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PROTECTION OF SURFACE-TO-AIR MISSILE SYSTEMS AGAINST UNMANNED AERIAL VEHICLE STRIKES

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Abstract This article examines the protection of surface-to-air missile systems against threats posed by unmanned aerial vehicles (UAVs). The increasing use of UAVs in modern conflicts has created new challenges for the survivability and operational effectiveness of air defense systems. The study analyzes existing approaches to detecting UAV threats, improving the survivability of surface-to-air missile systems, and reducing their vulnerability to aerial attacks. Particular attention is given to early warning, camouflage, mobility, dispersion, electronic protection, and the integration of different defensive measures. The study is based on a review and comparative analysis of relevant Uzbek and international scientific literature and open-source materials. The findings indicate that the effective protection of surface-to-air missile systems requires an integrated approach combining organizational, technical, and protective measures. The article concludes with general recommendations for improving the survivability and operational resilience of surface-to-air missile systems against UAV threats.
Keywords: surface-to-air missile systems; unmanned aerial vehicles; counter-UAV; resilience; layered air defence; risk assessment.

Annotatsiya. Ushbu maqola yer-havo raketa tizimlarini uchuvchisiz uchish apparatlari (UAV) tomonidan yuzaga keladigan tahdidlardan himoya qilishni o'rganadi. Zamonaviy mojarolarda UAVlardan tobora ko'proq foydalanish havo mudofaasi tizimlarining omon qolish qobiliyati va operatsion samaradorligi uchun yangi qiyinchiliklarni tug'dirdi. Tadqiqotda UAV tahdidlarini aniqlash, yer-havo raketa tizimlarining omon qolish qobiliyatini oshirish va ularning havo hujumlariga nisbatan zaifligini kamaytirishning mavjud yondashuvlari tahlil qilinadi. Erta ogohlantirish, kamuflyaj, harakatchanlik, tarqalish, elektron himoya va turli mudofaa choralarini integratsiyalashga alohida e'tibor qaratilgan. Tadqiqot tegishli o'zbek va xalqaro ilmiy adabiyotlar va ochiq manbali materiallarni ko'rib chiqish va qiyosiy tahlil qilishga asoslangan. Topilmalar shuni ko'rsatadiki, yer-havo raketa tizimlarini samarali himoya qilish tashkiliy, texnik va himoya choralarini birlashtirgan kompleks yondashuvni talab qiladi. Maqola yer-havo raketa tizimlarining UAV tahdidlariga qarshi omon qolish qobiliyati va operatsion chidamliligini oshirish bo'yicha umumiy tavsiyalar bilan yakunlanadi.
Kalit so'zlar: yer-havo raketa tizimlari; uchuvchisiz uchish apparatlari; UAVga qarshi; chidamlilik; qatlamli havo mudofaasi; xavfni baholash

Аннотация. В статье рассматриваются вопросы защиты зенитных ракетных комплексов (ЗРК) от угроз, исходящих от беспилотных летательных аппаратов (БПЛА). Широкое применение БПЛА в современных конфликтах создало новые вызовы для живучести и боевой эффективности систем противовоздушной обороны. В работе анализируются существующие подходы к обнаружению угроз со стороны БПЛА, повышению живучести ЗРК и снижению их

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уязвимости к ударам с воздуха. Особое внимание уделяется системам раннего предупреждения, маскировке, мобильности, рассредоточению, радиоэлектронной защите и интеграции различных защитных мер. Исследование базируется на обзоре и сравнительном анализе профильной научной литературы (как узбекской, так и зарубежной) и материалов из открытых источников. Результаты исследования свидетельствуют о том, что эффективная защита ЗРК требует комплексного подхода, сочетающего организационные, технические и защитные меры. В заключение статьи представлены общие рекомендации по повышению живучести и оперативной устойчивости ЗРК в условиях угрозы со стороны БПЛА.

