Safety & Defense

2021
ISSN: 2450-551X
Special Issue
Volume 7 Issue 2

Centrum Rzeczoznawstwa Budowlanego
ANDARTA
Fundacja Nauka dla Bezpieczeństwa

SAFETY & DEFENSE
Volume 7 Issue 2 (2021)

"Science for Knowledge, Knowledge for Safety & Defense"

ISSN:2450-551X

Table of Contents

Dear Readers,

In October 2021, we are proud to publish the new and special issue of the "Safety & Defense" journal. On this occasion, on behalf of the Editorial Board, I would like to thank all the authors for their very interesting papers and the reviewers for the effort put into evaluating the submitted articles. As always, we would like to invite everyone interested in issues related to safety and defense to send their work to our journal.

I would also like to emphasize that the October issue was produced amid the organization of the Polish Nationwide Science Conference entitled "Challenges and Development of Polish Air Defense: Defensive Power of Poland," which was held on October 20-21, 2021, at the Polish Military University of Aviation.

The main aims of this conference are to:

- define the nature of the latter-day air threats, as well as to determine the current counteraction capabilities of the Polish air defense system;
- diagnose the main areas of the Polish air defense development and its framework after the long-term technological modernization program of the Polish Armed Forces;
- present the results of recent research on the organization and functioning of the planned Polish air defense system carried out by the nationwide research and development centers and the Polish arms industry.;
- exchange the views and promote knowledge on air defense.

Taking into account the above points, I would like to invite all of you to read the papers published in the latest issue of our journal. In this issue of "Safety & Defense," there are twelve peer-reviewed papers that constitute an interesting review of theoretical and empirical research conducted in various areas of military and non-military security.

The first paper presents considerations on the significance of the missile defense system to the military deterrence at the Allied (NATO) and national level. The results of the carried out research show that the missile defense system of Poland, other alliance members, and the NATO Integrated Air and Missile Defense System should be treated as the crucial elements of military deterrence.

The current issue includes a discussion on the origins, current state, and the future of Baltic States Integrated Air Defense. Changes to the security environment after 2014 gave a new impetus to the development of the air defense of the Baltic states, both to the efforts undertaken by NATO and the national capability development.

The subsequent analysis focuses on issues related to the presentation and evaluation of the influence of the Chinese and Russian Anti-Access/Area-Denial (A2/AD) systems on the global changes of international relations and distribution of military power. The research led to the conclusion that some A2/AD systems serve to defend borders, while the rest are created to influence the geopolitical and military situation or to gain an advantage in the area of military operations.

Identification and characteristics of challenges and threats for international security posed by hypersonic weapons are the subject of the following paper. In their inquiry, the authors emphasize that hypersonic weapons are an indispensable tool for the Russian Federation to position itself on higher ground in the arena of international competition and can be treated on equal terms with nuclear weapons.

Another publication contains a summary of research conducted at the Military University of Aviation concerning the employment of unmanned aerial vehicles for warfare purposes. Alongside the theoretical analyses, the paper focuses on the conceptual solutions of the employment of unmanned systems on the contemporary battlefield. Moreover, the article discusses the difficulties of introducing new combat systems and extending their autonomy and survivability.

No less interesting are the results of the research presented in the following paper. The article describes the possible benefits of the use of suborbital missiles used for security and defense purposes. The author presents the capabilities of the Łukasiewicz Research Network – Institute of Aviation in the area of suborbital rockets and the development process of the ILR-33 AMBER2K missile development.

The next paper is focused on the tactical and technological operation conditions of the S-200C Vega system on the modern battlefield. The carried out analyses refer to the up-to-date employment of the Vega SAM system and the justification of further usage of the system.

The capabilities of the Anti-Air Missile System (AAMS), which is included in the Narew program, are the subject of another paper. The multi-criteria assessment method designed exclusively for evaluating the AAMS capabilities should, as the author argues, provide a valuable database useful in the selection process of the short-range air defense missile system for Poland.

The following research presents an interesting discussion of the factors impacting the number of accidents in civil aviation. There is no doubt that numerous dangers to civilian flights exist in all phases of the flight.

The diagnostics and assessment of the military pilot selection and training process in Poland are addressed in the following paper. The results of the research defined the main improvement directions for the selection process of military pilots.

The Polish-USA cooperation regarding the protection of classified information is the topic of another article. The author draws the readers' attention to the issue of mutual security measures available for both countries, which are expected to guarantee the effective protection of sensitive information and work in the best interest of either nation. The conducted research made it possible to answer the question of what security measures determine the effectiveness of protecting classified information regarding the military issues between the states-parties of an agreement.

The special issue of "Safety & Defense" is concluded with a paper depicting the decisive contribution of general's Ion Bugnescu to the development of Romanian Anti-Air Artillery. The paper's primary focus is placed on the rapid growth of military aviation in the interwar period.

We hope you enjoy this latest issue.

Safety & Defense

Special Issue Editor

Tomasz Kulik

Contribution of the Polish arms industry to the Development of Polish Air Defense System

Speaking of the Polish Air Defense System, one cannot forget about the Polish defense industry, which has been involved in strengthening the potential of the Polish Army from its inception. The challenges faced by the armed forces were also taken up by our companies. Before starting any discussion on the development of the Polish air defense, it is necessary to underline what we have achieved so far in this area.

Taking into account the basic components of the air defense system, we can distinguish three key product lines: means of threat detection, systems for managing and transmitting information, and effectors allowing to eliminate threats from the air. In each of these areas, the Polish defense industry has provided solutions that have allowed the armed forces to ensure safety in the Polish sky.

The roots of radiolocation in Poland date back to the 1930s, when in 1934 the National Telecommunications Institute was established, which was then recreated as the Industrial Telecommunications Institute, or PIT (Polish: Przemysłowy Instytut Telekomunikacji) in the postwar years. The second pillar of our armament industry in this domain since the 1950s has been the Warsaw Radio Works RAWAR. Their merger gave rise to PIT-RADWARE, which for years has been the main supplier of radiolocation systems for the Polish Army. The products developed by our facilities have been used for supervision of the Polish air space for decades, while the newest products of the company – BYSTRA systems, and in the near future also PET/PCL, P-18PL, and SAJNA will constitute the pillars of this segment in the Polish Armed Forces.

The second area is command and control systems. The first implementation of such a solution developed by the domestic armaments industry took place in the 1970s. In the following decades, more and more modern products were developed. It is noteworthy that few countries in the world were able to develop and implement for production and operation such a modern comprehensive system, which was withdrawn from service at the beginning of the 12th century and replaced by another domestic product – the DUNAJ system. From the very beginning, the DUNAJ had features of network-centric systems that are currently being developed and implemented in air and missile defense formations around the world. This constituted a breakthrough in the development of C4ISR systems in our country, and, based on its architecture, further solutions were developed and implemented for the Polish Armed Forces – PRZELOT-SAMOC, ŁOWCZA/REGA or SD PILICA.

The third pillar of air defense are effectors – also, in this case, the Polish armament has always answered the army's needs. We have come a long way from developing the "wz. 36" cannon, innovative for its time, to producing the latest anti-aircraft effector systems in the Polish Armed Forces – the PSR-A PILICA, POPRAD, and GROM/PIORUN systems.

Keeping the competencies mentioned above in mind and considering their potential, one can move on to discuss the future of the air defense industry. We must begin this section by identifying the fundamental threats and challenges facing the formations responsible for securing this theater of the battlefield.

The most commonly cited modern airborne threats include:

- Unmanned aerial vehicles – autonomous platforms that require low cost and operational inputs from the user; they are increasingly exposing the flaws and shortcomings of systems designed for large-scale, symmetric conflict.

