UDC 004.056.5:623.462 doi: https://doi.org/10.20998/3083-6298.2026.01.04

Tymur Kurtseitov[1], Rostyslav Pikul[1], Kyrylo Petrenko[1]

[1]National Defense University of Ukraine, Kyiv, Ukraine;

ENSURING INFORMATION SECURITY OF FLIGHT TRAJECTORIES OF OPERATIONAL-TACTICAL MISSILES BY REDUCING THEIR RADAR VISIBILITY

Abstract. Topicality. Nowadays, the concept of ensuring the survivability of weapons in conditions of dense missile defense is focused on protecting the information features of the object. Analysis of combat operations over the past decade shows that concealing the flight paths of operational-tactical missiles from radar reconnaissance systems is a critical element of information security. The development of technical means of detection allows the enemy to receive unmasking signal signs necessary for identifying and destroying the target, which, in turn, necessitates the need to reduce radar visibility. **The subject of study** in the article is methods and technical means of controlling the scattering of electromagnetic waves, in particular passive methods of reducing the effective scattering area of operational-tactical missiles. **The purpose of the** article is to substantiate the possibilities of reducing the radar visibility of operational-tactical missiles through a systematic analysis of existing radio-absorbing materials and methods of modifying the environment around the object to increase stealth in the middle section of the trajectory. **The following results** were obtained. The work has conducted a comparative analysis of flat-layer, gradient and geometrically inhomogeneous coatings, and also assessed the prospects of using artificial plasma formations. It has been determined that for operational-tactical missiles, the priority requirements are the minimum mass, thermal stability (up to 1500 K) and a wide absorption band in the mm-cm ranges. **Conclusion.** The scientific contradiction between the growing capabilities of detection means and the limited characteristics of modern passive protection methods indicates the existing dependence of overcoming the missile defense system on the level of radar visibility. It has been proven that to ensure the information security of the trajectories of operational-tactical missiles, it is necessary to develop new combined coatings with improved mass-dimensional and temperature indicators.

Keywords: information security; operational-tactical missile; radar visibility; effective scattering area; radio-absorbing materials; missile defense.

Introduction

Problem relevance. Analysis of combat operations over the last decade shows that the issue of ensuring the stealth of aircraft in the process of countering reconnaissance and target detection systems is given serious attention by the opposing parties. This is due, first of all, to the development of methods and technical means of reconnaissance of targets for various purposes and obtaining radar information before and during the performance of a combat mission.

As is known, the main efforts of the opposing parties in the process of conducting radar reconnaissance are aimed at obtaining unmasking signal signs of aircraft necessary to achieve the main goal - to detect an object and strike it [1].

To create effective counteraction to radar detection systems, it is necessary to apply special measures aimed at ensuring the stealth of aircraft when performing a combat mission in various conditions of their flight.

The current state of methods and technical means of countering radar reconnaissance is characterized by the integrated use of both traditional methods of organizing masking and imitating interference [2–4], and the use of the latest technologies for reducing the visibility of aircraft, aimed at changing the effective scattering area and distorting the radar characteristics of objects [5]. It is known that the use of active countermeasures to solve the problem of radar masking allows you to mask the reflected radar signal in the receiver of a radar station detecting an interference signal (due to a decrease in the signal/noise ratio) in order to create difficulties for radar stations in detecting, identifying, and therefore in further tracking and destroying the target. In most cases, the main condition for the effectiveness of the use of active masking means is to ensure a level of interference above the signal that will allow you to achieve the desired effect. And this, as a rule, is a rather complex issue, connected, first of all, with the requirements for limiting the mass, dimensions, energy consumption, volume and cost of on-board equipment [6–8]. In this regard, passive methods of creating interference are of great importance. At the same time, these interferences, as well as active ones, can distort the target signal due to the weakening and masking effect on radar detection and reconnaissance means and imitate signals reflected from surveillance objects [9].

Literature review. Research by prominent scientists of recent decades indicates that the following methods of reducing the effective scattering area are currently most widespread:

– improving the aerodynamic shapes of aircraft and its structural elements;

– controlling the scattering of radio waves;

– using special radio-absorbing materials and coatings [2].

