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The evolution of air threats in future conflicts

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Abstract

Currently, there is an observable trend towards continuous and comprehensive development in both fixed-wing and rotary-wing aircraft design. Furthermore, a dynamic progression has been also witnessed in the evolution of unmanned aerial vehicles, loitering munitions, lethal auton-omous weapons systems, ballistic missiles, cruise missiles, hypersonic cruise missiles, lighter-than-air sensor platforms, high altitude pseudo satellites and any others.
The development of modern technologies and the acquisition of new materials create opportu-nities for the modernization of existing air threats as well as the development of novel types. Additionally, the potential of artificial intelligence in unmanned systems is a significant factor that should not be overlooked.
The aforementioned circumstances have prompted the author of the article to conduct a thorough examination of contemporary military air threats and to make a forecast regarding the evolution of air threats in future conflicts.

Keywords: air threats, artificial intelligence, future conflicts, future weapon, lethal autonomous weapons systems, loitering munitions

1. Introduction

Air threats have long been and undoubtedly will remain an integral component of military operations. Currently, a significant increase in diversity and dynamic development of various types of air strike assets has been observed, as well as their growing importance in armed conflicts. To effectively counter air threats in future military conflicts, it is unquestionably necessary to seek answers to the following questions: *What types of air threats will we encounter in the future, and how will they evolve?* The more accurately our predictions reflect future realities, the greater the chances that the air defense systems currently being constructed and acquired will be able to ensure the desired level of effectiveness and, consequently, aerial security in the future.

Contrary to appearances, providing an answer to such a formulated question may prove challenging due to the possibility of unforeseeable events. Factors that can significantly shape the future development of air threats include discovering and advancing new technologies (Zajas, 2009). Novel propulsion sources that can surpass current limitations regarding speed and improve maneuverability parameters for certain types of air threats are particularly significant in this context. Additionally, the mastery of energy storage technology, characterized by relative lightweight and high capacity, holds importance in terms of air threat evolution. An alternative could be the invention of efficient, lightweight, and compact energy generators. Both energy storage systems and generators can create optimal conditions for implementing microwave beam weapons and high-energy lasers on both manned and unmanned aerial platforms.

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The development of special thermally insulating coatings for missiles and material and technical solutions enabling heat dissipation can play a fundamental role in the evolution of air threats, especially those associated with hypersonic speeds. These advancements are crucial in ensuring effective heat management for missiles operating under such extreme conditions. Another emerging challenge can be Artificial Intelligence (AI), which, when implemented in various types of new air threats, can provide partial or even full autonomy. This introduces a new dimension to the potential capabilities of air threats, as AI can enhance their ability to operate independently and adapt to changing circumstances. Furthermore, the development of air threats can be regulated by legal frameworks, various conventions imposing certain limitations on signatories, or sanctions restricting access to technologies and resources for states and other entities covered by them. These legal measures play a significant role in controlling the proliferation and potential misuse of advanced air threat technologies. Additionally, there are other factors that cannot be currently predicted but may prove to be groundbreaking.

In addition to the factors determining the development of future air threats, there are also factors that determine their use in armed conflicts. The time horizon under consideration will have particular significance. In this article, the author has decided not to extend their forecasts beyond a twenty-year horizon. The countries involved in the future conflict will also play a crucial role. The nature of the conflict will differ between superpowers, asymmetric conflicts, or countries at intermediate levels of development. Furthermore, experiences from the war in Ukraine demonstrate the significant importance of the conflict duration. It should be noted that even the most extensive stockpiles of modern weaponry will eventually deplete, and in place of advanced air threats, parties to the conflict may resort to using older-generation air attack means. Certainly, some factors determine the use of air threats in armed conflicts, which the author of this article is currently unable to predict.