- Radio-electronic warfare means – in a computerized world, the vast majority of equipment requires constant contact with their master and slave systems. Disruption of battlefield communications and command support assets are one of the greatest threats facing today's armed forces.
- Stealth systems – more and more formations are using stealth systems, which have a reduced effective reflective surface area, reducing their ability to be detected and targeted by most traditional radar systems many times over.

The ones mentioned above and, of course, a whole host of other challenges require appropriate countermeasures. Thanks to its experience and competence, Polska Grupa Zbrojeniowa offers a range of solutions and systems that are able to respond to the challenges posed to air and missile defense forces.

In the area of radiolocation, we offer products that have a passive location capability, allowing them to detect and target multiple objects simultaneously, including hard-to-detect targets. In the area of command systems, we have network-centric solutions that can conduct tasks both in full complement and in dispersion, perfectly matching the doctrine of creating equipment-tailored task forces designed to carry out specific objectives and threats that soldiers may encounter. In the area of effectors, we develop and supply the Polish Armed Forces with state-of-the-art missile and artillery products to combat the full spectrum of aerial attack means.

All this is a preparation for implementing the national industry program to acquire short-range air defense missile sets for the Polish Armed Forces, known under the code name NAREW. This program is one of several most important projects for the Polish armaments industry in the history of our country. NAREW is our great opportunity – a project that will involve several of our companies in its implementation. As a result of NAREW, we will establish new competencies in missile technology, radiolocation, and communication and command support systems.

Air defense is undergoing a constant process of modification – new threats require rapid response. This is addressed by Polska Grupa Zbrojeniowa and its offer.

PREZES POLSKIEJ GRUPY ZBROJENIOWEJ

Sebastian Chwałek

SAFETY & DEFENSE
ISSN 2450-551X

Modern Missile Defense System as an Indispensable State's and NATO's Deterrence Tool

Maciej MARSZAŁEK

War Studies University, Warsaw, Poland;
m.marszalek@akademia.mil.pl, ORCID: 0000-0003-4490-4530

DOI: https://doi.org/110.37105/sd.157

Abstract

The main aim of this article is to prove the significance of the missile defense system for military deterrence at the allied (NATO) and national level (the US, Poland, etc.). To achieve the aim, theoretical research methods such as analysis, synthesis, comparison and generalization were applied. The results of the conducted research show that the missile defense system of Poland and other alliance members, and the NATO Integrated Air and Missile Defense System should be considered as the crucial elements of the military deterrence, even though such systems are not offensive in nature. Thus, the formulated thesis undermines the up-to-date understanding of the problem, and therefore may contribute to further discussion on the topic of using means of defensive deterrence.

Keywords:

ballistic missiles, intercepting missiles, military deterrence, missile defense system, security

Submitted: 18.08.2021 Accepted: 26.08.2021 Published: 20.10.2021

1. Introduction

Weapons of mass destruction and their carriers – ballistic missiles – remain one of the most important contemporary threats to the international security. These two elements (WMD and the capacity to carry it) become specifically dangerous if possessed by a state that has hostile intentions towards countries like Poland, and its allies. Poland, as a border state of the North Atlantic Alliance and the European Union, realizes policies that too often seem hard to accept for the Russian Federation. In such cases of higher tensions between these two states, Moscow usually deploys ISKANDER ballistic missiles to the Kaliningrad Oblast (Region), that borders Poland. Despite its classification as a short-range system, it should be underlined that its range covers virtually the entire territory of the Republic of Poland.

In the third decade of the 21st century, it is hard to imagine the security of the Republic of Poland without a missile defense system. Furthermore, it is seems more than reasonable to consider such national and NATO missile defense systems not only in case of an attack but in the context of the deterrence as well.

Attempts at expanding such a system may meet strong opposition from experts who too easily accept the mainstream media narration on future warfare. Recently, the conflict in Eastern Ukraine, and its hybrid character, have been widely acclaimed as a model for future conflicts. It is worth noting that the term "hybrid" has recently become very popular, assuming a firm position in theoretical discussions on contemporary and future warfare. However, when attempting forecast future conflicts, one must ask the following question: does it mean that all future wars will be similar to that in Ukraine since 2014? Unfortunately, based on the comments in the mass media and numerous popular and scientific, and academic articles, we could assume so. If that is the case, a future war, in which Poland and NATO will participate, will have such a hybrid character and characteristics of the Russian-Ukrainian conflict, it would seem that ballistic missiles with nuclear (or conventional) warheads will not be used in combat, and the battlefield would be dominated by "the little green men". Accepting such a scenario could be perilous. Hybrid warfare does not exclude any other means, tools and methods of using force against the adversary. To the contrary – hybrid precisely refers to a mix of conventional and unconventional methods, thus potentially including WMD. With these extremely dangerous weapons, potential adversaries of the US and its European allies intend to level the conventional potential advantage of the aforementioned actors. Thus, they intensify research and development of WMD and ballistic missiles (Marszałek & Żabicki, 2007, p. 68).

The main research question is reflected by the following question: Should a contemporary missile defense system (and also the Integrated Air and Missile Defense System) be considered as an indispensable military deterrence tool for the state and Alliance, and why?

Due to the complexity of such a question, it ought to be divided into three supplementary research questions:

1. How has the US missile defense system evolved over the past years?
2. What is the new NATO approach to the missile defense system?
3. What is military deterrence and what is its relation to the US and Polish missile defense systems and the integrated NATO air and missile defense system?

Employing the results the author's many years of research on the US and NATO missile defense system, and considering results of initial research on the topic of the identified (and aforementioned) main research question, the following hypothesis has been proposed: increasing the effectiveness of the contemporary missile defense system makes it a very important and even an indispensable tool of military deterrence. Thus, the missile defense system (and also the NATO Integrated Air and Missile Defense System) should discourage a potential adversary from ballistic missile attacks on the territory of the US or other North Atlantic member state, including Poland.

The aim of the conducted research was to prove that the missile defense system (or the Integrated Air and Missile Defense System in the case of NATO) is an essential element of the widely understood military deterrence of a single state and the Alliance.

The research methods employed in the research process are founded on the critical analysis of the literature devoted to ballistic missile threats, the missile defense system, and the military deterrence. The most important academic and scientific publications, especially from the US, were carefully examined, including official reports by the US governmental agencies (*Missile Defense Review, 2019;* Karako et al., 2017).

2. **NATO's approach to missile defense**

In order to objectively assess and analyze future battle-space, one must assume that the threat of using WMD will not vanish. NATO missile defense will therefore become a crucial element of the defense system of the Alliance (Office of Secretary of Defense, 2019, pp. XVIII). It is not surprising that, recently the missile defense has been treated as a priority mission of the North Atlantic Alliance, focused on reacting to missile threats, potentially armed with nuclear warheads. It is also worth noting that missile defense is considered as a specifically important component of the NATO Integrated Air and Missile Defense System (NATINAMDS), which itself is a key element of the collective defense. What is more, among Western experts, both theoreticians and practitioners of the North Atlantic Alliance, the missile defense system is considered as an important element (means) of countering the proliferation of the WMD.

Despite some doubts raised by the Alliance's opponents, there is no doubt that the NATO missile defense system is of a solely defensive character. It should be considered as a long-term defense investment and not as an incidental commitment. In June 2016, the Alliance declared achieving certain (initial) operational capacity of the missile defense system. In its present form, the system has significantly greater capacity in defending NATO member states' populations, territories and armed forces against possible missile threats in southern Europe.