It is known that the formation of a low-reflective architecture of weapons and military equipment significantly reduces the probability of target detection and recognition [7]. In the works of Cong Z., Chen R. and Pettijohn, S., the issues of improving the aerodynamic shape of aircraft for various purposes are considered in detail in the works [4, 10].

At the same time, in the works of Sukharevskyi O. and Ryapolov I. it is noted that the selection of the optimal shape of the combat units of an operational-tactical missile in order to ensure the minimum effective scattering area can be carried out within certain limits, which are established based on aerodynamic and design requirements. First, the shape of the warheads of operational-tactical missiles should provide convenient placement of the warhead. Second, the warhead of an operational-tactical missile should have such an aerodynamic shape that would ensure stable flight of its carrier [11–12].

However, the isolated giving of a low-reflective shape to an object does not provide the necessary reduction in radar visibility. Therefore, in practice, the formation of a rational architecture of the design of aircraft for various purposes is carried out comprehensively, taking into account the use of optimal shapes and structures of their design, or radio-absorbing materials and coatings [8]. The solution of this problem allows you to significantly reduce the effective scattering area of aircraft in a wide range of waves, from optical to short waves of the radio range, that is, practically in the entire possible range of operation of reconnaissance and information systems for target detection [13].

The purpose of the research is to substantiate the possibilities of reducing the radar visibility of operational-tactical missiles through a systematic analysis of existing radio-absorbing materials and methods of modifying the surrounding environment to increase stealth in the middle section of the trajectory.

Main research

Analysis of the direction of increasing the stealth of aircraft, associated with the control of the scattering of electromagnetic waves, shows that the ability to purposefully influence the main radar characteristics of the target allows not only to control the radar visibility of the object, but also to additionally create various interferences in the reflected field, simulate targets, diagnose sources of echo signals, etc. [9].

Passive cloaking means can be used in a wide range of frequencies and do not require a priori information or detailed information about the characteristics of enemy systems. If used correctly, they are effective simultaneously against a large number of enemy radar stations. These properties determine the most important role that is given to them in the development of new methods, methods, algorithms for increasing stealth and protecting objects from foreign complexes for detecting and destroying aircraft, which are continuously being improved.

Given the specifics of solving the problem of reducing the visibility of operational-tactical missiles when breaking through the missile defense system, it is necessary to emphasize that the use of methods and technical means of creating passive obstacles to mask an object in order to counteract enemy reconnaissance equipment is aimed, first of all, at changing the main signal characteristic of the target - its effective scattering area [12].

In other words, in order to make the target stealthy, it is necessary, as much as possible, to reduce the amplitude of the reflected radio wave, that is, to reduce the effective scattering area as much as possible [5].

Despite the fact that it is quite difficult to make aircraft completely invisible to detection systems, serious attention is paid to solving this problem abroad and in our country, including the use of modern technologies to increase stealth in the development of new missile systems for various purposes [1].

At the same time, it is possible to increase the stealth of the missile itself in flight by using various means of radar masking based on the application of:

– methods of reducing the effective scattering area and distorting the radar characteristics of the missile;

– methods of modification around the object environment, which provide a significant attenuation of the radio signal;

– methods of creating false targets, which complicate the work of operators in identifying real targets [14].

In addition, it is necessary to take into account that special measures of passive missile masking are most effective in the middle section of its flight trajectory [2, 6].

This is explained, firstly, by the fact that in this section of the trajectory the operational-tactical missile has the most informative unmasking features that can be used in the missile defense system to solve such important tasks as recognizing missile warheads against false obstacles and target distribution of detected warheads between missile defense fire control systems and individual missile launchers. Secondly, in the middle section of the trajectory, especially in its extra-atmospheric part, fairly simple and relatively inexpensive means of radar masking of objects can be used, for example, radio-absorbing coatings.

