate existing platforms are implemented, which are often not connected to a single air defense complex.

However, the Russian-Ukrainian war led to the emergence of at least one comprehensive approach to the organization of air defense elements [4]. Today, Ukraine has already implemented a scheme to shoot down the Shahed/Gheran drones from pickup trucks armed with large-caliber machine guns. They rotate/alternate in the regions through which the typical flight paths of these drones run through the territory of Ukraine, or near cities and possible targets in the rear. Identification/detection of drones and determining the trajectory of their movement is carried out using a network of directional microphones according to a specific sound signature using specialized computer programs. Such a system of air defense against these drones has already proven its effectiveness.

In the USA, the Anvil-M anti-drone system is being developed, which consists of drones that are launched from the ground and have weapons to defeat small drones [5].

Methodology for the development of air defense against drones

We describe the design of a hierarchical organization of an air defense system. This system will be built from automated platforms for identifying enemy drones and making decisions on organizing defenses to destroy enemy drones. Some platforms may be autonomous, and some will include a human operator to make decisions and control the corresponding drones.

A system for identifying drones. It consists of ground and air platforms that can be stationary and mobile. The platforms should apply different identification principles. For example, these will be radars, acoustic systems with a database of enemy drone signatures, and optical systems in different frequency ranges. The platforms can include specialized neural networks, artificial intelligence, and human operators.

Wheeled, tracked, and flying mobile platforms should be designed according to Lego principles: they can be equipped with various universal blocks for identifying enemy drones. Such identification platforms and their blocks can be used both for the rear and on the front line.

Flying platforms are the most effective due to the following reasons:

1. The ability to cover a larger area with fewer platforms.
2. Short time to move and change positions.
3. Identification of moving targets against the background of the ground is of higher quality.
4. They allow for echeloning by height, where different identification methods will be used more effectively.
5. They allow for the simultaneous use of removable units using different physical principles.
6. Platforms of different sizes can be used for higher protection against enemy aircraft and missiles.

Decision-making platforms: stationary and mobile, with or without human operator participation, with or without the use of repeaters, in constant motion or not. They can be organized according to the example of coordinator drones described in [6], which allows one to use prepared sets of scenarios and carry out training both with the use of computer simulation and with the use of existing game platforms (World of Warplanes, Warplanes: WW2 Dogfight, Wings of War, etc.).

Systems for enemy drones destroying. They can be stationary and mobile, with or without human operator participation, with or without the use of repeaters, in constant motion or not.

The approach to design for organization of the air defense system in the rear

Identification of enemy drones is carried out in echelons as follows (all platforms have “home-foreign” identifiers and recognize them in targets).

Manned aircraft (which are capable of staying in the air for long periods of time) are platforms for long-range sensors ("long-range" defense). These are mainly active and passive radars. They are aimed at large drones or at localized groups of drones. At the same time, they also track aircraft and cruise missiles. Information about the general situation at a distance of several hundred (thousand) kilometers is obtained here. Sometimes such aircraft can also serve as general command and analytical centers, information processing centers, etc. Such planes can cover the space of the entire country.

Closer to the front line, barrage drones are used, which are able to stay in the air for a long time in a given region. They are platforms for sensors of a different nature (defense of "medium" action). In addition to radars, acoustic sensors (either of a wide range or of a combination of the required frequencies) and video cameras for a long distance in both the visible and infrared/ ultraviolet regions of the spectrum are involved. Their computers are able to classify both sound signatures and video images. Such platforms create a strip with a width of several tens of kilometers (there can be several such strips).

In the same regions, several lines of protection from stationary sensors are used, the areas of which are overlapping. Sensors of different natures can be formed on the same platform, or different platforms can be used (which allows for forming a more flexible defense). There can be several such "close" lines of defense. They can also create defense circles that protect local objects (cities, critical infrastructure objects, etc.).

There should be several *decision-making centers* at each level (for the country as a whole, regional, local), and their duplication should be created. Mobile decision-making centers can be used for local and regional needs.

Systems of enemy drones' neutralization. The organization of the enemy drone destruction system should also be constructed in echelons according to the size of the hunter drones. Hunter drones will be used for this (some of the possible solutions are presented below). The use of hunter drones has several advantages. First, hunter drones are reusable drones and therefore can destroy quite a large number of enemy drones. Secondly, they have enough speed to keep the enemy drone in the aiming field for a long enough time, which dramatically increases the probability of its destruction. Third, hunter drones can use an autonomous search mode, which will not require a large number of highly skilled operators.