It is worth noting that the operational capacity of this system is shaped by the member states at the implementation, and not declarative, level. On the basis of their willingness and commitment in building and sharing national resources (of detection, command, control, and strike), member states contribute to the emergence of the overall NATO missile defense system. Some of them are already constructing their national systems, while others are still acquiring the components. Poland and Romania belong to the latter – they have just bought the US Patriot missile defense systems that counter conventional means of air attack and intercept ballistic missiles on the last stage of the trajectory.

for many years, the missile defense system was considered a key issue among NATO military experts and political decision-makers. However, at the beginning of the 21st century, one could have had the impression that the issue was treated more theoretically than as an area of NATO's practical involvement and implementation. The lack of political will, and in fact – the reluctance to spend enormous funds to develop the missile defense system virtually from scratch was clearly visible. Finally, the ever-present threat of a ballistic missile attack motivated NATO's decision-makers to agree on creating NATINAMDS, which took place at the Lisbon Summit in 2010. It seems that member states agreed on a justified concept of building the new system upon already existing Integrated Air Defense System. Poland was among the supporters of the project of extending the defense system. The US European Phased Adaptive Approach (EPAA) anti-missile defense system became an important part of the NATO system with intercepting missile launchers to be based on the territory of Poland.

NATO's Strategic Concept from Lisbon 2010 is considered the Alliance's key political document founding basis for creation of NATO's missile defense system (Zarychta, 2013, p. 78). The document states the following: "The proliferation of nuclear weapons and other weapons of mass destruction, and their means of delivery, threatens incalculable consequences for global stability and prosperity. During the next decade, proliferation will be most acute in some of the world's most volatile regions" (NATO, 2010, p. 10), and vows to "develop the capability to defend our populations and territories against ballistic missile attack as a core element of our collective defense, which contributes to the indivisible security of the Alliance We will actively seek cooperation on missile defense with Russia and other Euro-Atlantic partners" (NATO, 2010, p. 16).

The aforementioned paragraphs clearly point out that the anti-missile defense was created intensively in that period. What is more, it was a time when attempts were made at normalizing relations with Russia, and that is why cooperation with Moscow in the anti-missile defense domain was taken into consideration. The creation of the Theater Missile Defense (TMD) was considered to be such a common endeavor. After the Russian-Georgian war ended, it was intended to further pursue this project, perhaps even to the point of enlarging it to the area of the national defense systems (Kupiecki, 2013 p. 31). It seemed that the much needed constructive cooperation with Russia was at NATO's reach. This optimist approach was, however, ill-founded. From today's perspective, we can be glad that some solutions were not implemented as presently they may be counterproductive and even dangerous to the security of the member states. They were mainly related to the location of the radar system on the territory of the Russian Federation.

3. The essence of the missile defense system

The US has the greatest experience in building missile defense systems. The fundamentals of ballistic missile defense have changed little over 70 years (Karako et al. 2017, pp.14). The beginning of the US national missile defense system dates back to the 1950s. The threat of the Soviet ballistic missiles was intended to be countered with "Nike-Zeus" guided missiles with nuclear warheads. The warheads were meant to be detonated at a very high altitude of even 100 km in the Arctic region. Possibly, it was meant to avoid collateral damage resulting from the use of nuclear warheads. Another program that was conducted by the US was the "Nike-X" project, which was later replaced with the "Sentinel" program. After president Nixon took power, the missile defense program was replaced again. The whole idea behind the program functionality was changed, and the program was renamed "Safeguard". It was intended to defend locations of the American offensive ballistic missile storage. This way, the caches were intended to survive the first Soviet rocket strike and be used in a retaliatory strike.

When characterizing the evolution of the US missile defense system, the ABM Treaty cannot be overlooked. This treaty, that significantly contributed to the evolution of the system, was signed by the US and the Soviet Union on May 26th 1972. This treaty prohibited the parties to deploy missile defense systems on the entire territory of their countries. Each parties was supposed to name only two locations that were supposed to be defended with 100 single-warhead intercepting missiles (Kaczmarski, 2004, p. 17). One such missile defense system could protect the capital, while the other missile launcher of intercontinental ballistic missiles in other locations. Protocol from 1974 reduced the number of systems to one. Therefore, each party had therefore to make a choice (Hildreth, 2007, p. CRS-2). The US decision-makers decided that the system should defend the offensive component of the system in Grand Forks. The Soviet counterparts, on the other hand, decided to defend their capital, Moscow.

Another significant date for the development of the US missile defense program is March 23rd, 1983. On this day, President Ronald Reagan vowed to create a defense shield that would significantly reduce the striking capacity of the ballistic missiles (Kaczmarski, 2004, p. 19). According to some experts, it could have replaced deterrence with real defense. It is hard to argue with this assumption, as we have already assumed at the beginning of this article that the missile defense realizes mainly its deterrent function. The Strategic Defense Initiative (SDI), thanks to the Massachusetts senator, Edward Kennedy, became known as "Star Wars" (Blumberg, 1989, pp. 75-85). The project was introduced by President Reagan on January 6th, 1984. It was assumed that it would be realized within 5 years. However, taking into account the ABM treaty, the SDI program could have been only a research project. Only in 1987 was it implemented. A new multilayered system was intended to be capable of defending around 3500 objects (Kaczmarski, 2004, p. 18). The system was based on the activities of small satellites that, in the first phase, were to detect adversaries starting ballistic missiles. In the second phase, sensors tracking trajectory of the missiles were employed. In the third and final phase, the actions of the SDI envisaged the destruction of enemy ballistic missiles with intercepting missiles fired from the outer space-based launchers.

It is worth mentioning that the evaluation of the SDI program are not unanimous. Some military experts underline its greater input in quicker fall of the Soviet Union than its real operational capacities (Cutter, 2009, p. 241). The introduction of outer space rivalry between Washington and Moscow upset the Soviet economy. According to the experts on missile defense, President Reagan firmly contributed to planting this expensive and not necessarily efficient idea of missile defense in American society. It may be considered an important success that allowed for pursuing further work on the missile defense and setting up bases for the creation of the new National Missile Defense (NMD) system (Jankowski, 2011, p. 28).

An important impulse to develop the contemporary missile defense system of the US was the Rumsfeld Committee Report from 1998 (Rumsfeld, 1998). Potential threats from North Korea and Iran were underlined in the report. At that time, both of these states intensively pursued their ballistic missiles programs that were intended to threaten US territory at the beginning of the 21st century. The report content contributed to the US withdrawal from the ABM treaty. This step was deemed necessary to eliminate the Cold War-era restrictions, and thus facilitate works on the intercontinental ballistic missile defense system.

The concept of missile defense was presented to the European allies for the first time at the conference in Munich devoted to the security policy. In his speech, Donald Rumsfeld explained how the US perceives its missile defense. He connected the collective strengthening of the US security with that of other democratic states, referring specifically to the European allies.

After the 9/11 attacks, the US activities in the domain of missile defense accelerated. This defense was intended to be one of the most decisive responses to the emerging threats from so called the "rogue states". Thus, the creation of a missile defense system of a new quality was deemed necessary to ensure national and international security at the proper level. From our perspective, it can be said that the creation of the “system of the systems”, as it has often been referred to, proved to be a huge challenge for the Bush administration (Kozi ej, 2008, p. 24). In the meantime, the US also re-arranged the administrative structure of the system, creating the Missile Defense Agency (MDA) from the BMDO. According to experts, the creation of this agency significantly accelerated the work on the missile defense.

In those days, some well-founded doubts as to whether the traditional concept of deterrence as a sufficient basis for defending NATO members is valid were raised. Some of the politicians representing member states of the organization claimed that the deterrence strategy, while being ineffective towards terrorists, still was efficient in terms of state-to-state deterrence (Rabee, 2008, p. 13).

As it has been already mentioned, the missile defense project, in its current version of the beginning of 21st century, brought a new quality in the domain of missile defense due to its complexity. Components of the system were supposed to be placed on land, sea, in the air and outer space. The concept behind the system relied on the ability to intercept and destroy hostile missiles at every stage of their flight. The aim of the system was to be effective no matter the location from which the rocket would be launched and regardless of its trajectory.