Ключевые слова: зенитные ракетные комплексы; беспилотные летательные аппараты; противодействие БПЛА; устойчивость; эшелонированная противовоздушная оборона; оценка рисков.

INTRODUCTION

Unmanned aerial vehicles have changed the air-threat environment by expanding the availability of airborne sensing, surveillance and strike capabilities. Their diversity complicates traditional distinctions between high-value aircraft threats and smaller aerial objects. Surface-to-air missile (SAM) systems are therefore not only instruments of air defence but also assets whose own operational continuity requires attention. This article examines that challenge at the level of resilience policy, architecture and institutional preparedness, rather than tactical positioning, weapon employment or system-specific vulnerabilities [1–3].

The research question is: Which broadly applicable resilience principles are most consistently supported by Uzbek and international open literature concerning protection of SAM systems from UAV-related disruption? The study aims to

- compare domestic and international perspectives;
- classify recurring protection themes; and
- formulate non-operational recommendations for research, governance and assessment.

The contribution is a transparent synthesis, not a claim of experimental validation.

LITERATURE REVIEW

Uzbek scholarship provides relevant starting points. Nurmuhamedov, affiliated with the National University of Uzbekistan, surveys approaches used by foreign armed forces against UAVs and emphasizes comparative study as a basis for national air-defence development [4]. Khurramov and Bobomurodov, researchers affiliated with Uzbekistan's Higher Military Aviation School, consider survivability under unmanned and manned aerial threats [5]. Their work indicates that protection should be discussed at the system level; however, the present review does not reproduce or operationalize particular countermeasures. Ermetov discusses contemporary attacks on air-defence systems and the intersection of UAVs with electronic and cyber threats [6]. These publications establish a domestic research trajectory while varying in methodology and publication venue.

International institutional sources provide a broader conceptual framework. NATO's 2025 Integrated Air and Missile Defence Policy explicitly links active and passive defence, layered architectures, resilience, redundancy and continuity of command and control [1]. NATO's 2026 Layered Counter-UAS Initiative stresses the integration and testing of sensors, decision-making and response capabilities rather than evaluating individual technologies in isolation [2]. The United Nations Institute for Disarmament Research (UNIDIR) primer describes UAV diversity and the

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technical, legal and humanitarian issues surrounding counter-UAS measures [3]. A NATO Review analysis cautions against assuming that any single counter-drone technology is a universal solution [7].

The literature converges on integration and adaptation but exhibits three gaps. First, many public publications are conceptual or descriptive rather than controlled comparative studies. Second, technical outcomes reported for general counter-UAS settings cannot automatically be transferred to SAM-system protection. Third, interoperability, human factors, legal constraints and post-disruption recovery are not always assessed using common indicators. These gaps motivate a qualitative synthesis with explicitly limited claims.

MATERIALS AND METHODS

A structured narrative review was conducted using publicly accessible sources available by 9 October 2026. Searches targeted the concepts “counter-UAS”, “air-defence survivability”, “integrated air and missile defence”, and relevant publications by Uzbekistan-based researchers. Sources were selected for direct topical relevance, traceable authorship or institutional provenance, and availability of identifiable publication information. Priority was given to official NATO and UNIDIR documents and identifiable scholarly articles. The review is not a PRISMA systematic review and does not claim exhaustive coverage.

Analysis. Each source was read for high-level claims concerning protection, continuity, integration, governance and evidence quality. Concepts were coded into five thematic categories:

1. layered protection;
2. information integration;
3. passive resilience and redundancy;
4. training and organizational adaptation; and
5. safety, law and evaluation.

Claims were compared across domestic and international literature; only themes with identifiable support were retained. No classified information, performance specifications, geographic layouts, engagement timelines or operational countermeasure instructions were used.