The purpose of this article is to thoroughly examine the evolving nature of air threats in future military conflicts. The author explores the development and transformation of various types of air threats, including fixed-wing aircraft (FWs), rotary-wing aircraft (RWs), unmanned aerial vehicles (UAVs), loitering munitions (LMs), lethal autonomous weapons systems (LAWS), cruise missiles (CMs), ballistic missiles (BMs), hypersonic cruise missiles (HCMs), hypersonic glide vehicles (HGVs), lighter-than-air sensor platforms (LAPs), and others (such as dual-use technologies). The article aims to provide insights into the potential changes in air threat capabilities, tactics, and technologies, taking into consideration advancements in artificial intelligence (AI), materials, and propulsion systems. Due to limitations, the author of this article has chosen to provide a forecast focusing on selected air threats.

2. Future manned air threats

It can be argued that fighter aircraft will remain the primary source of air threats for many more years to come. It is estimated that in future armed conflicts, fighter aircraft will be engaged in countering the enemy's air capabilities through Offensive Counter-Air (OCA) and Defensive Counter Air (DCA) operations, while also providing support to other components such as ground, maritime, and special forces. In order to create the necessary conditions for carrying out the aforementioned tasks, fighter aircraft will be required to perform missions aimed at achieving the desired level of control in the airspace (DD/3.3. 2014). This includes operations to suppress enemy air defenses (SEAD) and destroy enemy air defenses (DEAD), as well as serving as a key player in Joint SEAD operations.

The author believes it would be a mistake to assume that only fifth and sixth-generation fighters will be carrying out missions in the air over the next twenty years. While the primary burden of air operations, such as Offensive Counter-Air (OCA), Defensive Counter Air (DCA), Suppression of Enemy Air Defenses (SEAD), and Destruction of Enemy Air Defenses (DEAD), will indeed fall on these advanced aircraft, the role of fourth-generation and fourth-plus generation planes will still be significant (Bronk, 2020). Currently, we are witnessing a cycle of modernizing fourth-generation fighters in many countries to keep them in service for several more decades until they are eventually replaced by fifth and subsequent generation fighters. These modernizations primarily focus on enhancing the survivability of the aircraft, primarily through the installation of electronic self-defense systems that disrupt and deceive the enemy's sensors and effectors (Radomyski, 2014). A significant aspect of upgrading older aircraft involves replacing the existing radars with new ones featuring active electronically scanned array (AESA) technology, which can operate in active, passive, and electronic warfare modes. The modernized aircraft are equipped with integrated reconnaissance, targeting, and navigation systems, and they are adapted to use advanced air-to-ground munitions, including stand-off weapons and those with reduced radar detectability.

There is no doubt that fifth-generation aircraft will play an increasingly significant role in the coming years. This will be achieved through the utilization of stealth technology, which relies on specific airframe designs, composite materials that absorb or scatter specific wavelengths of electromagnetic radiation, and the reduction of thermal signatures emitted by jet engines. It is thanks to this technology and its ability to deliver precise strikes from long distances and high altitudes that it will be particularly desirable in future armed conflicts. Everything indicates that by utilizing network-centric command and control systems, fifth-generation aircraft serve as one element within a comprehensive system-aerial platform-incorporating sensors and effectors that can be flexibly configured according to the mission's requirements.

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However, even the most advanced fifth-generation fighters will undergo gradual transformations. Intensive efforts are already underway to develop aircraft of the so-called sixth generation. Such fighters would have the capability to conduct missions without the presence of a pilot on board. Furthermore, during air operations, they would be integrated with unmanned aerial vehicles (UAVs), loitering munitions, and loyal wingmen, serving a controlling function over them.

After the invention of relatively small yet efficient energy storage or generation systems, specifically designed to power the directed-energy weapons (DEWs) onboard fighter aircraft, the aircraft would acquire additional capabilities in terms of engaging a greater number of targets and also defending against enemy missiles. This capability could prove to be crucial in aerial combat, for instance, when facing swarms of adversary drones.