Therefore, it is worth mentioning that there are three phases of the ballistic missile flight. The first phase - the boost phase - is the initial or starting one and lasts only 3 to 5 minutes. The second one, the mid-course phase, lasts the longest, up to 20 minutes. In this phase the missile travels outside the atmosphere (its flight becomes exo-atmospheric). Finally, the last phase is called terminal and lasts around1 minute (Jankowski, 2011, p. 44).

Combat components of the missile defense system were supposed to intercept and destroy ballistic missiles at every stage of their flights. Due to obvious reasons, the optimal and safest solution was to intercept them in the first phase, over the enemy’s territory. Thanks to that, there was a possibility of limiting negative consequences of destroying a rocket with a WMD warhead. To serve this purpose, a laser weapon (Kinetic Energy Interceptor, KEI) based in outer space or on land and naval platforms was supposed to be used. In the first decade of the 21st century, the ABL concept – a Boeing 747 with a laser launcher – was strongly lobbied. This system had been developed since November 1996 to February 2012. The project costed around. $5.3 billion. It seems that the main reason behind scrapping the project was insufficient results in terms of the laser effective range. The range was too limited due to susceptibility of Boeing 747 to guided missiles. Increasing the range of the weapon itself, on the other hand, would mean increasing the laser power 20-30 times more than initially planned. Consequently, this would translate into significant technical issues, at the time impossible to overcome.

To destroy ballistic missiles in the second phase, the intercepting missiles were planned to be used. Practically, the responsibility for this task fell on Ground-Based Midcourse Defense (GMD) and the sea based Aegis Missile Defense. These two components were intensively developed in the first two decades of the 21st century for they guaranteed achieving the operational capacity with the highest probability, which indeed happened. Development of such technologies by the US would reduce the cost and burden of missile defense systems in realities of a conflict (Piotrowski, 2019, pp.2).

The ground-based missile defense systems such as THAAD (Sankaran & Fearey, 2017, pp. 2) and the Patriot were responsible for neutralizing the targets in the last phase of their trajectory. These systems are better suited for protecting smaller areas where important military installations and critical infrastructure may be located (Perkovich & Vaddi, 2021, p. 75). It should be underlined that these sets (sub-systems) can operate autonomously, as well as cooperate in combating enemy’s ballistic missiles. Thanks to the US industry involvement, Europeans allies attempted to build an alternative system to the Patriot – the Medium Extended Air Defense System (MEADS).

By analyzing the functionality of various combat components in the terminal stage of ballistic missiles trajectory, we must come to conclusion that the only operational element is the Patriot system. It was employed during the first coalition's intervention in the First Gulf War in 1991 (McDowell, 1993, p. 87), and during the second coalition's intervention in Iraq in 2003. It seems well founded to conclude that the operational capabilities of the Patriot was positively verified in combat conditions, and these are much different that those of the tests. The latter are even often described as "laboratory conditions". The air defense system, the Patriot, will remain the main element of combating short-range ballistic missiles in their final stage of trajectory (Kowalski, 2016, p. 6).

We should positively assess the growing number of states that have acquired or plan to acquire the Patriot system. Afterwards, we can assume that the operational capabilities of the NATO Integrated Air and Missile Defense System to combat conventional and non-conventional means of air attack are consequently being increased. It results from the multi-functionality of the Patriot system as well.

4. **Military deterrence and air defense system**

Military deterrence has existed and has been used in practice for a long time. It does not mean, however, that it has been placed highly in the art of war and the practice of the use of armed forces. It seems that only with the development of the nuclear weapon and its carriers, the theory and strategy of nuclear, and thus military, deterrence were developed. It should be noticed that in that period military deterrence was associated with weapons of mass destruction, and mainly with the nuclear weapon. Presently, the conventional military deterrence is also taken into account.

The ultimate goal of military deterrence is to secure oneself from military aggression by making it unprofitable for the aggressor. Certainly, the development of means of warfare contributed to the increase of efficiency and credibility of military deterrence. The usefulness of the military deterrence to ensure one's security is seen by many states, even those that do not possess nuclear weapons. Some of these countries described military deterrence in their defense strategies as the aim and as one of the basics tasks of the defense system.

The idea of military deterrence seems relatively simple and relies on achieving desirable behavior of the adversary by a credible threat. The threat is based on the promise of using force as the ultimate means allowing the desirable political goals to be achieved. Therefore, the basic issue with military deterrence seems the identification of the means of employing the threat against the potential foe, in order to ensure the desired outcome. The foe's desisting from aggression due to unprofitability of such actions is considered the optimal and thus desired outcome. Causing such an impression can be achieved by implementing a wide array of political, propaganda, psychological and military undertakings.

The essence of military deterrence is to use the threat in order to achieve the desired behavior of the adversary. Such a threat must be based on a credible and factual foundation. In other words, deterrence is about convincing the adversary that his own interests force him to refrain from any hostile behavior (Olszewski, 1998, p. 16).

From the conducted analyzes on various definitions of military deterrence, it unambiguously shows that the most important goal of deterrence is to change the behavior of the adversary, who should refrain from using force. Common elements of existing definitions include:

- military deterrence has to restrain the adversary from using force, armed forces, or attempting a military action;

- deterrence requires persuasive actions on the position and motivation of the adversary through discouragement, dissuasion, restrain, convincing, encouraging;
- a threat is the instrument of deterrence that takes the shape of specific military sanctions: a punishment, reprisal, or a reciprocal attack in case when the adversary undertakes a military action (Olszewski, 1998, p. 16).

In light of our considerations, it seems well-founded to define the aim of military deterrence under various conditions of state (or a group of states, e.g. the Alliance) functioning. During peace-time, the aim of deterrence is to prevent military actions by an adversary (like surprising missile attack on a given target). The achievement of this goal is determined by possessing an adequate and credible combat potential, making an aggression unprofitable. Implementing these general considerations to the national missile defense system, that is simultaneously a part of the allied defense system, we should underline its desired operational readiness not only in times of peace but also under other conditions. The readiness of the system may discourage a state that would like to make threats with a ballistic-missile attack, and deter the state from a real attack.

The awareness of the existence of a missile defense system on its own can be enough to encourage military and political decision makers to assess the costs of the attack. Most probably, the relation of cost and result may prove to be unfavorable not only in military but also political terms. It is the latter dimension that may prove to be decisive in changing of the behavior of the potential adversary, for a missile attack in the time of peace can cause the aggressor to face more costs than benefits.

In the time of crisis, the aim of military deterrence is to restrain its escalation and to prevent the use of military force. In this state, besides increased psychological actions, it is necessary to undertake active demonstrative actions by the deterrence forces in order to convince the adversary about the capacity, determination and credibility of its retaliation.

In times of war, the aim of military deterrence is to restrain the adversary from escalating military actions and stop them (Olszewski, 1998, p. 19). In such circumstances, in which the fate of the nation perhaps even that of humankind (as the nuclear catastrophe cannot be excluded) may be decided, the meaning of the missile defense system of the US and NATO Integrated Air and Missile Defense System is huge. Let us remember that most contemporary armed conflicts and wars have started from decisive air-force and missile attacks.

In this case, an efficiently functioning missile defense system can discourage the adversary from firing other ballistic missiles, having in mind that, with a high level of probability, they may not reach the target. One can consider whether the efficiency of the US and NATO missile defense systems would reach a similar level.

Considering the complexity of the state's military deterrence system (that of an organization, e.g. the NATO), the missile defense system has to be unambiguously recognized as a part of the military deterrence. Such an approach seems entirely valid despite the fact that offensive means (e.g. ballistic missile with nuclear warheads, or combat air-force) are more often considered as such an element. The combat air-force's capacity to conduct efficient retaliatory attacks on the enemy's territory in virtually any conditions and at short notice is underlined as one of the most important of its characteristics.

