CHAPTER «ENGINEERING SCIENCES»

CONCEPT OF PROTECTING CRITICAL INFRASTRUCTURE FACILITIES AGAINST THE DESTRUCTIVE INFLUENCE OF AIR ATTACK MEANS

Heorhii Dementiiuk[1]
Maksym Iasechko[2]

DOI: https://doi.org/10.30525/978-9934-26-310-1-1

Abstract. The monograph examines and analyzes the use of air attack tools against critical infrastructure facilities in the conditions of the Russian-Ukrainian war, tactical and technical characteristics, options and priority of use. In the leading countries of the world, along with the development and modernization of traditional weapons, there has recently been an intensive development and use in military conflicts of high-tech weapons, primarily high-precision weapons designed to damage critical infrastructure. Among high-precision weapons, cruise missiles with radar correlation algorithms of extreme guidance play a significant role. The developed samples of high-precision weapons, depending on the method of delivery, are capable of hitting critical objects at a distance of up to a thousand kilometers, which significantly exacerbates the problem of ensuring the survivability of critical infrastructure objects, which determines the effectiveness of their operation. Based on this, one of the important issues in the development, modernization and operation of critical infrastructure is to increase the degree of protection of critical infrastructure from air attack means with radar correlation extreme targeting algorithms. One of the most important factors contributing to the possibility of normal life in the conditions of hostilities (war) is the means of protection, which ensure the maximum permissible levels of striking factors. The goal is to ensure the reliable

[1] PhD Candidate, Lecturer at the Department of Combat Use of Air Defense Weapons of the Army, Ivan Kozhedub Kharkiv National Air Force University, Ukraine
[2] Doctor of Technical Science, Associate Professor,
Head of the Department of Combat Use of Air Defense Weapons of the Army,
Ivan Kozhedub Kharkiv National Air Force University, Ukraine

functioning of critical infrastructure facilities under the conditions of the destructive influence of air attack means. *The object* of the study is the process of protection of technical facilities, machine (engine) halls of critical infrastructure facilities. *The subject* of the research is methods of protecting critical infrastructure objects from the destructive action of air attack means. *The research methods* are determined by the set of scientific research tasks and were carried out using: methods of system analysis; methods of numerical modeling. Based on the analysis, principles and requirements have been developed that allow for further research and development of means of protecting critical infrastructure objects from the destructive impact of air attack means. *The results* of the research project can be useful: in the development of the principles of the use of means of protection against the destructive effect of air attack means of various types; in the development of new and improvement of existing methods of reducing the impact of air attack on critical infrastructure objects to the maximum permissible level.

1. Introduction

In today's conditions of the russian-Ukrainian war, at this extremely difficult historical stage, many issues related to the preparation and conduct of hostilities are being reviewed.

In the war against Ukraine, the russian aggressors quite often use high-precision means of attack, such as Kalibr, X-55, X-101 cruise missiles, Iskander-type ballistic missiles and recently, Iranian kamikaze drones of the "Shahed-136" and "Mohajer-6" type, which are capable of operating at extremely low altitudes and bypassing the terrain.

A significant number of obstacles and closing angles significantly affect the detection and destruction of air attack means. These factors allow the enemy's air attack vehicles to go almost unnoticed to the line of destruction of objects, cruise missiles – to directly hit targets, unmanned aerial vehicles to conduct reconnaissance and hit targets. In addition, attacks on non-military targets are carried out with the aim of demoralizing the civilian population. By striking civilian and cultural objects, russia is unsuccessfully trying to break the will of the Ukrainian people.

Recently, the russian invaders quite often began to use Iranian kamikaze drones of the type "Shahed-136" and "Mohajer-6" to launch strikes on objects on the territory of Ukraine. This may be related to the desire to more economically use high-precision weapons such as Kalibr, Kh-55, Kh-101 cruise missiles and Iskander ballistic missiles.

The use of "Shahed-136" in the russian-Ukrainian war revealed a number of its features. It must be admitted that this UAV turned out to be simple and easy to manufacture. Its group application became a priority. Massive russian attacks by unmanned aerial vehicles "Shahed-136" exacerbated the issue of finding countermeasures taking into account the "cost-effectiveness" ratio.

Based on historical experience, air defense of infrastructural facilities can be carried out by long-known methods. Starting from the time of the First World War, the use of barrage balloons began. They used gas (or heated air) with a density lower than the density of the surrounding air to create lift. Enemy aerial objects were struck when they met the balloon cable, their shell or explosive charges suspended from them. For example, in 1940 there were 1500 balloons in the air over Great Britain, more than a third of them were over London. The ceiling of such balloons did not rise higher than 1,500 m, this was not enough against heavy bombers, but it was enough against the V-1 ("Vau-1") cruise missile. Such balloons were constantly hovering over particularly important objects, they also effectively deterred aerial bombs [1]. The last military operation in which barrage balloons were massively used was the covering of the Aswan Dam during the Arab-Israeli war of 1967–1970.

Figure 1. British air "apron" of barrage balloons from the Second World War (Several balloons were connected and the gaps between them were filled with cables)

The modern cruise missile differs from the V-1 only in the use of new materials, a more modern engine, a longer flight range and higher accuracy of guidance. In terms of flight speed and geometric dimensions, the V-1 does not differ from the "Tomahawk" and the X-55.

In addition to the use of barrage balloons, there are other examples of attempts to protect objects from an aerial enemy. At the beginning of 1940, Winston Churchill proposed to consider a method of rapid deployment of wire barriers in the path of enemy aircraft detected by radar stations. One of the committees of the created department DMWD (Directorate of Miscellaneous Weapon Development – "Directorate for the development of various weapons") was proposed to raise the wire fence with the help of rockets. The warhead of the rocket released a parachute that held a long wire. Another proposal was the use of mobile groups to cover objects. Powerful cars with winches made it possible to move the raised balloons even during an air raid, which in principle could disrupt the "Junkers" diving on the target. These methods did not have time to be fully tested due to the end of the war [2].

The experience of the enemy's use of unmanned aerial vehicles in the russian-Ukrainian war to destroy civilian critical infrastructure in Ukrainian cities showed that standard means of air defense, electronic warfare and anti-drone guns are not always effective in the fight against this type of weaponry. There is a need to use other methods for the physical destruction of such complexes [3].