In this regard, from the unified position of organizing radar masking of operational-tactical missiles, we will analyze the possibility of using known methods of ensuring the stealth of aircraft to solve the problem of breaking through the missile defense system with operational-tactical missiles.

The main means of controlling the scattering of radio waves are controlled structures and coatings, which are placed on the surface of protected objects or near them. They include controlled elements that change their electrophysical and spatial parameters under the influence of control signals from external sources. The most common designs of controlled structures are controlled loads, screens, reflectors-antennas, reflective gratings. Mechanical ferrite, ferroelectric, liquid, plasma, impedance elements located in the antenna loads or antenna focusing areas are quite effectively used as controlled elements.

It should be noted that known methods of modifying the environment around the object based on the creation of various types of masking screens can significantly reduce the level of the reflected signal of radar detection stations in a wide frequency range.

Analysis of such methods shows that they are characterized by a wide variety of mechanisms of action on the probing signal and are determined by the features of the operating ranges of detection means.

Even greater diversity is distinguished by technical means of modification that implement different strategies for organizing masking curtains and allow:

– to change the effective scattering area;

– to change the signal / interference ratio in the receivers of observation means;

– to introduce distortions into the signal characteristics of observed objects;

– to form false objects in areas of space where there are no real targets;

– to reduce the contrast of real observed targets to the background level.

The literature emphasizes that one of the effective methods of modifying the environment around a radar target is the use of artificial plasma formations [15].

It is known that in a wide range of radio waves, the degree of ionization of space has a significant impact on their propagation. The effect of ionization of the environment is manifested in the fact that radio waves undergo reflection, absorption and refraction. These factors can lead to disruption of the normal functioning of the radio line.

Thus, there is a possibility of creating passive interference to radar detection stations by artificial ionization of local areas of the environment around aircraft. The advantage of this method of reducing the visibility of the target is the possibility of overlapping a wider frequency range compared to the use of narrow-band absorbing coatings. Analysis of works devoted to this issue shows that serious attention is now being paid to the development of methods and improvement of technical means of forming artificial plasma formations, which are based on the well-known physical phenomenon of absorption or reflection by plasma. However, a clear classification that would allow us to clearly present and analyze the development of these methods of forming artificial plasma formations to solve the problem of ensuring the stealth of aircraft is not provided in the known literature or is limited to considering two methods of forming an ionized environment: burning easily ionizing substances (for example, cesium) and high-altitude nuclear explosions [15].

Assessment of the features and main disadvantages characteristic of the specified methods allows us to conclude that their use, with certain advantages in comparison with narrow-band impedance structures and coatings, does not allow to effectively solve the problem of increasing the stealth of operational-tactical missiles for the following main reasons:

– the need to use powerful ionization sources;

– the short life time of ionized formations;

– a high level of noise for on-board receivers;

– a high consumption of working substance;

– a noticeable increase in the weight of aircraft - the carrier.

All this, ultimately, determines a rather low possibility of using the considered methods of forming artificial plasma formations around operational-tactical missiles to solve the problem of breaking through the enemy's missile defense.

Literature analysis shows that abroad the main direction of development of radio-absorbing materials for protecting aircraft remains the desire to increase their operating range, thermal resistance and radiation resistance. In addition, developments are underway to solve the problem of absorption or attenuation of optical waves. A promising direction in this aspect is the development of qualitatively new masking coatings, which are a combination of layers designed to create a masking effect in the optical and ultrahigh frequency ranges of the spectrum.

The principle possibility of using radio-absorbing materials and coatings to reduce the radar visibility of aircraft, as well as a detailed description of the principles of operation of radio-absorbing materials and coatings, methods for calculating scattering characteristics are presented in the works [16]. The results of experimental studies of the scattering characteristics of different types of radio-absorbing materials at different frequencies at different separation angles between the transmitting and receiving points.

However, as our analysis has shown, there is currently no systematic data on the parameters of radio-absorbing coatings and the possibility of their application on operational-tactical missiles to increase their stealth when breaking through the missile defense system. In order to determine the possibilities of using radio-absorbing coatings on this class of missiles, we will analyze the characteristics of existing coatings and, first of all, determine the main tactical and technical requirements for them.