Summarizing these short considerations on the military deterrence, we must understand and remember that to deter means to influence the opponent's decisions by using a credible threat of the solid defense and decisive retaliation. For there is a connection between deterrence and the decision-making protocol on the highest levels of command of a state or an alliance. The decision on the use of ballistic missiles armed with weapons of mass destruction surely would not be taken on the tactical or operational levels due to its enormous military and political weight.

5. Conclusions

The missile defense system remains an incredibly interesting and always current area of research both among theoreticians and practitioners. Considered in technical, military or political contexts, it has been an important subject of research and international analysis for the past decades (Kupiecki, 2015, p. 9). Its currency stems not only from the threat from weapons of mass destruction and ballistic missiles, but also from the still visible imperfections of the system. For neither political nor military decision-makers of the US and the NATO have not declared full operational readiness of the missile defense system(s).

Conclusions from analyzes of development of the US missile defense system (what applies to the NATO as well) clearly point to the importance of its political dimension. What is more, at some point of the development of the missile defense system, one could have the impression that the aforementioned political dimension is more important than the military one related to detecting and combating hostile ballistic missiles capable of carrying WMD warheads.

We should remember that the missile defense system is rightfully considered as an essential tool to counter the proliferation of WMDs, what is reflected in the NATO strategic concept of 2010. It is the elimination or neutralization of such weapons that the defending party is focused on. The ballistic missile itself, however, hard as a weapon to intercept, is only a carrier of the warhead. Yet due to the immense consequences of the neutralization of a ballistic missile carrying a warhead with WMD over a populated territory, it is crucially important to counter ballistic missiles far away of one's own state frontiers, or of those of the allies.

It seems that possible doubts concerning the relation between the missile defense system with the military deterrence were addressed. Developing and fielding credible and effective defensive capabilities may not only protect our forces during hostilities but also deter an adversary from attempting an air or missile attack (Joint Chiefs of Staff, 2013, p. 3). Taking into account the essence of the military deterrence, we can conclude that the very existence of the missile defense system can impact actions of a potential adversary. Political decision-makers (leaders) of a state that could have hostile intentions towards the US or the NATO (or any other state with the ballistic missile defense capabilities) can refrain from any hostile actions just because their awareness of the functioning of the missile defense system. In such a case, an attack would be inefficient, for the attacking party could lose more than it could gain. This would make the concept of military deterrence real.

It should be mentioned that the missile defense system, yet in the preparatory phase on its way to achieve full operational capability, performs a very important function of political integration of the states involved in its construction. Even making the land available for the US to place its defense system on another state's territory already increases the cooperation between these states. It is worth mentioning here the cooperation between the US, Poland, and Romania or the Czech Republic. Unfortunately, we have to observe as well that even among the Alliance member states opinions regarding the cooperation varied, divided, and thus not always positive. It is hard to believe that initially both the North Atlantic Treaty and the European Union were skeptical towards the American project of missile defense (Adamczyk, 2014, p. 46). Most probably, this stems from the fact that the system components deployed in Europe aim primarily at protecting the US from the intercontinental ballistic missiles fired from the Middle East.

The rocket launcher based in Alaska is of lower efficiency when it comes to counter ballistic missiles fired from the Middle East. According to the experts, it is because of a narrow window of opportunity to intercept a missile flying at a very high speed (up to 5000 m/s in the terminal phase). Thus, the region of Eastern Europe has gained in importance in the context of the US missile defense.

The integrating function of the missile defense system, consolidating the North Atlantic Alliance's member states is also visible in strengthening the collective defense, exemplified by creation of the NATO Integrated Air and Missile Defense System. Therefore, in the case of a missile attack on the US or any other NATO member state, it will be considered an attack on the whole Alliance. In such a case, a potential aggressor has to seriously reconsider whether it is worth to risk a military clash with the world's most powerful organization.

Declaration of interest – The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

References

1 Adamczyk, N. (2014). *Znaczenie amerykańskiej tarczy antyrakietowej dla bezpieczeństwa narodowego Polski,* Czasopismo Krakowskiej Szkoły Wyższej im. Andrzeja Frycza Modrzewskiego 8/2, http://cejsh.icm.edu.pl/cejsh/element/bwmeta1.element.mhp-fb8f2c6d-1c31-4590-b1eb-d1313eb82f9c.

2 Blumberg, A. (1989)., *The strategic defense initiative: An update and critique*, Interdisciplinary Peace Research: formerly Pacifica Review: Peace Security Et Global Change, pp.75-85, http://dx.doi.org/10.1080/14781158908412713.

3 Cutter, A. (2009). *System Obrony Przeciwrakietowej w amerykańskiej koncepcji bezpieczeństwa narodowego*, Prace naukowe Akademii im. Jana Długosza.

4 Hildreth, S. A. (2007). *Ballistic Missile Defense: Historical Overview*, CRS Report for Congress.

5 Joint Chiefs of Staff (2013). *Joint Integrated Air and Missile Defense*: Vision 2020.

6 Jankowski, D. (2011). *Amerykański system obrony przeciwrakietowej,* Wydawnictwo Adam Marszałek.

7 Kaczmarski, M. (2004). *Obrona przeciwrakietowa Stanów Zjednoczonych i jej implikacje międzynarodowe,* Wydawnictwo Adam Marszałek.

8 Katona A. (2015). *NATO Territorial Ballistic Missile Defense and its Implications for Arms Control,* The Nonproliferation Review, pp.253-272, http://dx.doi.org/10.1080/10736700.2015.1117314.

9 Karako T., Williams I., Rumbaugh W. (2017). *Missile Defense 2020. Next Steps for Defending the Homeland,* Center for Strategic & International Studies.

10 Kowalski, M. (2016). *Obrona przeciwrakietowa Stanów Zjednoczonych*, Pułaski Policy Paper.

11 Koziej, St. (2008). *Amerykański system obrony przeciwrakietowej*. Rocznik Strategiczny 2007/2008, https://https://wnpism.uw.edu.pl/wp-content/uploads/ 2020/03/01_2008. pdf

12 Kupiecki, R. (2013), *Międzynarodowe uwarunkowania modernizacji polskiego systemu obrony powietrznej,* [in:] *System obrony powietrznej Polski*, Akademia Obrony Narodowej.

13 Kupiecki R. (2015), *Obrona przeciwrakietowa w polskiej perspektywie,* Polski Instytut Spraw Międzynarodowych.
14 Marszałek, M., Żabicki, K. (2007). *Balistyczne pociski rakietowe teatru działań – wirtualne czy rzeczywiste zagrożenie dla bezpieczeństwa międzynarodowego*, *Zeszyty Naukowe*, no 2(67).
15 McDowell D. (1993). *Theater Missile Defense: A Joint Enterprise,* Joint Force Quarterly.
16 *Missile Defense Review* (2019), Office Of The Secretary Defense.
17 NATO (2010) *Active Engagement, Modern Defence. Strategic Concept for the Defence and Security of the Members of the North Atlantic Treaty Organization Adopted by Heads of State and Government at the NATO Summit in Lisbon 19-20 November 2010,* Brussels: NATO Public Diplomacy Division.
18 Olszewski, R. (1998). *Lotnictwo w odstraszaniu militarnym,* Dom Wydawniczy Bellona.
19 Petrovich, G., Vaddi P. (2021). *Proportionate Deterrence: A Model Nuclear Review*, Carnegie Endowment For International Peace.
20 Piotrowski, M.A (2019). *Założenia nowego Przeglądu obrony przeciwrakietowej USA,* Warszawa, Polski Instytut Spraw Międzynarodowych no 15 (1763).
21 Rabee, S. (2007). *Amerykańska tarcza antyrakietowa w Europie. Konieczność, warunki, adaptacja,* Konrad Adenauer Stiftung.
22 Rumsfeld D. (1998) *Executive Summary of the Report of the Commission to Asses The Ballistic Missile Threat to United States*, http://fas.org/irep/threat/bm-threat.htm.
23 Sankaran J., Feary B.BL. (2017). *Missile defense and Strategic Stability: Terminal High Altitude Area Defense (THAAD) in South Korea*, Contemporary Security Policy, pp. 1-24, http://dx.doi.org/10.1080/13523260.2017.12680744.