Given the experience of combat use of cruise missiles spanning six and a half decades, they can be considered a mature technology that has proven itself well. During their existence, there has been a significant development in the technologies used in the creation of cruise missiles, covering the airframe, engines, means of defeating air defenses and navigation systems.

Thanks to the technologies of creation, rocket gliders became more and more compact. Now they can be placed in the internal compartments and external suspensions of aircraft, tube-type ship launchers or submarine torpedo tubes.

Air defense countermeasures emerged in the 1960s as air defense systems became more effective. These include low altitude flight with contouring of terrain or rocket flight at an extremely low altitude above the sea surface in order to hide from radars, and increasingly their shape increases inconspicuousness, and the use of radio-absorbing materials is designed to reduce radar visibility.

The basic idea of all cruise missiles is that these weapons can be launched at a target beyond the range of enemy air defense systems in order not to expose the launch platform to a retaliatory attack.

The first combat cruise missile was the German FZG-76/V-1, more than 8,000 of which were used, mostly against targets in Great Britain [1]. Judging by modern standards, its navigation system was quite primitive: the gyroscope-based autopilot maintained the course, and the anemometer the distance to the target. The missile was set on a planned course before launch and the estimated distance to the target was displayed on it, and as soon as the odometer indicated that the missile was above the target, the autopilot took it into a steep dive. The missile had an accuracy of about a mile and this was enough to bomb large urban targets such as London. The main purpose of the bombing was to terrorize the civilian population and divert the British military forces from offensive operations and direct them to perform air defense tasks.

In the 1950s, the first conventional post-war tactical cruise missiles entered service, primarily as an anti-ship weapon. While on the marching part of the trajectory, guidance continued on the basis of the gyroscope, and sometimes was corrected by radio communication, the accuracy of guidance on the final part of the trajectory was ensured by a homing head with a short-range radar station, semi-active in early versions, but soon replaced by active radars. Missiles of this generation usually fly at medium and high altitudes, diving when attacking a target.

In the 1960s, there were significant improvements in the accuracy of inertial systems, and the cost of such equipment also increased. As a result, this has led to conflicting demands for accuracy and cost. As a result, a new technology emerged in the field of cruise missile navigation, based on the system of determining the location of the missile by comparing the radar mapping of the area with the reference mapping program. This technology entered the service of US cruise missiles in the 1970s and Soviet missiles in the 1980s. TERCOM technology (Digital Correlation System with Terrain Terrain of the Cruise Missile Guidance Unit) was used, as was the astronavigation system, to zero out the cumulative inertial system errors.

The experience of the enemy in the russian-Ukrainian war using cruise missiles with a radar guidance method to destroy civilian critical infrastructure in Ukrainian cities showed that standard means of air defense are not always effective in combating this type of weaponry. There is a need to use other methods to physically destroy such targets.

The purpose of the monograph is to analyze the destructive impact of air attacks on critical infrastructure facilities, to develop requirements and recommendations for countering air attacks.

2. Literature review and problem statement

A large number of works have been and are being carried out by such famous scientists as V.I. Kravchenko, O.P. Kovtunenko, V.I. Slyusar devoted to the development of methods and means of protecting infrastructure facilities from the destructive effects of air attack, S.O. Tyshchuk, S.M. Sholokhov, M.V. Balyuk, L.M. Kechiev and others [4–15]. However, the existing methods and means are not able to provide the necessary effectiveness of the protection of infrastructure facilities due to their characteristics. With regard to unmanned aerial vehicles – the inability of existing protection systems to quickly respond to the impact of aviation and unacceptable weight and size characteristics. With regard to the destructive impact of cruise missiles with a radar navigation method, there is an insufficient number of air defense systems to protect and disperse critical infrastructure facilities. Therefore, a contradiction arose, caused, on the one hand, by the presence of the destructive effect of cruise missiles with a radar guidance method, and on the other hand, by the lack of technologies, methods and means that would provide the necessary level of protection of a critical infrastructure object without prejudice to their functioning and which can be implemented on critical infrastructure facilities without significant financial losses and the involvement of air defense assets.

3. Materials and research methods

In the course of hostilities during the russian-Ukrainian war on the territory of Ukraine, the Armed Forces of the russian Federation recently noted the intensive use of unmanned aerial vehicles of the type "Shahed-191", "Shahed-129", "Mohajer-6", "Mohajer-4" and "Shahed 136" kamikaze-type unmanned aerial vehicles (russia calls them "Geran-2") and "kamikaze drones" of the "Lancet" type.

Figure 2. Appearance of the "Shahed-129" UAV (Shahid-191)

Unmanned aerial vehicle "Shahed 129" (Shahid 129) is an Iranian single-engine medium-altitude attack unmanned aerial vehicle, developed by Shahed Aviation Industries in 2012 for the IRGC, capable of performing combat and reconnaissance missions.

Tactical and technical characteristics are given in the Table 1.

Table 1

Tactical and technical characteristics of Shahid 129

Flight range, km	3400
Combat radius, km	1700
Cruising speed, km/h	150
Maximum speed, km/h	200
Maximum flight height, km	7,3
Accuracy, m	no information available
Payload mass, kg	400
Wingspan, m	16
Length, m	8
Armament	4(8) high-precision bombs "Sadid-345"

Based on the analysis of information obtained from open sources regarding the tactical and technical characteristics of the UAV "Shahed-129" (Shahid-129) is a single-engine propeller UAV with a narrow cylindrical fuselage, approximately 65-75 cm in diameter, equipped with an electronic-optical and infrared sensor, a laser range finder for day and night missions, real-time video data transmission. The flight time is about 24 hours. Equipped with a Rotax 914 aircraft engine. There are suspensions for 4 – 8 ammunition, including guided ammunition "Sadid-345". The declared flight range is 1700 km.

It is similar in size, shape and principles of application to the American MQ-1 "Predator" and MQ-9 "Reaper" and is considered one of the most effective UAVs in the Iranian arsenal.

Strengths of the "Shahed-129" UAV:

Thanks to the electronic-optical camera, the UAV can conduct aerial reconnaissance at a distance of 60 to 80 km (under ideal weather conditions).