Small (light) hunter drones can be equipped with small-caliber machine guns. These machine guns have low recoil and will not greatly affect the movement of drones. Also, small drones can carry one unguided air-to-air missile, which, when exploded, scatters the elements of damage in the form of a cloud, cone or disc. Accordingly, the aiming system should be organized. The distance for damage can be hundreds of meters, and the aiming itself is organized by a video camera. At night, one can use a video camera and a spotlight, which is guided by the sound signature or is directed from the decision-making center. The detonation distance is set when using, for example, a laser rangefinder. Light drones can also use nets to capture enemy drones or propeller entanglement tapes, as well as anti-drone radio electronic guns and the like. However, enemy drones can use self-destruct elements when out of control, which can damage hunter drones when using short-range neutralization agents. Note that small hunter drones can also be kamikaze drones. This will be aimed mainly at expensive enemy drones, usually reconnaissance drones or kamikaze drones with a powerful explosive charge, as well as drones that are capable of maneuvering (then it is advisable to use FPV drones). Small drones can be based both on the ground (that is, be stationary) and on mobile platforms (cars, armored personnel carriers, etc.). Also, small hunter drones can be based on flying or floating platforms (for example, large drones, airplanes, helicopters, etc.). Small hunter drones can be equipped with a software product that will take them out of combat (with prior notification to decision-making centers) and send them to special landing sites for further maintenance and ammunition replenishment. Exit from the battle can be in cases of running out of ammunition or when the fuel supply (or battery capacity) is enough only to reach the nearest landing pad.

As a general rule, it is advisable to use the small hunter drones ahead of attacking enemy drones, because they have, as a rule, a lower speed. Therefore, small hunter drones will be localized in the form of air defense lines (preferably close to the front line or border), localized taking into account sufficient time for them to reach a possible interception region, or around cities and elements of critical infrastructure.

Medium and large hunter drones can be used effectively against existing kamikaze drones (such as the Iranian and Russian Shahed 136) because they have speeds comparable to such enemy drones (or even much faster than them). Baykar Bayraktar TV-2/3, Baykar Bayraktar Akıncı, and Baykar Bayraktar Kızılelma platforms can serve as examples of such hunter drones (these platforms can potentially be produced in Ukraine). Medium and large hunter drones, unlike small ones, can carry a combination of various weapon complexes. They also have greater autonomy in the air and more ammunition. This allows the use of medium and large hunter drones for long-term patrolling of certain regions. This significantly reduces the response time in cases of a sudden attack. In addition, medium and large hunter drones can serve as platforms for delivering a fairly large number of small hunter drones to a given region. This allows you to gain significant advantages

on the local battlefield.

Finally, medium and large hunter drones can be successfully used to intercept Long-range subsonic, Medium-range subsonic, and Short-range subsonic cruise missiles. The speed of such missiles is compared, for example, with the speed of the Baykar Bayraktar Kızılelma platform, which can not only hit these missiles themselves, but also create a curtain in front of them with a sufficiently large number of small hunter drones.

The approach to design for organization of the air defense system at the front line

The goal is to protect against reconnaissance and attack drones. All of the above solutions should be applied here. The only flawed addition is that the hunter drones should also be used in enemy territory. It is also necessary to identify the enemy's means of identifying our attack drones and enemy decision-making centers. An additional specificity is the presence of a time factor, because on the battlefield decisions must be made very quickly. Countermeasures against enemy electronic warfare can be used in the same way as against one's own attacking drones.

It should be noted that small hunter drones can be delivered over enemy territory using large carrier drones, cruise missiles, or large-caliber shells and missiles from multiple launch rocket systems.

Small drone hunters can be delivered over enemy territory using large carrier drones, cruise missiles or large-caliber shells, multiple launch rocket systems, and cassettes from aircraft or helicopters. In this way, local kill zones can be created in the path of enemy drones. Cassettes with small drone hunters can also be delivered over enemy territory using mobile wheeled, tracked, floating, and underwater platforms.

Discussion and outlook

Above is a variant of an effective program for forming an order for the modernization of existing and development of new drones for air defense. Based on this program, personnel training for its implementation is also organized. Also, based on the results of the article, a strategic formation of the country's air defense system can be developed for both the war and the post-war period.

The use of swarms of drones allows reaching a new level of human interaction and technical means of warfare, including for the air defense system. Some directions of development of distributed hierarchical control for autonomous drone swarms [6] can determine the future development of air defense systems.