Helicopters currently play a significant role in armed conflicts due to their specific capabilities, namely vertical takeoff and landing, as well as the ability to transport personnel and supplies to inaccessible areas. They are involved in various tasks, including close air support (CAS), close combat attack (CCA), transport operations for combat search and rescue (CSAR), as well as special operations and electronic warfare. Helicopters are an excellent platform for carrying a large amount of guided and unguided weaponry. Often, by flying at very low altitudes, they are able to penetrate the enemy's radar undetected. However, there is an observable trend towards limiting the role of attack helicopters on the battlefield. Experiences from ongoing armed conflicts demonstrate that attack helicopters are highly susceptible to machine gun fire and specialized anti-aircraft defenses. The significant losses in both pilots and helicopters have led to their displacement by UAVs. A similar situation can be observed with reconnaissance tasks. However, this does not mean that helicopters will not be utilized in future armed conflicts. They will more frequently perform transport, CSAR and special operations tasks. As for offensive missions, they will be carried out in collaboration with UAVs and loitering ammunition, allowing the helicopter to remain outside the range of MANPADs, enemy anti-aircraft artillery, and machine guns. In the future, currently existing helicopters will undergo modernization, equipped with integrated targeting and navigation systems and fitted with night vision and thermal imaging devices. They will also be adapted to employ modern weaponry. Similarly to aircraft, the implementation of DEWs on helicopter platforms is foreseen, also to provide them with self-defense capabilities.

It is evident that the combat capabilities of both fighter jets and helicopters largely depend on the aerial weaponry they can employ. Moreover, there is a noticeable increase in target precision by utilizing multiple guidance methods, including Inertial Navigation System (INS), Global Positioning System (GPS), infrared, radar, or other means, to direct missiles and bombs towards their intended targets. This not only enhances the resilience of such aerial weaponry against countermeasures but also enables their miniaturization, as seen in the case of the small diameter bomb (SDB). The precision of these strikes allows for a reduction in the warhead mass, facilitating the carriage of more bombs by fighter jets and helicopters and enabling the engagement of a greater number of targets. Importantly, this approach also helps mitigate the risk of collateral damage. It is also expected that in the future, fighter jets will be increasingly armed with missiles, glide bombs, and cruise missiles built with stealth technology. Furthermore, many of these weapons will have the capability to be launched or dropped from outside the range of Surface-Based Air Defense (SBAD) systems. Recently, we have observed the use of entirely new types of aerial weaponry. Russian hypersonic air-launched ballistic missiles (such as the Ch-47M2 Kinzhal) and hypersonic cruise missiles (such as the 3M22 Zircon) are already being launched from aircraft. It can be predicted that this trend will continue to rise (Radomyski & Michalski, 2021). Additionally, it is likely that we won't have to wait long for the widespread use of laser and microwave beam weapons.

3. Future unmanned air threats

It is difficult not to agree with the statement that among various types of air threats, unmanned aerial vehicles (UAVs) are developing most dynamically. They are taking on an increasing number of tasks previously carried out by manned platforms and are also undertaking new ones, thanks to their unique characteristics. Today, the largest UAVs are capable of conducting missions lasting several dozen hours on the other side of the world, while smaller ones can navigate through urbanized environments, both outdoors and indoors. Therefore, it is reasonable to ask: What else can UAVs surprise us with in the future?

Certainly, future UAVs will be characterized by improved operational and technical parameters compared to their current counterparts, such as increased maximum range and altitude, extended endurance, higher speed, and enhanced data transmission capabilities. They will also exhibit greater survivability by reducing their radar and thermal signatures through the use of stealth technology, employing electronic countermeasures (ECM), and even by mimicking certain natural organisms like birds in their design. Thanks to the miniaturization of aerial weaponry, even Class I UAVs will be capable of carrying guided bombs, missiles, and electronic warfare systems. Currently, we can already observe cases of UAVs collaborating with loitering munitions. Such actions have taken place, for example, in the Nagorno-Karabakh conflict, and they appear to be highly promising, indicating that this tactic will be further refined in the future. The concept of mass deployment of small UAVs, known as swarm tactics, is particularly prospective. These tactics seem to be especially useful for overcoming robust groups of SBAD.