Optical-electronic aerial reconnaissance complexes of UAVs ensure the formation of images of areas and objects in various ranges of the spectrum of optical radiation (visible, infrared) with a high degree of detail.

During one sortie, "Shahed-129" can hit from 4 to 8 targets (depending on the modification), attacking them both simultaneously, and consistently.

Has the ability to automatically return to the operational airfield (take-off point) in case of loss of control using the inertial system.

Weaknesses of the "Shahed-129" UAV:

UAV "Shahed-129" (Shahid 129) due to its effective scattering surface is a sufficiently visible object for its detection and tracking by air defense radar means.

It should also be noted that the low flight speed (up to 150 km/h) does not provide technical opportunities to carry out an anti-missile maneuver.

In addition, the absence of a warning system at the control point about the launch of anti-aircraft guided missiles does not allow the operator to remove the UAV from the attack in time.

Meteorological conditions, especially low cloud cover and fog, also significantly affect the quality of combat missions of the "Shahed-129" UAV (range of conducting optical reconnaissance in difficult meteorological conditions from 15 to 20 km).

In addition, there is a high probability that this UAV is unsuitable for use in winter conditions (difficult meteorological conditions: wet snow with rain, heavy fog) and lacks a protection system against icing (sticking wet snow), as it has never been used in a temperate continental climate part of the globe, but only in southern latitudes.

According to Iranian state media, direct control of the Shahed-129 UAV is possible only within a radius of 200 km (the range of a stable signal from the control point), the declared 3,400 km can be flown only on autopilot, which makes it impossible to use it as an attack UAV.

Figure 3. Appearance of the "Shahed-191" UAV

The "Shahed-191" UAV is a slightly reduced copy of the American RQ-170 Sentinel drone and is also built according to the "flying wing" scheme. He made his first flight in 2014. Tactical and technical characteristics are given in Table 2.

Table 2

Tactical and technical characteristics of the "Shahed-191" UAV

Flight range, km	500
Combat radius, km	450
Cruising speed, km/h	275
Maximum speed, km/h	350
Maximum flight height, km	7,5
Flight duration (max), hours	4,5
Payload mass, kg	100
Armament	2 high-precision bombs "Sadid-342"

According to Iranian media, it is equipped with a turbojet engine as a power plant, which accelerates the drone to 275 km/h and provides autonomy of about 4.5 hours of flight at a distance of up to 500 kilometers and an altitude of up to 7,500 meters.

The UAV can be armed with two guided bombs with fragmentation warheads "Sadid-342", which are placed in the internal compartments. Take-off is carried out from a car that has special mounts on the roof (the acceleration speed of the car on the runway is unknown).

It is worth noting that there is also a Shahed-181 drone, which has an identical airframe and differs from the "Shahed-191" only by the installed piston engine, a different design of the air intake and the weapons compartment.

The "Shahid" drone has several modifications. Currently, russia uses the Shahed 136 kamikaze drone most in Ukraine.

Strengths of the "Shahed-191" UAV:

The possibility of aerial reconnaissance at a distance of 60 to 80 km (depending on weather conditions) in various ranges of the spectrum of optical radiation (visible, infrared) with a high degree of detail.

During one sortie, "Shahed-191" can hit 2 targets.

It has the ability to automatically return to the operational airfield (to the take-off point) in case of loss of control using the inertial system.

Weaknesses of the "Shahed-191" UAV:

UAV "Shahed-191" (Shahid-191) due to its effective dispersion surface is a sufficiently visible object for its detection, tracking and destruction by air defense means.

Difficult meteorological conditions, especially low cloud cover and fog, significantly affect the quality of the performance of combat tasks of the "Shahed-191" UAV in terms of reconnaissance and fire damage and reduce its effectiveness (the range of optical reconnaissance determined by the manufacturer is from 60 to 80 km, taking into account difficult meteorological conditions will not exceed 15 to 20 km).

The multipurpose UAV "Mohajer-6" is designed for reconnaissance, surveillance, reconnaissance and fire damage. Tactical and technical characteristics are given in Table 3.

Capable of carrying up to four high-precision munitions. The start of production of this UAV falls in 2017.

Figure 4. Appearance of the "Mohajer-6" UAV

Table 3

Tactical and technical characteristics of the "Mohajer-6" UAV

Flight duration (max), hours	12
Combat radius, km	2000
Cruising speed, km/h	150
Maximum speed, km/h	200
Maximum flight height, km	7,3
Payload mass, kg	100
Wingspan, m	10
Length, m	5,67
Armament	2 Qaem TV/IR missiles or 2 ALMAS missiles

"Mohajer-6" (Mohajer-6) has a fixed three-support chassis, which is removed after take-off, the complex provides automatic take-off and landing.

It has a maximum take-off weight of 600 kg, a payload of 100 kg and a flight range of 200 km. It has a maximum speed of 200 km/h, a flight duration of 12 hours and a maximum flight height of 5,400 m.

The UAV is equipped with a multispectral sensor camera, a laser range finder, two pods, one under each wing, each of which can carry one Qaem TV/IR guided missile or one Almas missile. In another modification, the drone has 4 suspensions, 2 under each wing, carrying missiles of the same type.

Strengths of the "Mohajer-6" UAV:

The possibility of conducting aerial reconnaissance in various ranges of the spectrum of optical radiation (visible, infrared) with a high degree of detail.

During one sortie, "Mohajer-6" can hit from 2 to 4 targets.

It has the ability to automatically return to the take-off point in case of loss of control using the inertial system.

Has the possibility of conducting electronic warfare.

Capable of carrying guided missiles Almas (air-to-air missile) or Qaem TV/IR (laser, infrared or optical homing heads (hereinafter – GOS), which are capable of hitting aircraft and moving targets.

Weaknesses of the "Mohajer-6" UAV:

Based on its size, the UAV is a sufficiently visible object for detection, tracking and destruction by air defense means.

Meteorological conditions, especially low cloud cover and fog, also significantly affect the quality of the performance of combat missions in terms of reconnaissance and fire damage. In addition, like the previous UAV "Mohajer-6" (Mohajer-6) is not suitable for use in winter conditions and does not have an anti-icing system, as it was used only in southern latitudes.