Safety & Defense
ISSN 2450-551X

Air Defense of the Baltic States: Looking toward the Future

Eugeniusz CIEŚLAK

University of Natural Sciences and Humanities, Faculty of Social Sciences, Siedlce, Poland; eugeniusz.cieslak@uph.edu.pl, ORCID: https://orcid.org/0000-0002-6476-3643

DOI: ttps://doi.org/110.37105/sd.158

Abstract

The article offers a discussion of the origins, current state, and the future of air defence for the Baltic states. It relates developments in the field of air defense to changes in the security environment and the defence policies of the Baltic states. The article starts with a retrospective on the origins and development of air defence in the Baltic states before they joined NATO. Then, it focuses on the early years of integration with NATO Integrated Air Defense System and implications for air defence related to changes in the security of the Euro-Atlantic region stemming from aggressive Russian actions. An assessment of the current posture of air defence in the Baltic states serves as a starting point for a discussion on requirements for future developments and predicting possible outcomes. The research uses unclassified, publicly available documents and analytical reports to provide background information for a discussion on the future of air defense for the Baltic states. The Baltic states are aware of the limitations of their air defense and try to develop this capability within available resources. Changes to security environment after 2014 gave a new impetus to develop the air defense of the Baltic states, both through efforts undertaken by NATO and for national capability development.

Keywords

air defense, air defense system, Baltic states, NATO

Submitted: 19.08.2021 Accepted: 05.09.2021 Published: 20.10.2021

1. Introduction

Air defense is a crucial capability for guarding the sovereignty over national airspace and preventing aggressive actions by hostile air and missile threats. It is continuously needed during peacetime, crisis, and conflict. Air defense contributes to national defense and deterrence, and during conflict, it becomes a part of the joint force efforts to create favorable conditions for friendly military operations. The case of the Baltic states is a telling example of the criticality of air defense for national security. It shows also the challenges that small nations face in developing credible capability to defend against air and missile threats. The Baltic states' efforts in the field of air defense date back to the first days of their independence after the collapse of the Soviet Union. With limited resources available, the Baltic states were initially able to provide only for air surveillance of their national airspaces and did not develop capabilities to engage air threats. Membership in NATO brought allied support to the Baltic states in the form of air policing. The early days in NATO contributed to the increased interoperability of the Baltic states' air defense systems, but the development of air defense capabilities was rather slow. A turning point in the development of air defense of the Baltic states was Russian aggression against Ukraine and the occupation of Crimea. These aggressive actions added a sense of urgency for both NATO and the Baltic states' actions. Allied reassurance measures reinforced the air defense posture in the Baltic states, and increased funding supported the development of air defense capabilities by the Baltic states. While the development of air defense capabilities by the Baltic states competes for resources with other defense capabilities, it clearly remain one of the top priorities in defense spending. With allied support and long-term national modernization plans, the air defense of the Baltic states is destined to develop and be better prepared to face air threats in the future.

This research aims to discuss the origins, current state and the future of air defense in the Baltic states. It looks at external and internal factors that have influenced development of air defense capability by the Baltic states. The research explores the synergy of NATO, bilateral defense cooperation, and national efforts in the field of air defense. It uses unclassified, publicly available documents and analytical reports as a source of information for the discussion on the origins, current state, and future of air defense of the Baltic states. The research focuses on several distinctive periods in the development of air defense for the Baltic states.

The article starts with a retrospective on the origins and developments of air defence of the Baltic states before their membership to NATO. Then it focuses on integration of air defense of the Baltic states within the NATO Integrated Air Defense System prior to 2014. The next part of the article examines the implications for the air defence of the Baltic states related to changes in the security of the Euro-Atlantic region stemming from Russian aggression against Ukraine and the occupation of Crimea. The final part of the article discusses the future of the air defense of the Baltic states while trying to reconcile requirements for future developments and possible outcomes.

2. Doctrinal framework for studying air defense

Air defense is crucial for state sovereignty as it assures the integrity of national airspace and prevents aggressive actions against the state by hostile air and missile threats. Air defense is an essential, continuous mission in peacetime, crisis, and conflict. It aims at safeguarding and protecting state territory, populations, and forces against air and missile threat and attack. Air defense contributes to national defense and deterrence against both state and non-state actors. Should the deterrence fail, air defense as a part of joint counter air operations aims at assuring the required level of control over the airspace to create favorable conditions for friendly military operations. While studying the air defense of a particular state or a group of states, a valid question to pose is to what extend their air defense is capable of providing protection during peacetime, crisis, and war. It depends on the nature and magnitude of air and missile threats and the costs of development and maintenance for these air defense capabilities.

Another important point for studying air defence is the organization and conduct of air defense operations. Such operations are implemented through the integrated air defense systems, comprising of elements allowing for the effective execution of air defense functions. That is especially relevant to those functions that enable active air defense. Air defense system should allow for integrated detection, identification, assessment, interception and engagement of air and missile threats to facilitate active air defense operations and support passive air defense. The implementation of those functions requires an air defense system to have specialized components such as airborne and surface based combat assets, surveillance assets, and command and control elements (NATO Standardization Agency, 2010). The issue of integration is an important point for studying air defense. The integration of air defense system elements allow for simultaneous coordinated engagement of air and missile threats, mutual support and increased survivability. It is crucial to understand what air defense functions can be performed by such an air defense system and to what extent. Air defense related capabilities need to be studied along with respective capacities.

Air defense, which aims at the protection of friendly forces from enemy air and missile attacks, is seen in military doctrine through the prism of active and passive defense. Active air defense activities include the use of airborne and surface based air defense assets to destroy missile and air threats or reduce the effectiveness of their employment. While many researchers focus on active defense, it is worth noting the value of passive defense as well. A good point for studying air defense is a comparison of the case studied to a model set up. A desired model for air defense calls for a layered defense-in-depth that allows for multiple engagement opportunities and integrated employment of airborne air defense assets along with surface based air and missile defense assets. It aims at combining active air defense operations with passive air defense and to increase the survivability of defended assets (NATO Standardization Office, 2016). As it is difficult to find an ideal air defense in the real world, how case studies differs from the doctrinal model and what are the consequences of these differences must be analyzed. For any assessment of air defense, it is important to understand the synergic capabilities of different types of assets and operations. In addition, it is important to realize implications of not having a specific capability or assets, for example for effectiveness of engagement against air and missile threats or for the survivability of an air defense system.

While studying air defense of the Baltic states, one need to address most of those important problems. Starting with understanding the nature and magnitude of missile and air threats that this air defense has faced, one needs to explore the divide between the capabilities required for effective air defence compared to those that can be afforded in more detail.

Then, it is possible to discuss the choices that have been made, their implications for air defense operations, and the organization of air defense system.

3. Development of air defense of the Baltic states prior to NATO membership

After collapse of the Soviet Union, the Baltic states had to develop their armed forces nearly from almost nothing. They did not inherit advanced post-Soviet combat weapon systems nor trained personnel. With struggling economies, the militaries of Estonia, Latvia, and Lithuania were doomed to remain small, low-tech, land-centric and light for a long time. Air forces of the Baltic states tasked with air defense missions lacked virtually all components of an integrated air defence system. A priority for the development of air defence back in the nineties was the integration of national air surveillance assets into a joint air surveillance system of Estonia, Latvia and Lithuania. The decisions to establish an integrated air surveillance system for the Baltic states were made in 1994 and 1995. The project gained external support as a year later the United States decided to extend its Regional Airspace Initiative to the Baltic states. Thus, the Baltic states took the path of introducing Western standards similar to Poland and other Central European states seeking membership to NATO (Cieślak, 2019).