The analysis shows that existing radio-absorbing materials do not have the necessary absorbing properties in a sufficiently wide range of wavelengths in which modern radar reconnaissance systems operate [16]. In addition, the use of these coatings to reduce the effective scattering area of operational-tactical missiles is associated with a number of structural, aerodynamic and physical-electrical requirements, the main of which are [8]:

– minimum mass per unit area;

– high strength characteristics;

– ability to operate in a wide range of mechanical and temperature conditions (300–1500 K);

– resistance to aggressive environments;

– radiation resistance;

– reliability and durability;

– low cost.

Each of the above requirements is quite important from the point of view, first of all, of the mass-dimensional and operational characteristics of the material under harsh, dynamic physical conditions of flight associated with temperature and pressure drops.

However, it should be emphasized that the uniqueness of the use of absorbing coatings on operational-tactical missiles, taking into account the specified requirements, should also lie in the ability to satisfy the requirement of the maximum possible attenuation of electromagnetic energy in a wide frequency range (mm–cm).

We will define this requirement in combination with restrictions on the mass and dimensions of the coating per unit area of the missile as priority.

Thus, taking into account the practical requirements imposed on coatings, as well as the conditions of combat use of radar detection and electronic warfare systems, we will analyze the main characteristics of modern radio-absorbing coatings that can be used to mask aircraft. Currently, materials and coatings used for radar masking of aircraft are divided into several main types: flat-layer (interference), gradient and geometrically inhomogeneous [3]. However, interference coatings are resonant and are designed for a given fixed frequency.

Given that modern radar reconnaissance means of the missile defense system operate in a wide frequency range, multilayer stepped radio-absorbing coatings and materials are used to increase the frequency interval of the coating [11]. They are characterized by the fact that the electrophysical parameters of individual layers change according to a certain law. However, such coatings are operational only in the extra-atmospheric part of the trajectory and therefore must be supplemented with heat-resistant components, which sharply increase the mass of the aircraft and complicate the technology of manufacturing its body. Ferrite materials are used as radio-absorbing coatings, which are characterized by magnetic losses. However, single-layer ferrite coatings are also relatively narrow-band. For example, the reflection coefficient of coatings based on ferrite materials N2-31, N2-41 and N2-51 ("Ecosorb") is 20 dB (i.e. no more than 1% of the incident energy is reflected) with a coating thickness of 5...8 mm in the frequency band of 250...400 MHz.

To cover a wider frequency band, as in the case of dielectric radio-absorbing coatings, it is necessary to apply multilayer coatings. Given the high specific gravity of ferromaterials (4630 kg/m3), this is not always permissible, and the use of such coatings for operational-tactical missiles is impractical.

The use of ceramic ferrite materials intended for protection of combat units of operational-tactical missiles in the range from meter to centimeter waves is known. However, the thickness of such a coating is 5-7 mm, and the mass per m2 is more than 5 kg. In addition, the fragility of the ferrite material and the sharp deterioration of its quality with increasing temperature do not allow its use on operational-tactical missiles.

Note that if the number of layers of a multilayer radio-absorbing coating is increased indefinitely, the flat-layer structure will turn into a gradient-type coating, in which a sharp change in the distributed parameters is not allowed. Such coatings reflect electromagnetic energy poorly in a wide frequency band, but are the most complex in terms of their calculation and practical implementation [7]. Geometrically inhomogeneous radio-absorbing coatings and materials have a wide operating frequency band with a low reflection coefficient, but, despite this, in most cases their dimensions significantly exceed the dimensions of flat-layer coatings [10].

Some scientists note the possibility of using chiral materials, which are isotropic dielectrics, to reduce the visibility of aircraft, which are chaotically distributed mirror-asymmetric elements in the form of small metal or ceramic spirals. Artificial bianisotropic materials also have a low reflection coefficient.