The low cruising speed (150 km/h) of this UAV, combined with its large dimensions and flight height, make it an easy target for air defense equipment, including MANPADS.

The "Mohajer-4" UAV is designed for reconnaissance, surveillance, reconnaissance and fire damage. The tactical and technical characteristics are listed in Table 4.

Figure 5. Appearance of the "Mohajer-4" UAV

Table 4

Tactical and technical characteristics of the "Mohajer-4" UAV

Flight range, hours	150
Cruising speed, km/h	150
Maximum speed, km/h	180
Maximum flight height, km	3,5
Flight duration (max), hours	3-5
Payload mass, kg	400
Wingspan, m	5,3
Length, m	3,64
Armament	2 unguided missiles "Hydra 2"

Capable of carrying up to two unguided munitions ("Hydra 2" missiles). "Mohajer-4" has a Hyarat 3 guidance and control system that uses GPS navigation.

As a rule, it flies along a pre-programmed trajectory, but the operator can make changes to the program during the flight on the radio channel. Has a fixed front-facing camera for navigation and/or a downward-facing camera for conducting aerial photography.

Strengths of the "Mohajer-4" UAV:

The possibility of aerial reconnaissance in different ranges of the spectrum of optical radiation (visible, infrared).

During one sortie, "Mohajer-4" can hit up to 2 targets.

It has the ability to automatically return to the operational airfield (to the take-off point) in case of loss of control using the inertial system.

It has the ability to conduct electronic communications and relay communications.

Weaknesses of the "Mohajer-4" UAV:

Based on its size, the UAV is a visible object for detection, tracking and destruction by air defense means.

Not suitable for use in adverse weather conditions (rain, snow, fog, etc.).

The low cruising speed of this UAV combined with its large dimensions and flight height make it an easy target for air defense equipment, including MANPADS.

Small combat radius.

Figure 6. Appearance of the "kamikaze" UAV "Shahed 136"

Unmanned aerial vehicle "kamikaze" "Shahed-136" (Shahid-136) is an Iranian unmanned aerial vehicle (barrage munition), designed to hit fixed ground objects by targeting and contact detonation of the warhead of the unmanned aerial vehicle.Can be launched in a volley from mobile launchers disguised as a dump truck body, each of which can simultaneously launch up to 5 UAVs.

Tactical and technical characteristics are given in Table 5.

Table 5

Tactical and technical characteristics of the "kamikaze" UAV "Shahed 136"

Flight range, hours	1500
Accuracy, m	1000 (unconfirmed data)
Guidance system	inertial
Mass of the high-explosive warhead, kg	40

Strengths of the "Shahed-136" UAV:

The long flight range allows it to be used to hit stationary targets deep in the territory of Ukraine.

Small dimensions (EPR of about 0.05 square meters) and high speed reduce the probability of damage to Shahid-136 kamikaze drones by anti-aircraft missiles.

The possibility of preparing for launch in the field by downloading the flight task using a portable computer (laptop, tablet).

Weaknesses of the "Shahed 136" UAV:

Low accuracy of hitting targets due to the "accumulation of errors" in determining the location of the device during flight with an increase in its range and wind speed (an inertial navigation system is used).

Inability to hit moving targets.

Inability to adjust the flight path and redirect the device to another target after its launch – "kamikaze drones" "Shahid-136" are not equipped with communication and data transmission systems.

In calm weather, the noise from a working engine can be heard at a distance of more than 20 km. (the engine makes noise like a moped or chainsaw).

A small combat unit, which, combined with low accuracy, creates limited opportunities for hitting targets.

Cannot be used to hit moving targets.

The tactics of using "kamikaze drones" "Shahid-136" of the Armed Forces of the russian federation envisage the possibility of their massive use to damage military and civilian infrastructure objects (mainly buildings) in the depths of the territory of Ukraine.

From the conducted analysis of the time of use of "kamikaze drones" "Shahid-136" of the Armed Forces of the russian federation, it was established that since the beginning of the armed aggression, these UAVs were used throughout the day, but the most frequent and most effective is their use in the dark time of the day in the period from 11:00 p.m. until 06.00 a.m. In order to complicate their visual detection, determine their number and reduce the effectiveness of the use of means of direct cover of objects.

UAV "kamikaze" "ZALA Lancet" (Lancet) is a russian barrage munition (UAV-kamikaze) created together with the UAV Zala 421 developed by the company Zala Aero Group and intended for defeating artillery systems on positions, air defense means and radar stations. Tactical and technical characteristics are given in Table 6.

Figure 7. Appearance of the "kamikaze" UAV "ZALA Lancet"

Table 6

Tactical and technical characteristics of the "kamikaze" UAV "ZALA Lancet"

Flight range, km	40
Accuracy, m	no information available
Guidance system	coordinate, optical-electronic
Maximum flight height, km	no information available
Flight duration (max), hours	40-60
Mass of the high-explosive warhead, kg	1-3

Lancet has an electronic-optical control system, which makes it dangerous mainly in daylight.

Today, it is known about the existence of two versions of the attack drone – "Lancet-1" and "Lancet-3". Both have the same airframe with twin X-wings and similar internal systems. The main difference is the size and payload. The maximum take-off weight of "Lancet-3" is up to 12 kg, "Lancet-1" – 5 kg, with warheads (explosive fragmentation) up to 5 kg and up to 3 kg, respectively.

"Lancets" develop a speed of 80-110 km/h. However, when diving on a target from a height of several hundred meters, barrage ammunition can accelerate up to 300 km/h.

The range of use of drones from the ground control point is up to 40 kilometers.

It is also known that "Lancet" is equipped with several types of guidance systems: coordinate, with the help of optical and electronic means, and combined. So, for example, with the help of a television communication channel, the operator can watch the picture from the drone online until the target is destroyed. It is also claimed that "Lancets" do not need satellite navigation. The on-board intelligence, navigation and communication module allows you to "determine the coordinates of various objects."

As a rule, these drones are used by mobile reconnaissance groups of the russian federation and try to strike at the locations of air defense systems, artillery forces and means, and where, in their opinion, there are accumulations of ammunition, for example, on green boxes from shells, etc.