The value of BALTNET to the development of air defense for the Baltic states stemmed from the fact that it facilitated introduction of Western and NATO standards and fostered interoperability. The Baltic states cooperated closely with NATO's Committee for European Airspace Co-ordination and the NATO Air Defense Committee in air surveillance and air defense matters. The international support to the BALTNET project involved training, provision of equipment, and expertise. Extensive US, Norwegian, and Danish support to the project must be noted. Supporting countries have also assisted in the development of the concept of operations and standard operating procedures for the BALTNET system. BALTNET proved to be a successful cooperation project for the Baltic states themselves. They were able to work together in planning the placement of radar sensors in the three states, avoid unnecessary multiple radar coverage, and ensure economical use of resources (Harper, Lawrence, & Sakkov, 2018).

Modernization efforts related to air defense prior to membership in NATO focused on air surveillance and control elements of the national air defense systems. Lithuania and Latvia bought a limited number of man-portable air defense systems, which could be used for the land forces' organic air defense missions. Only Lithuania possessed two jet trainers L39 which offered limited capability to react to air threats in peace time. Bearing that in mind, one could argue that prior to 2004, the Baltic militaries were able to perform only a part of air defense functions. They could detect, track, and identify aerial objects but lacked the capability to engage them. The air defense of the Baltic states lacked fighter force and credible surface based air defenses. National air surveillance assets integrated within BALTNET offered basic radar coverage of the Baltic states' airspace and provided a backbone for limited command and control capability to active air defense operations.

4. Integration with the NATINADS and developments before 2014

Integration of the air defense assets within the NATO Integrated Air and Missile Defense System started before the Baltic states formally joint the Alliance in 2004. BALTNET was integrated into the allied air surveillance and command and control structures, and its role expanded to include not only air surveillance but also air traffic control and tactical management of air policing operations. Efforts undertaken by the Baltic states within BALTNET project paid dividends, as they enabled the NATO Baltic Air Policing mission to start on the first day of their membership to the North Atlantic alliance. Air policing has constituted the principal Allied air presence in the Baltic states since March 2004. It was agreed as a peacetime mission to ensure the integrity of airspace of all member states of the Alliance. The main aim of the mission was to offer assistance to the Baltic states, as they did not possess air defense fighters. This mission was initially planned for a limited period of time, but it was changed in 2012 to a standing one. Until 2014, the Baltic Air Policing mission was considered primarily as a means for demonstrating allied cohesion, shared responsibility, and solidarity (NATO, 2021). To put this mission into a broader context, one need to reflect on the nature of air threats at that time. Relations between NATO and Russia were quite stable and cooperative, and the focus of air defense operations in peacetime was preventing terrorist use of civilian airplanes (a stark reminder of the 9/11 attacks). Because of these considerations, the Baltic Air Policing mission was limited in scale. It used one air base in Siauliai, Lithuania as a home for usually four air defense fighters deployed by Allied nations on three and then four months rotations. While some politicians and even researchers did not consider the NATO Baltic Air Policing to be an air defense mission, in fact it has been such, although restricted by division of national/allied decision-making authorities and responsibilities. In peacetime, the decisions to intercept aircraft violating national airspace of any of the Baltic states is made by the NATINAMDS command and control agencies. However, when use of deadly force against such aircraft is considered, the decision-making authority rests with the nation in which airspace this engagement occurs. With a fighter force belonging to an allied nation, the decision-making process would involve not only one or more of the Baltic states, but also a nation that deployed its fighters to the mission. Despite the aforementioned limitations, there is no doubt that the air defense of the Baltic states benefited from the Baltic Air Policing mission. The message that the airspace of the Baltic states started being protected by NATO has been understood by all stakeholders (Adamowski & Banks, 2019). The success of this mission depended heavily on the host nation support provided by Lithuania, which put substantial efforts in upgrading Siauliai Air Base and assuring combat support and combat service support functions to deployed aviation detachments. Air policing served also as a catalyst for development of the Baltic states air defense' intelligence, surveillance and reconnaissance and command and control capabilities. It provided numerous training opportunities for the air defense personnel of the Baltic states and prioritized modernization efforts.

A retrospective on the first decade of the Baltic states' membership to NATO brings two points to discussion on air defense. One of the factors that influenced air defense of the Baltic states before 2014 was the focus of NATO operations and burden sharing debate. Allied commitment to out of area operations in stabilizing the security environment overshadowed the issue of article five operations. As an armed aggression against NATO states deemed unlikely, there was no appetite among the member states to develop capabilities for high intensity conflict operations. Limited air defense capabilities centered on airborne assets were considered sufficient in peace time, and legacy surface based air defenses remained in service, but were not considered a critical capability. The Baltic states were expected to contribute to NATO and coalition expeditionary operations and rely on allied support for air defense. Such thinking was in line with the smart defense initiative that called for role specialization and avoiding overlaps in capabilities and defense spending. A decision on making the Baltic Air Policing mission a continuous presence agreed by the North Atlantic Council in February 2012 serves as a good example of the smart defense concept. The Baltic Air Policing paved the way for other missions that assisted member state without sufficient air defense assets in assuring integrity of their airspace. Missions in the Balkans, Benelux, and Iceland, along with enhanced air policing, are telling examples of NATO commitment to collective defense and solidarity for all its member states. In 2012, the NATO Secretary General observed that “collaboration in air policing also exemplifies the kind of cooperation among Allies that will become increasingly important in the future, as we reconcile our security requirements with budgetary realities”. Ten years later, it still holds true.

Another factor, which limited allied support to development of air defense of the Baltic states, was the interpretation of the founding act of 1997 between NATO and Russia. During early years of the Baltic Air Policing, some of member states opted for a very limited, temporary air policing so as to not to provoke negative reactions of Russia and to stick literally to promises of not deploying major forces to the new member state territories (Lorenz, 2012). The discussion on burden sharing inside NATO raised the need for the Baltic states to contribute to NATO expeditionary capabilities to compensate for support to their air defense. The opponents of the Baltic Air Policing claimed that the threat in the region was marginal, and the Baltic states did not do enough for their own security to warrant additional allied support. For the supporters of the Baltic Air Policing mission, it was evident that it was crucial for the credibility of NATO collective defense. Russian aggression against Georgia in 2008 and the military exercises *Zapad* and *Ladoga* in 2009, during which simulated attacks against the Baltic states were rehearsed, raised allied support to the Baltic Air Policing mission. The pledge of the Baltic states to increase the support to the mission was also helped in the continuation of the Baltic Air Policing. One must however note that increased support to NATO missions also meant limiting budgets for national air defense capabilities of the Baltic states prior to 2014.

5. Air defense of the Baltic states after 2014

Russian aggression against Ukraine and the occupation of Crimea since 2014 has served as a turning point in thinking about the defense of the Baltic states. This translated into actions taken both by NATO and the Baltic states themselves. For NATO, collective defense returned as the number one priority and a unifying principle for actions taken by its member states. Immediate reinforcement of the NATO Eastern Flank under the framework of reassurance measures translated into enhanced Forward Presence, and for the air defense of the Baltic states, it meant the enhanced Baltic Air Policing. Enhanced air policing became a means for demonstrating the collective resolve of Allies and the defensive nature of NATO. It has served as a military tool for deterring Russia from aggression or the threat of aggression against NATO Allies. An inherent feature of enhanced air policing is its flexibility and scalability that allows for tailored response to changes in the security situation. Enhanced air policing offers also capability to send a strong, unambiguous message to all of the stakeholders. In practice, member states make additional air defense assets available to NATO to reinforce the Baltic Air Policing capabilities and, augmenting national air policing capabilities in other regions (NATO, 2021).