To reduce the effective scattering area of aircraft of various types, band scattering-absorbing structures can be used, in which the effects of scattering and absorption of electromagnetic wave energy are used together [16]. In electrodynamic terms, their model is a combination of layered inhomogeneous and geometrically inhomogeneous magnetodielectric coatings.

An assessment of the main characteristics of radio-absorbing materials and coatings used to reduce the visibility of aircraft, presented in Tables 1 and 2, shows that each of them is designed for a certain frequency (or frequency range). The common frequency range is 2...18 GHz. The maximum absorbing effect (20 dB) is achieved when using wide-band coatings such as LAO and K-RAM. The thinnest material (0.7...2 mm) is the radio-absorbing coating ARAM.

Table 1 – **Main characteristics of radio-absorbing materials from Plessy (Great Britain)**

№	Name of radioabsorbing material	Thickness, mm	Specific gravity, kg/m	Rated frequency range, GHz	Signal attenuation, dB
1	*ARAM, wideband*	0,7-2	1.7 (at 1.5 mm)	8-16	6-15
2	*LAO, wideband*	12-20	0.844 (at 12 mm)	4-36	15-20
3	*Narrowband*	7	28-28,5	0,9-1,15	15
4	*Narrowband*	3,6-4	16,5-17,5	2,6-3,95	15
5	*Dual-band*	6 5 and 4.3 - 2.2	15	2,6-12,4	15
6	*D × 20, narrowband*	not given	1,2	8,2-12,4	1 5 (at an angle of incidence of 90o)
7	*K-RAM, wide-range structural*	5 -10	7-15	2-40	20 (may be resonant at two or three frequencies)

Table 2 – **Main characteristics of radio-absorbing materials developed abroad**

№	Name	Composition	Frequency range, GHz	Operating temperature range, C°	Thickness, mm	Weight of 1 sq.m of material, kg
1	*"Ecosorb" FGM – 40 USA*	Silicone rubber with filling	4…10	up to 260	1.0	4.9
2	*"Ecosorb" FGM – 125 USA*	Silicone rubber with filling	2…12	up to 260	3.2	12.2
3	*"Ecosorb" MF – 5 00 USA*	Iron, epoxy resin	3…8.6	up to 260	10	16…46
4	*"Ecosorb" FDS USA*	Ferrite, silicone rubber	1.2…8.6	up to 260	0.7	4.3
5	*"Ecosorb" ZN USA*	Ferrite, ceramics, epoxy resin	0.2…10	up to 540	3.2	17
6	*AN - P73 USA*	Polyurethane	8…12	-70…150	11.1	0.78
7	*AN – 73 USA*	Polyurethane	7.5…26	-70…150	10	1.34
8	*AN - P74 USA*	Polyurethane	5…12	-70…150	20.6	1.46
9	*AN - P75 USA*	Polyurethane	2.5…12	-70…150	1.59…4.76	2.44
10	*AN – 75 USA*	Polyurethane	2.4…26	-70…150	29	2.15
11	*FGM - 40 FGM - U – 40 USA*	Iron, silicone or urethane rubber	4…10	up to 218 (120)	1.0	4.88
12	*FGM – 125 USA*	Ferrite, silicone or urethane rubber	8…12	up to 218 (120)	3.2	12.2
13	*AAP – SS USA*	Multilayer foam-based material	2…4 4…8 8…12 12…18	-55…130	13…25 6…13 5…6 2…5	0.9…1.5 0.8 0.7 0.5
14	*MC USA*	Has a honeycomb structure		-51…190	24.6	-
15	*ECA – FS FRG*	Two-component absorber	1…10	-	-	-
16	*Broadband absorber FRG*	Absorbent-impregnated organic or ceramic foams	more than 2	-	more than 4	less than 5
17	*Broadband absorber FRG*	Ferrite, silicone rubber	2…16	-	-	-
18	*ε=μ absorber*	Ferrites with similar values	0.1…10	-	more than 1	less than 40
19	*IN Japan*	Refractory material with ferrite addition	1…10	-3…40	-	-
20	*IR Japan*	Ferrite, rubber, plastic	0.5…15	up to 300	-	-
21	*IG Japan*	Carbonyl iron, rubber	7…100	up to 100	-	-
22	*IB Japan*	Sintered ferrite	0.5…5	up to 500	-	-
23	*IL Japan*	Ferrite, rubber, rubber-like paint	1…15	up to 300	-	-

Thus, the analysis of the main areas of application of radio-absorbing materials and coatings developed in the USA, Great Britain and Japan, as well as the assessment of their main characteristics, allow us to identify a number of parameters that ultimately determine the inexpediency of their use on operational-tactical missiles.