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The experiences gained from the war in Ukraine have demonstrated that under certain circumstances, a significant number of UAVs with simple designs and low production costs can successfully rival technologically advanced and consequently highly expensive UAVs. The accessibility of advanced technologies can also pose a barrier for many countries when it comes to independently manufacturing UAVs, particularly if they lack permission to acquire modern UAVs from other nations. Moreover, the procurement costs alone can present a substantial obstacle for some countries. As a result, in the future, we can anticipate the utilization of both technologically advanced UAVs and simpler machines capable of mass production.

In the future, the combat application of UAVs may see a particularly significant role played by Artificial Intelligence (AI). UAVs have the potential to function as autonomous systems capable of detecting, identifying, and engaging targets. The degree of human control can vary, ranging from a human in the loop, where a human initiates weapon actions (in other words, not fully autonomous), to human on the loop, where a human can intervene or interrupt the action, and even to human out of the loop, where no human involvement is required (Kowalczewska, 2021; Scharre, 2016).

We can anticipate similar trends in the development of loitering munitions. Like UAVs, loitering munitions will experience advancements in their tactical and technical parameters, as well as reductions in radar and thermal signatures. The implementation of AI will further enhance their existing dual-role capabilities as both sensors and shooters. There is also optimistic potential for the utilization of loitering munitions in swarm tactics. However, it is important to expect that in future conflicts, relatively inexpensive and simplistic designs of such munitions will dominate the landscape. These cost-effective solutions will be produced and deployed in large quantities to enable mass combat operations. Furthermore, it is anticipated that loitering munitions will be employed from diverse platforms, including mobile land-based launchers, manned and unmanned aerial vehicles, as well as surface ships and submarines.

A significantly less common yet intriguing solution involves the utilization of lighter-than-air sensor platforms (LAPs). These unmanned aerial objects have proven to be challenging to engage, relatively affordable, and easy to operate, primarily serving reconnaissance purposes. While LAPs have notable limitations in terms of course correction, they can be advantageous under specific favorable circumstances. Therefore, it is not excluded that conflicting parties may consider deploying such platforms in the future.

4. Forecast of missile development

The term “missiles” encompasses the projection of development for ballistic missiles, cruise missiles, as well as the most recent ones that present significant challenges to air defense systems: Hypersonic Glide Vehicles (HGVs) and Hypersonic Cruise Missiles (HCMs) (GAO, 2019).

When it comes to ballistic missiles, it is expected that they will maintain their current advantages. These encompass their ability to be launched from stationary land-based platforms, mobile launchers, ships, and even aircraft, such as the aero-ballistic Kh-47M2 Kinzhal. Ballistic missiles demonstrate high precision in targeting, particularly in the latest versions. They offer global range, with intercontinental ballistic missiles (ICBMs) being especially notable in this regard. Furthermore, they can be launched from outside areas controlled by adversaries and are equipped with systems to enhance their survivability. Due to their low radar signature and high speed, they present difficulties in detection and interception. Importantly, ballistic missiles possess the capability to carry diverse types of warheads, including conventional, nuclear, chemical, and biological.

When considering development trends, it is anticipated that forthcoming ballistic missiles will showcase improved precision in target guidance by employing multiple guidance methods. Additionally, they will exhibit heightened resilience against jamming of their guidance systems. Ballistic missiles are already equipped with and will continue to incorporate increasingly sophisticated decoys to confuse interceptor missiles tasked with neutralizing them. Undoubtedly, the effectiveness of ballistic missiles will be further enhanced through the utilization of flight stealth, achieved by employing flattened flight trajectories and leveraging aerodynamic forces during the terminal phase to manipulate flight parameters, including executing maneuvers with very high accelerations. All of this is aimed at making them even more challenging to be countered by air defense systems. In future conflicts, it is important to consider that older generation ballistic missiles will be deployed, undergoing various modifications, particularly to enhance their range and accuracy. These modifications will be undertaken by medium and lower-level developed states and so-called “rogue” states.