In addition, these kamikaze drones are used in coordination with the Orlan-10(30) or "Mohajer4(6)" multi-purpose unmanned aircraft complex, which hovers at a height determined by the operator in the rear of the Ukrainian Armed Forces and acts as a kind of repeater, giving exact coordinates for their guidance. He determines the target, and "Lancet" hits them.

It was repeatedly noted that the use of the "Orlan-10(30)" or "Mohajer 4(6)" complex were as distracting forces (means) for the exit of air defense systems of the Armed Forces of Ukraine from the concentration areas to destroy the specified types of UAVs and were damaged by drones. kamikaze type "Lancet".

Strengths of the "kamikaze" UAV "ZALA Lancet":

They are equipped with electric power plants, which provides them with relative acoustic invisibility.

It is equipped with several types of guidance systems, coordinate, using optical-electronic means and combined. So, for example, with the help of a television communication channel, the operator can watch the picture from the drone online until the target is destroyed. It is also claimed that "Lancets" do not need satellite navigation.

Weaknesses of the "kamikaze" UAV "ZALA Lancet":

The charge of the combat unit is often not enough to cause significant damage when attacking the first-best target – for example, a tank.

There are rare cases of drones falling in a clear field, which may indicate either inaccurate targeting or successful relocation of a predetermined target.

It was assumed that "Lancets" would be able to independently patrol a certain area, identify targets and dive on them. However, the maximum time in the air of this barrage ammunition is 30-40 minutes, which is clearly not enough for independent determination of the target directly using the Lancet itself. For effective work, it needs the "help" of a separate reconnaissance UAV to find a target and objectively control the damage.

The nature of war is changing and kamikaze drones (barrage munitions) are coming to the fore in the modern arsenal.

Kamikaze drones, also known as barrage munitions, gained widespread popularity during the 2020 Nagorno-Karabakh war, but their potential remains poorly understood.

The use of kamikaze drones challenges outdated ideas about long-range mission capabilities strikes, survivability of armored vehicles and logistics at the operational level.

The use of Lancet-type kamikaze drones on the battlefield definitely gives certain advantages to the enemy, but the use of this type of weapon cannot fundamentally change the course and character of the war.

All of the above obligates to carefully study and analyze the experience of the combat use of aviation, in particular UAVs, to search for new forms and methods of using air defense means for the timely destruction of UAVs of various classes, kamikaze drones (barrage of ammunition).

The first mass serial cruise missile was created back in the Second World War in Germany – "Fau-1". It was created as a Wunderwaffe – a "miracle weapon" that could turn the tide of war in favor of the Third Reich. It began to be actively used since 1943 for attacks on London with the aim of terrorizing the civilian population [2].

One of the main difficulties of the development was the guidance system. It looked as simple as possible – the autopilot monitors the course and altitude and measures the flight range. As soon as the "Fau-1" flew the specified distance, the autopilot put the missile into the pike. Later, the Germans developed the first inertial guidance system based on analog devices with a gyroscope and accelerometer for the V-2 ballistic missile.

It should be noted that the accuracy of any inertial system, even a modern one, is limited, it is closed in itself and has exactly only its initial coordinates, and then only calculates them independently, relying on the indicators of the devices. And the longer the inertial system works, the greater the error. And at the level of Western technologies of the 1970s and 1980s, it was about 600 meters per hour of work.

Therefore, it was quite logical to invent a mechanism that would adjust the indicators. TERCOM became this system for cruise missiles that had to fly hundreds of kilometers and stay in the air for hours. Its principle is that the rocket scans the surface below it and compares it with the standard. One of the simplest implementations will be, for example, terrain data – height differences recorded by the rocket's radio altimeter [16].

In this case, the missile route can be divided into certain control points, the map of which is stored in the missile's memory. They should be areas with contrasting topography, for example, rivers with steep banks, a network of ravines, or even individual large buildings. Having arrived, the rocket compares, locates itself and adjusts the inertial system indicators, resetting the accumulated error.

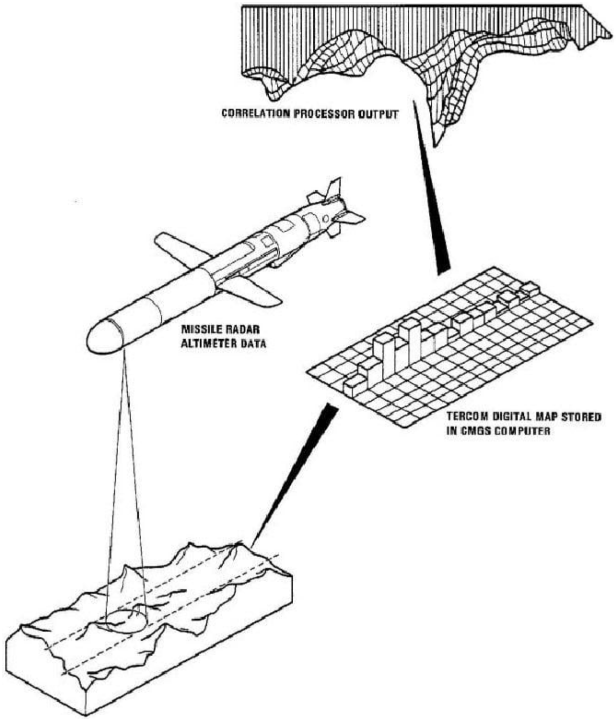

Figure 8. TERCOM (US Navy Tomahawk Cruise Missile Weapons System Technical Manual)

Currently, the TERCOM system uses not only terrain data, but also visual images. This is due to the fact that the route may not have a characteristic terrain. But this system is much more complex, because it requires work at the level of pattern recognition, but this technology, called DSMAC, was successfully mastered in the United States in the 1980s and integrated into the Tomahawk Block II cruise missile.

The main disadvantage of this system is that the inertial system can launch the missile completely past the control point and the missile will not be able to orient itself. Of course, the more powerful computers became, the larger the volume of maps could be laid, but still the system did not give a 100% guarantee.

The advent of satellite navigation changed the matter dramatically, because now it became possible to constantly receive one's coordinates, altitude and speed. It was for this that the USA initially began to deploy the GPS system in the 1970s, and in the 1980s the USSR began to deploy its GLONASS.