Quality controls. Institutional policy documents were treated as statements of doctrine or priorities, not as independent empirical proof. Scholarly articles were interpreted in light of their scope and reported methods. Because the evidence base lacks a harmonized dataset of SAM attacks and protection outcomes, this study presents no invented sample sizes, effect percentages, statistical significance or **modeled interception probabilities.**

RESULTS

The synthesis identifies five mutually reinforcing themes. First, layered protection is consistently framed as a combination of complementary measures rather than dependence on a single response technology [1,2,7]. Second, shared awareness and interoperability recur as requirements for coherent assessment and coordinated decision-making [1,2]. Third, passive resilience—including organizational redundancy, recoverability and continuity planning—complements active air defence [1]. Fourth, repeated evaluation, training and learning are necessary because UAV technologies and threat patterns change rapidly [2,4]. Fifth, assessment must account for legal, humanitarian and safety considerations alongside technical capability [3].

Table 1. Qualitative themes identified from the reviewed literature; the table reports conceptual findings, not measured protective effectiveness.

Theme	Synthesis from reviewed	Non-operational assessment

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	sources	dimension
Layered protection	Complementary measures reduce reliance on one component [1,7].	Architecture diversity and dependency mapping
Information integration	Interoperable awareness and decisions matter [1,2].	Information quality and coordination
Passive resilience	Continuity and redundancy complement active measures [1].	Recovery readiness and service continuity
Organizational adaptation	Learning cycles respond to evolving UAV challenges [2,4].	Exercise evaluation and lessons learned
Governance and safety	Counter-UAS choices have legal and humanitarian implications [3].	Compliance, accountability and safety review

Table 1 shows that the reviewed literature emphasizes an integrated approach to protecting surface-to-air missile systems against UAV threats. Layered protection and information integration are identified as important for reducing dependence on individual defensive components and improving coordination. Passive resilience and organizational adaptation support continuity and the ability to respond to changing threats. In addition, governance and safety considerations indicate that protective measures should be implemented in accordance with legal, humanitarian, and accountability requirements.

DISCUSSION

A central finding is that "protection" is a broader construct than the successful interception of an incoming UAV. The reviewed policy and research sources describe a resilient defensive enterprise as one that can sustain essential functions, absorb disruption, share reliable information and adapt after incidents [1–3]. This is especially relevant to SAM systems because their value derives from continued availability within a wider air-defence network. Accordingly, evaluation frameworks should distinguish asset-level survivability from network-level continuity.

The Uzbek literature helps localize the question by emphasizing comparative study of international experience [4] and survivability as an analytical category [5,6]. International sources extend the discussion toward integrated governance, interoperability and formal resilience principles [1–3]. The sources should not be treated as interchangeable evidence: doctrinal commitments express intended practice, while journal publications may offer conceptual arguments without independent field verification. Cross-national transfer also requires attention to institutional and legal context.

An important limitation is the absence of a reproducible quantitative dataset. This review cannot rank specific defensive technologies, estimate strike-prevention rates or identify an optimal configuration. Such claims would require clearly defined outcomes, independent validation and appropriately controlled data. Future research could use anonymized, non-sensitive organizational indicators—for example, training completion, communication reliability, incident-reporting quality and recovery-plan testing—to assess resilience without publishing tactical details.

CONCLUSION AND RECOMMENDATIONS

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The literature supports a holistic, resilience-oriented interpretation of SAM-system protection against UAV threats. Across Uzbek research and international institutional publications, the most defensible general conclusion is that technical capabilities should be considered together with organizational continuity, interoperability, learning and accountable governance. Public evidence is not sufficient to claim a universal or quantitatively superior protective configuration.

Recommendations for research and institutional policy are to:

1) develop a standardized, non-sensitive resilience assessment vocabulary;
2) evaluate continuity and recovery alongside technical detection outcomes;
3) incorporate interoperability and human-factors review into academic assessments;
4) maintain transparent legal and safety review of counter-UAS proposals; and
5) conduct future comparative studies with explicit methods, limitations and independently verifiable data.

These recommendations are intended for scholarship and governance, not operational deployment instructions.

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