In terms of Cruise Missiles (CMs), it is anticipated that future developments will result in increased range and the continuation of their ability to maneuver at low altitudes with high speeds. These new CMs will be capable of operating at both subsonic and supersonic speeds, particularly during the terminal phase. Lessons learned from the conflict in Ukraine suggest that for effective penetration of air defense systems, future CMs should be designed with stealth technology. The standard practice is expected to incorporate multiple guidance methods in CMs, such as the use of INS, GPS/GLONASS, infrared (IR), and terrain-contour matching utilizing radar (TERCOM). Additionally, a digital scene-matching area correlation (DSMAC) system will be integrated to enable optical comparison of the target area. The capability to launch CMs from diverse platforms, such as land-based, airborne, surface

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ships, and submarines, will remain a substantial advantage and play a significant role in future armed conflicts. However, it should be recognized that once the production technology for Hypersonic Cruise Missiles (HCMs) is fully developed, superpowers are more inclined to prioritize their utilization over CMs.

Hypersonic Cruise Missiles (HCMs) are considered highly advanced and promising weaponry. This is due to their ability to maneuver throughout the entire flight trajectory in the lower layers of the atmosphere at speeds ranging from 5 to 10 or more Mach. They have a low radar signature, making them practically undetectable, and their maneuverability during the entire flight path hinders accurate target extrapolation by the opposing side.

The distinctive features of HCMs stem from their propulsion system. They are initially boosted by a rocket to achieve hypersonic speeds and then utilize a scramjet, an air-breathing engine, to sustain that speed. The intake of air into their engines allows HCMs to employ smaller launch rockets compared to Hypersonic Glide Vehicles (HGVs), resulting in cost-effectiveness and broader launch capabilities from various platforms (Boyd, 2022).

However, a significant challenge that remains to be resolved is the effective dissipation of heat generated from the friction between high-speed HCMs and the dense air in the lower layers of the atmosphere. Nonetheless, it is predicted that engineers will overcome this obstacle in the near future, enabling the large-scale production of HCMs. It is important to note that only a few countries will possess the capability to demonstrate HCM production technology for many years to come.

Hypersonic Glide Vehicles (HGVs) are warheads used in ballistic missiles that have the capability to maneuver and glide at hypersonic speeds. Their primary purpose is to introduce significant changes to the trajectory of ballistic missiles after they have been launched. While HGVs share similarities with Maneuverable Re-entry Vehicles (MaRVs), they differ in that HGVs separate from their rocket boosters shortly after launch, whereas MaRVs can only maneuver shortly before impact. Traditional ballistic missiles follow predictable ballistic trajectories, making them vulnerable to interception by advanced anti-ballistic missile (ABM) systems. The in-flight maneuverability of HGVs adds an element of unpredictability, allowing them to effectively evade air defenses. The main attributes of HGVs include their global range, hypersonic speeds exceeding 5 Mach (around 10 Mach), resulting in a short time to reach the target, and their difficulty in detection and interception. Hypersonic glide vehicles (HGVs), similar to Hypersonic Cruise Missiles (HCMs), will pose a significant airborne threat in the future. However, only a few nations will possess this type of weaponry for several decades to come.

5. Other air threats with dual-use capabilities

The concept of other air threats with dual-use capabilities encompasses the utilization of commercial drones for military purposes, such as reconnaissance and targeted strikes. These drones can be equipped with model-specific adaptation kits to mount grenades, mortar shells, and other munitions, enabling the drone operator to deploy them against the enemy at the right place and time. In some cases, drones are even used for kamikaze missions.

Furthermore, software modifications are made for military purposes to overcome certain inherent limitations associated with civilian drone usage. It is important to note that civilian drones repurposed for military use are not as effective and resilient against countermeasures as their typical military UAV counterparts. However, as demonstrated in the conflict in Ukraine, the key to success lies in the tactical employment and the mass availability of these drones. The cost of acquiring and adapting drones for military purposes is significantly lower than military-origin UAVs.