First of all, these are:

– insufficient bandwidth (hundreds of MHz in the frequency range of 8-30 GHz);

– large mass (kilograms per m2);

– large thickness (centimeters);

– high coefficient of friction, which causes a significant increase in the level of infrared radiation;

– high hygroscopicity;

– insufficient temperature resistance (up to 540°) and strength, as a result of which the coating burns out at supersonic flight speeds;

– high cost of manufacturing and processing.

Thus, despite the variety of different types of electromagnetic wave absorbers, to date the problem of creating radio-absorbing coatings with minimal mass and dimensions in a wide frequency range has not been solved.

Discussion of results

The analysis of methods for reducing the radar visibility of operational-tactical missiles shows that ensuring the information security of their trajectories is a complex scientific and technical task. The introduction of classical "stealth technologies" to operational-tactical missiles is complicated by extreme operating conditions, in particular high kinetic surface heating during flight at supersonic and hypersonic speeds. Analysis of the physicochemical properties of existing radio-absorbing materials, which demonstrate high efficiency in the decimeter and centimeter ranges, revealed critical limitations in terms of their thermal stability and mechanical strength at temperatures above 1000–1500 K.

The article pays special attention to the use of plasma formations as a method of modifying the environment around the object. Despite their theoretical ability to absorb a wide spectrum of radiation, practical implementation on board operational-tactical missiles faces the problem of the additional weight of plasma generators and the negative impact of the ionized layer on the operation of the missile's own navigation and communication systems. This confirms that passive methods (coating and geometry change) remain the most promising, but require the transition to multifunctional composite structures.

Protection of information features of operational-tactical missiles is possible only through the creation of adaptive coatings that are able to change their electrophysical properties in real time depending on the frequency of irradiation by the enemy radar. This will allow to bypass modern air defense systems that use broadband signals to detect inconspicuous targets.

Conclusions

An analysis of the achievable characteristics and physical mechanisms used in known radio-absorbing coatings and materials has been carried out. It has been established that none of them fully satisfies the entire complex of tactical and technical requirements for passive protection of weapons and military equipment from radar detection and homing systems of high-precision weapons, and on this basis it has been shown that a contradiction has arisen, caused, on the one hand, by the growth of the capabilities of high-precision weapons with radar detection and homing systems to defeat weapons and military equipment with small effective scattering areas, and on the other hand, by the insufficient capabilities of existing methods and means of reducing the reflective and absorbing properties of weapons and military equipment in a wide frequency range of waves.

Prospects for further research lie in the development of mathematical scattering models for complex geometric shapes of operational-tactical missiles, taking into account the dynamic change in the phase composition of the plasma layer. The practical implementation of the proposed approaches will significantly increase the probability of breaking through enemy missile defense systems by minimizing the time for detecting and tracking a target.