When conducting an analysis of countering cruise missiles, one should pay attention to the materials of their production, which affect their detection by radar means. During the armed aggression of the russian federation against Ukraine, the enemy actively uses modern coatings of the "ZYPSIL 601 RPM-01" type, which make it possible to reduce the effective area of target dispersion. It is able to absorb ultra-high frequency energy and electromagnetic waves and radiation. This sheet is a thin, flexible, silicone (or fluorosilicone) base filled with magnetic nano- and microdisperse powders. The high-frequency absorbing sheet is available in different thicknesses, from 1.0 mm to 10.0 mm. The material "ZYPSIL 601 RPM-01" is an ultra-broadband, heatresistant ultra-high-frequency absorber (absorber of ultra-high-frequency energy, absorber of electromagnetic waves, absorber of ultra-high-frequency radiation). The heat-resistant silicone base gives the material the appropriate properties of flexibility, softness and elasticity. Broadband sheet wave-absorbing material provides high standards of electromagnetic compatibility, ideal for high-tech equipment and ultra-high-frequency devices. The main areas in which this letter is used are the aviation industry, shipbuilding, radar (radioelectronic) equipment and others [9].

This material is used to protect Soviet-made Kh-55 cruise missiles and its russian modernization Kh-555, as well as Kh-101 air-to-surface missiles, which additionally makes it impossible to be detected by radio-electronic means for further shooting down by anti-aircraft systems. It becomes more difficult for air defense units to detect them, in most cases, thanks to this material, detection does not occur from the beginning, but at the moment of the launch of the missile [10].

Regarding the use of cruise missiles by the russian Federation, the situation is as follows. Aviation X-101 and X-555 have all four components of navigation. Kalibr missiles most likely do not have DSMAC. But in the realities of the russian federation, another important factor is the availability of detailed, up-to-date and accurate radar and optical maps that are loaded into the missile's memory.

Now more and more often, the enemy began to use Kh-59M missiles, the most common of which, most likely, use only inertial and satellite navigation, and for direct targeting, a radar or television guidance system is turned on.

As for the Kh-22, it generally only has an inertial on the march section and a radar guidance system on the terminal. Both with extremely low accuracy on the Soviet technological base of the 1960s and 1970s. That is, it is launched in the direction of the target, which, moreover, should be as radio-contrast as possible.

Figure 9. Appearance of the Kh-22 missile

The X-22 missile was developed in the 1950s of the last century. Its main task was the destruction of aircraft carriers of the US Army. This is the largest non-nuclear missile currently in service with russia. The weight of the warhead is 960 kg, and the length is almost 12 m. Other missiles usually have a warhead weight of 200–500 kg and a length of 6–8 m.

Accordingly, the Kh-22 is capable of causing much greater destruction than most modern russian missiles. But it has a significant drawback – low accuracy.

The highest accuracy was achieved in the mode of active operation of the homing head on the entire flight path. But in this mode, the missile becomes visible to air defense systems at a long distance. Most likely, russia uses a combined guidance mode: most of the flight, the missile flies autonomously, and only at a certain distance to the target does the homing head turn on. In this mode, the accuracy drops significantly and amounts to several hundred meters, but the chances of interception decrease.

At the same time, the Kh-22 homing radar head is able to recognize only very large objects, such as a large warship or a large bridge [10].

On December 1, 2022, at a briefing of representatives of the Security and Defense Forces of Ukraine, fragments of the warhead of the Kh-55SM missile, which russia uses during shelling of Ukraine, were demonstrated [12]. This is a modification with an increased range of the Soviet Kh-55 aviation cruise missile, which is used by russia to attack Ukraine from Tu-95 and Tu-160 strategic bombers from March 2022. X-55 and X-555 rockets fly at subsonic speeds with terrain contouring at extremely low altitudes. They are intended for use at stationary strategically important objects [12; 16].

Basic characteristics of the X-55SM

flight range – up to 3,500 km;

flight speed – 720-830 km/h;

launch height – 0.6-12 km;

flight height (on the march) – 40-110 m;

dimensions – 6×3 m;

starting mass – 1.5 tons (fuel – 260 kg);

mass of the combat unit – 410 kg;

power – 200-500 kilotons;

accuracy – up to 20 m.

Since the beginning of hostilities, information has appeared about the first use of Kh-59 missiles. This is an old Soviet missile from the 1980s, but it is quite accurate. The circular possible deviation is indicated as less than 10 m, but the USSR and russia tend to exaggerate the real accuracy of their weapons [4].

The disadvantage of the X-59 is its short range – less than 300 km. That is, it can be applied only in the border areas or in the area of the Black Sea coast. It also carries the smallest charge (up to 300 kg) and cannot destroy a large object.

Figure 10. Appearance of the Kh-55 missile

Figure 11. Appearance of the Kh-59 missile

In order to terrorize and intimidate Ukrainians, russia strikes almost every day with the help of cruise missiles, in particular the Kalibr cruise missiles, which are launched both from the Iskander aerial operationaltactical complexes and from ships. Launches are carried out beyond the reach of Ukrainian means of destruction.

The Kalibr cruise missile has nothing revolutionary, it is an updated version of the Soviet-developed 3M10 missile, which in turn was a tracing paper from the American Tomahawk cruise missile [7]. Its ground version for the RK-55 complex lasted only a few years, and was prohibited by the treaty on the elimination of medium and short-range missiles between the USSR and the USA.

Thanks to this program, russia created the "short" 3M14 missile (4.8 meters long) and the "longer" 3M54 (7.2 meters long) with a flight range of more than 1,500 km. The last one was tested at the Iskander-K complex in 2009, called R-500, and stated that its range was no more than 500 km and the contract was not violated.