The obtained results indicate that the formation of air defense for the rear can have certain universal forms, and decision-making can allow time for a thorough analysis of the situation and even computer simulation of possible decision options to select the most effective one. In contrast, on the front line, it is necessary to take into account many variable features, which take into account the characteristics of the battlefield area, the military forces and equipment of both your own and the enemy, the resources available to you and the enemy, the features of the ability to maintain and use drones, etc. Here, the initiative of commanders will be maximally manifested. The relationship between human intelligence and artificial intelligence will be most critical on the front line. The emergence of hierarchically organized autonomous swarms of drones [6] for both attack and defense can bring the organization of the battle to a new level and significantly increase its effectiveness. It is important that on this path fundamentally new opportunities arise for a significant reduction of human mortality in the conditions of future wars. The role of people will be to use their intellectual capabilities.

The approach described in the article to the organization of drone control can be used to protect the Earth from an asteroid/comet threat from Space. Such experience will also be useful for the colonization of the planets and the asteroid belt of both the Solar System and the planetary systems of other stars in the Universe.

Conclusion

Today, a new reality is emerging in the war organization. The widespread use of drones at various levels of attack leads to the need to use drones in air defense systems as well. Thus, there is a transition to warfare both at the level of people and at the level of drones.

The article develops approaches (designs) for the functioning of an air defense system using special drones both for rear defense and on the battlefield. In this case, it is proposed to use both existing drones and technical platforms, and promising directions for the development of new drones and platforms for air defense are described. A description of existing strike drones and the design of protection systems against them are given.

It is proposed to create a new class of drones – drone hunters – to destroy enemy drones. Some platforms for destroying enemy drones are described in detail. A hierarchically organized system for organizing the protection of the country's territory from enemy drones using hunter drones with various structural details is developed. A system for organizing protection from enemy drones on the battlefield is briefly described. A concept for a universal organization of a hierarchically echeloned organization of air defense against enemy

drones is formed.

It is emphasized that many drone defense platforms can be effective against cruise and/or ballistic missiles. The results obtained in the article form a new approach to developing strategic programs for the development of drones in the conditions of modern warfare.

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Дрони як ключовий елемент формування протиповітряної оборони від дронів та крилатих ракет у тилу та на полі бою

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Дрони є ефективним інструментом для організації наступальних та оборонних дій у сучасній війні. Війна між Росією та Україною показала, що недорогі дрони можуть завдати критичної шкоди військовій техніці та цивільним об'єктам високої цінності. В результаті недорогі дрони, що використовуються для повітряних атак, стали ефективним інструментом для завдання дуже великих економічних втрат противнику. Вони також створюють великий психологічний вплив на населення, що призводить до значного фізіологічного виснаження. Такі втрати перевищують вартість самих дронів у десятки, сотні і навіть тисячі разів. Непрямі втрати можуть досягати співвідношення вартості навіть у сотні тисяч разів. Таким чином, сьогодні на полі бою з'явилася нова надзвичайно ефективна бойова зброя. Сьогодні виникла проблема розробки нових технічних систем для збиття повітряних дронів. Існуючі повітряні або наземні системи різного рівня (літаки, гелікоптери, гармати, ракети класу "земля-повітря", кулемети тощо) орієнтовані на збиття принципово різних повітряних військових платформ, таких як літаки, гелікоптери, крилаті ракети тощо. Тому ці технічні системи мають високу вартість і є економічно невигідними для збиття не лише пілотованих, а й автономних дронів. Отже, використання існуючих платформ для збиття повітряних безпілотників швидко економічно виснажує захисників. Метою статті є розробка підходів (проектів) функціонування системи протиповітряної оборони з використанням спеціальних безпілотників як для тилової оборони, так і на полі бою. У цьому випадку пропонується використовувати як існуючі безпілотники, так і технічні платформи, а також описані перспективні напрямки розвитку нових безпілотників та платформ для протиповітряної оборони. Наведено опис існуючих ударних безпілотників та проектування систем захисту від них. Пропонується створити новий клас безпілотників – мисливців за дронами – для знищення ворожих безпілотників. Детально описано деякі платформи для знищення ворожих безпілотників. Розроблено ієрархічно організовану систему організації захисту території країни від ворожих безпілотників з використанням безпілотників-мисливців з різними конструктивними деталями. Коротко описано систему організації захисту від ворожих безпілотників на полі бою. Сформовано концепцію універсальної організації ієрархічно ешелонованої організації протиповітряної оборони від ворожих безпілотників. Підкреслено, що багато платформ протиповітряної оборони можуть бути ефективними проти крилатих та/або балістичних ракет. Отримані у статті результати формують новий підхід до розробки стратегічних програм розвитку безпілотників в умовах сучасної війни.

Ключові слова: атакуючий дрон, дрон-мисливець, протиповітряна оборона, організація, розробка.

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