References

1. Vasilets, V. (2025), “Drone radar visibility: a look across frequency bands”, *Information Processing Systems,* 2(181), pp. 8–20, doi: https://doi.org/10.30748/soi.2025.181.01
2. Markarian, G., Staniforth, A. (2021), *Countermeasures for Aerial Drones*, Artech House, Boston, London, 234 p.
3. Sukharevsky, O., Zalevsky, G., Vasilets, V., Galkin, Y., Horielyshev, S., Sadovyi, K. (2021), “Characteristics of sec-ondary radiation of a tactical unmanned aerial vehicle in the meter, decimeter and centimeter wave ranges”, *Science and Technol-ogy of the Air Force of Ukraine,* 4(45), pp. 82–92, doi: https://doi.org/10.30748/nitps.2021.45.10
4. Pettijohn, S. (2024), Evolution, Not Revolution: Drone Warfare in Russia’s 2022 Invasion of Ukraine. *Center for a New American Security,* URL: https://www.cnas.org/publications/reports/evolution-not-revolution
5. Sukharevskiy O. I., Vasylets V. O., Nechytaylo S. V., Reznichenko O. A., Kudryashov G. V. (2023), “Research of radar characteristics of the loitering ammunition model “Shahed-136””, *Science and Technology of the Air Force of the Armed Forces of Ukraine,* 2(51), pp. 56–62, doi: https://doi.org/10.30748/nitps.2023.51.07
6. Riapolov I., Trystan, A. (2024), “Method for selecting the shape and materialsof unmanned aerial vehicle structural elementsto form their required radar signature”, *Collection of Scientific Papers of the National Academy of the National Guard of Ukraine,* 2(46), pp. 111–121, doi: https://doi.org/10.33405/2409-7470/2025/2/46/352581
7. Ryapolov, I., Vasylets, V., Kukobko, S., & Bodnar, S. (2024), “Modeling of surface geometry of unmanned aircraft vehicles, the design of which contains elements with different electrophysical properties”, *Testing and Certification*, 2(4), pp. 101–110, doi: https://doi.org/10.37701/ts.04.2024.13
8. Skibitsky, V. (2023), Under the sign of the owl. Ukrainian technologies and strategies: website. URL: https://gur.gov.ua/content/pid-znakom-sovy.html
9. Dudush, A., Kushch, P. (2022), “Evaluation of flight parameters of an operational-tactical missile: ballistic trajectory”, *Collection of scientific papers of the Kharkiv National University of the Air Force,* 1(71), pp. 7–12.
10. Cong, Z., Chen, R., He, Z. (2022), “Numerical modeling of EM scattering from plasma sheath: a review”, *Engineering Analysis with Boundary Elements,* 135, pp. 73–92, doi: https://doi.org/10.1016/j.enganabound.2021.11.013
11. Sukharevskyi, O., Vasylets, V., Klymchenko, V., Takhian, K. (2022), “Modeling the reflective properties of hypersonic cruise missiles”, *Science and Technology of the Air Force of the Armed Forces of Ukraine,* 1(46), pp. 64–71, doi: https://doi.org/10.30748/nitps.2022.46.09
12. Ryapolov, I., Ryapolov, E., Bodnar, S. (2024), “High-frequency methods for calculating the scattering characteristics of complex airborne radar objects”, *Testing and certification,* 1(3), pp. 85–95, doi: https://doi.org/10.37701/ts.03.2024.12
13. Ryapolov, I., Nechytaylo, S., Ryapolov, E. (2025), “Reduction of radar visibility of objects of simple geometric shape due to the application of radio-absorbing material on a limited area of the surface”, *Testing and Certification,* 2(8), pp. 113–119, doi: https://doi.org/10.37701/ts.08.2025.12
14. Krylyk, L., Bogach, I., Lisovenko, A. (2019), *Numerical methods. Numerical integration of functions.* Vinnytsia: VNTU. 74 p.

15. Ryapolov, I., Kukobko, S. (2024), "High-frequency methods for calculating the scattering characteristics of ground radar objects of complex shape", *Testing and certification,* 3(5), pp. 70–81. doi: https://doi.org/10.37701/ts.05.2024.08
16. Molloy, O. (2024), How are drones changing modern warfare? URL: https://surl.li/xfkusg

Received (Надійшла) 26.01.2026
Accepted for publication (Прийнята до друку) 23.02.2026

Відомості про авторів/ About the Authors

Куртсеітов Тимур Ленурович – доктор технічних наук, професор, заступник начальника науково-методичного центру організації наукової та науково-технічної діяльності, Національний університет оборони України, Київ, Україна;
Tymur Kurtseitov – Doctor of Technical Sciences, Professor, Deputy Head of the Scientific and Methodological Center for the Organization of Scientific and Scientific and Technical Activities, National Defense University of Ukraine, Kyiv, Ukraine;
e-mail: kurttimur@ukr.net; ORCID Author ID: https://orcid.org/0000-0001-6478-6469;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57190944450.