Prolonged conflicts are characterized by the eventual depletion of missile and ammunition stocks, even when they were initially plentiful. This situation is evident in the ongoing war in Ukraine, particularly in the actions of the Russian Armed Forces. As their supplies of ground-to-ground missiles diminished, the Russians opted to repurpose their ground-to-air missiles, specifically the S-300 and S-400 air defense systems, for engaging ground targets. While these missiles are less effective than conventional ground-to-ground missiles of comparable size, they serve to compensate for the resulting capability gap.

Both cases highlight how limitations spur engineers and military personnel to think creatively. Therefore, it is reasonable to anticipate that in future armed conflicts, airborne assets originally designed for different purposes may find applications in combat scenarios.

6. Conclusions

In conclusion, the article highlights the evolving nature of air threats in military operations, with a specific focus on various aircraft types, unmanned systems, and future weapons. The advancements in technology and materials offer opportunities to upgrade existing threats and introduce new ones. The integration of artificial intelligence in unmanned systems also plays a significant role. The overall trends in air threat evolution are depicted in the figure (Figure 1).

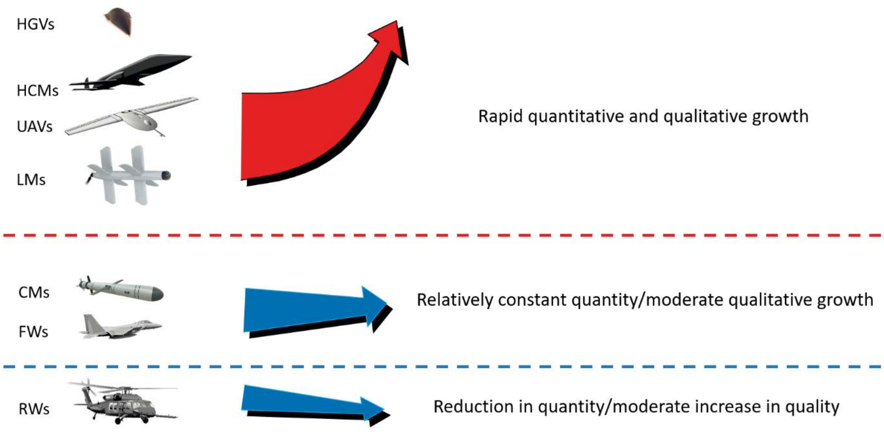

Figure 1. The trends of evolution in air threats
Source: Author's own work.

Fighter aircraft will continue to play a crucial role in future conflicts, with fifth and sixth-generation fighters dominating the scene. Fourth-generation planes will remain significant, especially after undergoing modernization efforts. The use of stealth technology, network-centric systems, and advancements in energy storage will enhance the capabilities of manned aircraft. Additionally, attack helicopters are expected to have a reduced role on the battlefield, likely operating in conjunction with UAVs and loitering munitions rather than independently.

UAVs are experiencing rapid development and assuming increasingly diverse tasks. Future UAVs will possess improved operational and technical parameters, greater survivability, and the ability to carry guided bombs, missiles, and electronic warfare systems (Dobija, 2019). The concept of swarm tactics and the integration of AI in UAVs and loitering munitions show promise.

However, it is important to acknowledge that even with assumptions about the next twenty years, answering the initial question posed in this article, "What types of air threats will we encounter in the future, and how will they evolve?" is a challenging task. There are factors that can completely disrupt the forecast presented above. However, this does not mean that such attempts should be abandoned. It is essential to anticipate the air threats we will face in the future in order to adequately prepare countermeasures. By considering advancements in technology, materials, and tactics, efforts can be made to ensure the effectiveness of air defense systems. Nevertheless, it is crucial to recognize the inherent uncertainties and the potential for unforeseen developments in the evolution of air threats.

Declaration of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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