Figure 12. Appearance of the Kalibr missile

3M54 "Caliber" – missile characteristics
Length: 7.2 m (without starting accelerator)
Wingspan: 3.3 m
Flight weight: 1320 kg
Weight of the warhead: 450 kg
Speed: Mach 0.7
Flight range: more than 1500 km

The Soviet X-55 and its more modern modification X-555 became an alternative to the Kalibr-type missiles at a longer distance. But these missiles can no longer be called highly accurate. For them, the circular deviation is 20–100 m [8].

russia uses P-800 Onyx cruise missiles to strike targets in southern Ukraine. This missile was developed in the late 1970s as a medium-range anti-ship missile. For export, a missile with a reduced flight range (300 km versus 600 km) is delivered under the name "Yakhont". From open sources, we can calculate that during the entire war, about 40 such cruise missiles were launched [8]. This is only 10% of the pre-war stockpile of missiles, which numbered up to 400 units. The peculiarity of the rocket is that it is supersonic. This is the only cruise missile that was used in Ukraine, which flies at 2.5 times the speed of sound, and this is the difficulty of intercepting it. The missile flies along a combined trajectory: in the first stage, it reaches a height of 10-14 km, on the approach to the target, it descends to 15 meters above the surface of the sea. The weight of the warhead is 300 kg.

Figure 13. Appearance of the "Onyx" ("Yakhont") rocket

In total, russia had almost 7,000 medium- and short-range missiles (up to 5,500 km) at the beginning of the war. Almost half of them are low-precision Kh-22, Kh-55 missiles [12].

At the first stage of the war, russia mostly used Kalibr missiles (sea-based) and Iskander missile complexes. Less than the Kh-101 missile, it has several times announced the use of its latest development, the Kh-47 Dagger.

In the russian-Ukrainian war, the Kh-101 is used – the latest cruise missile, which is launched from Tu-160 and Tu-95MS missile carriers. It is difficult to detect, intercept and shoot down with the help of air defense means. The peculiarity of this cruise missile is that it is able to change

Figure 14. Appearance of the Kh-555 missile

the target even when it is in flight. The development of the missile was completed in 2013, it has a long flight range, claimed to be 7,000 kilometres, as well as the use of stealth technology, which makes it quite difficult to intercept. At the same time, the Kh-101 is based on the Kh-555, which in turn is based on the Soviet Kh-55, which was adopted in 1983.

The inertial navigation system with a gyro-stabilized platform (Figure 16) is a mechanical three-axis gyro stabilizer in a gimbal suspension (Figure 17).

Figure 15. Appearance of the Kh-101 missile

Figure 16. Inertial navigation system. General appearance

Figure 17. Inertial navigation system. Mechanical three-axis gyro stabilizer in the cardan suspension

The equipment of users of satellite navigation systems is designed to provide the control system with the current values of coordinates (latitude, longitude, altitude), projections of the velocity vector of the cruise missile based on the signals of the satellite navigation systems GLONASS and GPS along the flight route of the cruise missile, regardless of meteorological conditions [5].

The receiving and computing unit (Figure 18) is installed in the nose part of the fuselage of the cruise missile under the inertial system unit.

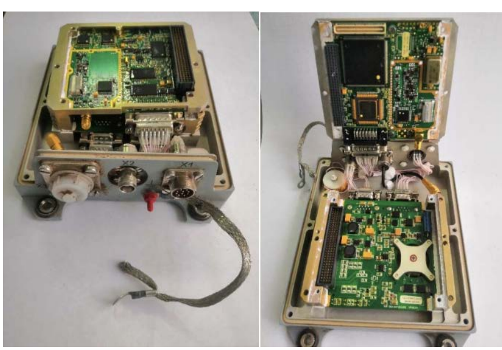

Figure 18. Acceptable computing unit of navigation equipment

The receiving and computing unit provides: solving a navigation problem in coordinate systems; measurement of navigation parameters with the following dynamic characteristics of object movement: speed up to 1000 m/s; height up to 15,000 m. automatic, continuous, real-time detection and issuance of:

– coordinates of the object;

– height;

– three components of the velocity vector;

– current time scales;

– root mean square value of the predicted accuracy of location coordinates.

The main technical characteristics of the navigation system:

24 parallel reception channels:

GLONASS: L1 band, VT and ST codes; GPS: L1-band, S/A-code; reception channel selection algorithm: All-in-view.

coordinate/height determination error in combined mode of operation (GLONASS and GPS) – 15 m; error of determining the velocity vector in the combined mode of operation (GLONASS and GPS) – 0.3 m/s; the time of a reliable solution to a navigation task at a cold/warm start – no more than 90/60 s; information update rate – from 1 to 10 Hz; power consumption, slightly more than 10 W; power supply voltage of the module – +27V; overall dimensions 182×140×58 mm; the mass of the block is no more than 1.3 kg.

As part of the navigation system, the optical-electronic system provides accurate determination of the current coordinates of the cruise missile in flight, and, if necessary, issuing signals to correct the parameters of the on-board inertial control system. The optical-electronic system is an autonomous system that provides navigation in geophysical fields, in particular, by the appearance of the terrain over which the cruise missile flies [6].

The system uses the optical contrast of the terrain in the visible range. Thanks to the high informativeness of the optical image, navigation can be ensured over almost any, including orientationless terrain (except water surface).

The system uses algorithms of correlation-extreme methods, which are based on an in-depth analysis of the mutual location of maxima, comparing the current and reference images with the use of several pictures obtained in different seasonal conditions as reference information about the area.

Thus, the creation of means of protection of critical infrastructure objects, taking into account the main characteristics, features of the application and functioning of cruise missiles with radar correlation-extreme guidance algorithms, should be aimed at the optimal combination and implementation of the following principles:

– lack of influence of protection means on the process of functioning of critical infrastructure objects;

– instant reaction of the application (ensuring the required speed, taking into account the notification of the launch of a missile strike);

– energy independence or minimum acceptable energy costs;

– multiple use;

– distortion of the reference image of the critical infrastructure object, which is used as the initial information of the cruise missile navigation system;

– allowable increase in the weight and overall characteristics of the critical infrastructure object;

– practical implementation and possibility of application in urban conditions.

The implementation of these principles is aimed at increasing the effectiveness of the protection of critical infrastructure facilities from the destructive effects of air attack weapons.

The main requirements for the means of protecting civil infrastructure objects from the destructive impact of air attack means are:

1. High speed.

2. Active use of an electromagnetic shield over civil infrastructure objects

3. Minimum mass per unit area.

4. High strength characteristics.

5. Resistance of the frequency range $\lambda = 3$ μm, $\lambda = 8$ μm.

6. Changing the reference image of the cruise missile navigation system by changing the radar signal reflected from the object.