Пікуль Ростислав Володимирович – заступник начальника центру, начальник наукового відділу досліджень та впровадження інноваційних технологій наукового центру проблем виховання доброчесності та запобігання корупції у секторі безпеки та оборони, Національний університет оборони України, Київ, Україна;
Rostyslav Pikul – Deputy Head Building Integrity Training and Educational Center, National Defense University of Ukraine, Kyiv, Ukraine;
e-mail: plkul.rostislav@gmail.com; ORCID Author ID: https://orcid.org/0000-0003-3928-9596;
Scopus ID: https://www.scopus.com/authid/detail.uri?origin=resultslist&authorId=57218644968.

Петренко Кирило Михайлович – доктор філософії, начальник кафедри інформаційної боротьби, Національний університет оборони України, Київ, Україна;
Kyrylo Petrenko – Doctor of Philosophy, Head of the Department of Information Warfare, National Defense University of Ukraine, Kyiv, Ukraine;
e-mail: petrenkokirill8881@gmail.com; ORCID Author ID: https://orcid.org/0000-0001-8420-8981;
Scopus ID: https://www.scopus.com/authid/detail.uri?authorId=57207819849.

ЗАБЕЗПЕЧЕННЯ ІНФОРМАЦІЙНОЇ БЕЗПЕКИ ТРАЄКТОРІЙ ПОЛЬОТУ ОПЕРАТИВНО-ТАКТИЧНИХ РАКЕТ ШЛЯХОМ ЗНИЖЕННЯ ЇХ РАДІОЛОКАЦІЙНОЇ ПОМІТНОСТІ

Т. Л. Куртсеітов, Р. В. Пікуль, К. М. Петренко

Анотація. Актуальність. На сьогоднішній день концепція забезпечення живучості засобів ураження в умовах щільної протиракетної оборони орієнтована на захист інформаційних ознак об'єкта. Аналіз бойових дій останнього десятиліття свідчить, що приховання траєкторій польоту оперативно-тактичних ракет від систем радіолокаційної розвідки є критичним елементом інформаційної безпеки. Розвиток технічних засобів виявлення дозволяє противнику отримувати демаскуючі сигнальні ознаки, необхідні для ідентифікації та знищення цілі, що, своєю чергою, зумовлює потребу зниження радіолокаційної помітності. **Предметом дослідження** у статті є методи та технічні засоби управління розсіянням електромагнітних хвиль, зокрема пасивні методи зниження ефективної площі розсіяння оперативно-тактичних ракет. **Метою статті** є обґрунтування можливостей зменшення радіолокаційної помітності оперативно-тактичних ракет шляхом системного аналізу існуючих радіопоглинаючих матеріалів та методів модифікації навколооб'єктового середовища для підвищення скритності на середній ділянці траєкторії. **Були отримані наступні результати.** У роботі проведено порівняльний аналіз плоскошарових, градієнтних та геометрично неоднорідних покриттів, а також оцінено перспективність використання штучних плазмових утворень. Визначено, що для оперативно-тактичних ракет пріоритетними є вимоги щодо мінімальної маси, термостійкості (до 1500 К) та широкої смуги поглинання в мм-см діапазонах. **Висновок.** Наукове протиріччя між зростаючими можливостями засобів виявлення та обмеженими характеристиками сучасних пасивних методів захисту свідчить про наявну залежність подолання системи протиракетної оборони від рівня радіолокаційної помітності. Доведено, що для забезпечення інформаційної безпеки траєкторій оперативно-тактичних ракет необхідна розробка нових комбінованих покриттів з покращеними масо-габаритними та температурними показниками.

Ключові слова: інформаційна безпека; оперативно-тактична ракета; радіолокаційна помітність; ефективна площа розсіювання; радіопоглинаючі матеріали; протиракетна оборона.