4. Conclusions

The cities of Ukraine, in particular Kyiv, Kharkiv, Odesa, Lviv, are subjected to massive missile attacks, there are currently no alternative ways to protect civil infrastructure, so it became necessary to analyze the use of air attack means and develop principles and requirements for their protection. The monograph analyzed the use of attack unmanned aerial vehicles and cruise missiles with radar correlation-extreme guidance algorithms used by the Russian Federation in the war against Ukraine, including for striking critical infrastructure objects. An analysis of the methods and methods of protecting critical infrastructure objects from the destructive impact of unmanned aerial vehicles and cruise missiles with radar correlation-extreme guidance algorithms was carried out. The main requirements and ways of creating means of protection of critical infrastructure objects are substantiated. Application analysis and combat experience showed that an important direction is the protection of critical civil infrastructure from the destructive effect of air attacks. The conducted research made it possible to formulate scientifically based recommendations for ensuring the protection of critical infrastructure objects from the destructive impact of various types of air attack means.

References:

1. Faziliev S.O. (2016) Aerostats in the World Wars of the twentieth century. *Actual problems of aviation and astronautics*, part 2, pp. 570–572. Available at: https://cyberleninka.ru/article/n/aerostaty-v-mirovyh-voynah-hh-veka/viewer

2. Christopher J. (2013) *The Race for Hitler's X-Planes: Britain's 1945 Mission to Capture Secret Luftwaffe Technology*, pp. 26–27.

3. Iasechko M., Larin V., Ochkurenko O., Salkutsan S., Mikhailova L., Kozak O. (2019) Formalized Model Descriptions Of Modified Solid-State Plasma-Like Materials To Protect Radio-Electronic Means From The Effects Of Electromagnetic Radiation, *IJATCSE*, no. 8(3), pp. 393–398. DOI: https://doi.org/10.30534/ijatcse/2019/09832019

4. Tyshchuk S.O., Sholokhov S.M. (2005) Electromagnetic weapons. *Volunteer*, no. 5 (37), pp. 18–21.

5. Iasechko M., Kolmykov M., Larin V., Bazilo S., Lyashenko H., Kravchenko P., Polianova N., Sharapa I. (2020) Criteria for performing breakthroughs in the holes of radio electronic means under the influence of electromagnetic radiation, *ARPN Journal of Engineering and Applied Sciences*, no. 15(12), pp. 1380–1384.

6. Iasechko M., Sachaniuk-Kavets'ka N., Kostrytsia V., Nikitchenko V., Iasechko S. (2020) The results of simulation of the process of occurrence of damages to the semiconductor elements under the influence of multi-frequency

signals ofshort duration, *Journal of Critical Reviews*, no. 7(12), pp. 109–112. DOI: https://doi:10.31838/jcr.07.13.18

7. Iasechko M., Larin V., Maksiuta D., Bazilo S., Sharapa I. (2020) The method of determining the probability of affection of the semiconductor elements under the influence of the multifrequency space-time signals, *Journal of Critical Reviews*, no. 7(9), pp. 569–571. DOI: https://doi:10.31838/jcr.07.09.113

8. Taran O., Kotlyarenko Y., Hryshchuk V., Korniichuk S., Kit H., Chernov O., Nikolus D., Yasenchuk V., Petrov Y., Bohdanevich M., Pidhornuy O., Chernyshov O., Hurskii I. (2023) *Methodological recommendations to "general military units on combating Iranian-made Shahed-136" ("Geran-2") and russian "Lancet-2" UAVs (based on the experience of the russian-Ukrainian war of 2022-2023)*, Military training and methodical publication for commanders (chiefs) for use during tasks, the Center for Operational Standards and Training Methods of the Armed Forces of Ukraine together with the Main Department of Doctrine and Training of the General Staff of the Armed Forces of Ukraine, pp. 6–13.

9. Iasechko M. (2017) Plasma technologies for the protection of radio electronic means from exposure to high-power electromagnetic radiations with ultrashort pulse duration. *Proceedings of the 1-st Annual Conference*, pp. 18–21. DOI: https://doi.org/10.21303/2585-6847.2017.00480

10. Kozubenko O., Shulman O. (2022) *The enemy uses Soviet missiles with erased serial numbers.* Armyinform. Available at:]https://armyinform.com.ua/2022/12/01/protyvnyk-vykorystovuye-radyanski-rakety-zi-stertymy-serijnymy-nomeramy/

11. Sytenko O.G. (1965) *Electromagnetic fluctuations in plasma*. KhGPU, pp. 1–183. ISBN: 9780323158381

12. Datsenko V. (2022) russia is increasingly hitting Ukrainian cities with old, inaccurate missiles. How many of them are left and why does air defense not provide full protection? *Forbes.* Available at: https://forbes.ua/inside/rosiya-vse-bilshe-gatit-po-ukrainskikh-mistakh-starimi-netochnimi-raketami-skilki-ikh-zalishilos-ta-chomu-ppo-ne-dae-povnogo-zakhistu-velikiy-gayd-06072022-7020

13. Kovtunenko O.P., Bogucharskyi V.V., Slyusar V.I., Fedorov P.M. (2006) *Weapons based on unconventional principles of action (status, trends, principle of action and protection against it)*. Poltava: PVIZ, pp. 1–247.

14. Tajirov A., Cwhanovskaya I., Barsova Z., Iluoykha N. (2012) Chemistry and technology of magnetite and barium-containing composite materials on its basis. *European Science and Technology: materials of the II international research and practice conference*, pp. 80–87.

15. Skoblikov O., Knyazyev V. (2012) Properties of Conductive Shells Exposed to Electromagnetic Impulse of Lightning. *International Conference on Lightning Protection* (*ICLP'2012*), pp. 1–8.

16. Dementiiuk H., Iasechko M., Bazilo S., Trofimov I., Horbachov K., Riazantsev S., Lutsyshyn A., Zaitsev I. (2023) Analysis of the destructive impact of attack drones on critical civil infrastructure: a combined method of protection based on the application of an electromagnetic shield. *Scandinavian Journal of Information Systems*, no. 35 (1), pp. 29–37. Available at: http://sjis.scandinavian-iris.org/index.php/sjis/article/view/226