The post-2014 period has seen an increase in the number and scope of NATO military exercises directly related to air defense of the Baltic states. Rammstein Alloy exercise focuses on air defense missions in the Baltic region and is conducted on regular basis bringing allied fighters and AWACS aircraft to the Baltic states airspace and air bases. It is worth noting that Sweden and Finland air defense forces participate in the exercise. NATO regularly conducts exercises that involve deployments allied surface based air defense assets in the Baltic states. Tobruq Legacy exercises involve air defense assets from Lithuania since 2015, and this series of exercises is conducted more and more frequently on the territory of the Baltic states. It is also the case for bilateral exercises between the Baltic states and the US military. In 2017, the first deployment of long-range Patriot systems to Lithuania took place, and a year later, such systems made it to Estonia. Although Patriot systems deployments to the Baltic states were initially considered rather symbolic, it is fair to say that this paved the way to more regular deployments in the future. Limited deployment of surface based air assets to exercises in the Baltic states so far is critically assessed by a number of experts (O'Hanlon, Skaluba, 2019). Some of them argue that as long as the number of surface based air defense assets deployed to the Baltic states do not change the balance of power in a meaningful manner, it has no credible deterrent effect (Ploom, Śliwa, & Veebel, 2020)

The Baltic states provide substantial support to NATO enhanced Forward Presence and air policing. In June 2016, the Baltic states signed a new agreement with NATO on airspace management arrangements in support of NATO's Air Policing mission and other air activities in the Baltic Sea region. The agreement facilitates an increase in the number of air training opportunities in the Baltic region by improving civil-military coordination and ensuring the safe and efficient use of airspace. The costs of host nation support provided by the Baltic states to allied air defense fighters detachments deployed to the Baltic Air Policing mission are also notable. The US security assistance to the Baltic states through the newly created Baltic Security Initiative may alleviate this situation to some extent.

Recent years have seen substantial development of air defense capabilities of the Baltic states. Russian aggression against Ukraine triggered a rise in defense budgets and military modernization programs in all three Baltic states. Looking at projects directly linked to air defense, it is worth noticing developments related to the air surveillance and command and control elements of evolving BALTNET and decisions on procurement of surface based air defense assets by the Baltic states. The Baltic states are successfully developing the air surveillance and C2 network for air defense, based on experience gained with BALTNET project (NATO, 2019). Starting from 2020, the BALTNET Future Configuration is operational. The Baltic states agreed in 2019 to establish three separate national Control and Reporting Centers that will conduct air surveillance respectively in their territories, and allow for enhanced command and control of active air defense operations (Riigiteataja.ee, 2019).

Procurement of additional RBS 70 and Stingers by Latvia and Mistral air defense systems by Estonia were the immediate reaction of the Baltic states to increased military threat from Russia after 2014 (Dura, 2015). While this improved air defense against low flying air threats, the problem of medium range air defenses has not been fully solved yet. Lithuania became the only Baltic state that introduced a short range Norwegian Advanced Surface to Air Missile System (NASAMS) that provide limited capability of area air defense. The remaining two states are capable of providing only a very limited air defense capability to protect their ground troops (Ministry of National Defense, Republic of Lithuania, 2020).

6. Future of air defense of the Baltic states

Discussion on the future of air defense of the Baltic states needs to address any changes to security environment and evolving air and missile threat first. Russian aggressive and opportunistic activities will remain most likely the major source of instability in the Euro Atlantic region. Those activities will demand continuation of NATO adaptation and reassurance measures and will remain a key driver for the national defense efforts of the Baltic states. This will translate into continuation of Allied support to air defense of the Baltic states. The Baltic Air Policing mission will most likely remain authorized as enhanced air policing, which allows for a greater flexibility and responsiveness to any deteriorations in security environment. At some point in the future, the proposal of changing air policing to air defense mission may also be revisited (Reuters Staff, 2016). Rotational deployments of allied fighter force will raise the interoperability capabilities of the national air defense forces of the Baltic states. Increased costs of host nation support in the Baltic Air Policing mission will have an impact on the availability of resources to develop national air defense capabilities of the Baltic states. With the continuous nature of the mission, contributions of the Baltic states need to be considered as long-term ones.

The regular deployments of allied surface-based air defense assets to the Baltic states will continue as a part of exercises and bilateral defense cooperation. One of the proposals for that is to integrate air defense capability into the NATO battalion battle groups that rotate in the Baltic states (Harper, Lawrence, & Sakkov, 2018). This type of activities may increase in the future if Latvia and Estonia acquire short range air defense system. Although the permanent deployment of ground based air defenses to the Baltic states has not been publicly discussed yet, it may be the case in the future. A number of deployments of Patriot missile systems to Turkey throughout the recent decade suggests that a serious deterioration of security in the Baltic region may be a trigger for deployment of allied surface based air defense assets on the territory of the Baltic states. Such a move may aim at the prevention of the escalation of a crisis and provide NATO a greater freedom of action and security in the region. As the allied decision-making process is lengthy and complex, such crisis deployments are likely to be a part of bilateral defense cooperation between the Baltic states and sending nations rather than a NATO-integrated mission.

Development of air defense capabilities by the Baltic states will continue. The evolving nature of air threat will need improvements in the air surveillance capabilities (Kulik, 2020). Threat of unmanned aircraft systems and hybrid threats employing civilian planes demand better radar coverage at low altitudes (Cieślak, 2021). At some point, dedicated anti-drone systems may become a priority for national air defense efforts by the Baltic states. Fielding short range air defense systems by Latvia and Estonia at some time in the future is very likely (Metha, 2018). While immediate modernization efforts by those Baltic nations favor ground forces and capabilities required for high intensity conflict (such as long range artillery), such assets will need cover from air threats. Therefore, one may expect further procurements of very short air defense systems, but also some attempts to field more costly short range surface to air missile systems. The US assistance program to the security of the Baltic states envisages air defense as one of the priorities, so it is likely that this may translate into acquisition of the US surface based air defense weapon systems (Harper, Lawrence, & Sakkov, 2018). With limited defense budgets, the Baltic states will most likely not attempt to field long range surface to air missile systems. The costs are clearly prohibitive, and limited capacities would undermine the value of developing such capability by the Baltic states.

Conclusions

Air defense remains crucial capability for the Baltic states' security and defence. The case of the Baltic states is a telling example of the criticality of air defense for national security. It also shows the challenges that small nations face in developing credible capability to defend against air and missile threats. The lessons learned by the Baltic states suggest that for states with small defence budgets, even long-term efforts result in a limited air defense capability. The period before the Baltic states joined NATO saw some developments only to air surveillance capability, while the functions of air defense related to engagement of air threats could not be performed. Allied support to air defense of the Baltic states has significantly improved the situation. Since 2004, NATO provided the Baltic states with the capability to react to intrusions into their national airspaces and offered credibility of protection against air and missile threats. Russian aggression against Ukraine and the occupation of Crimea in 2014 triggered reinforcement of air defense of the Baltic states. Implementation of reassurance measures by NATO reinforced air defense posture in the Baltic states by enhanced air policing and intensified trainings of surface based air defense troops. Development of air defense was given priority in the Baltic states, and some improvements to surface based air defense capabilities have been achieved. Looking into the future, one can expect that the air defense of the Baltic states is destined to develop in coming years. While it may not be able to deal with all of future air and missile threats, it will be better prepared to inflict attrition to a possible aggressor and to contribute to overall military deterrence of the NATO's Eastern Flank.

Declaration of interest - The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

References

1. Adamowski J., Banks M. (2019, June 16) Without a NATO-wide effort, the skies along the northeastern flank could be in peril. https://www.defensenews.com/global/europe/2019/06/16/without-a-nato-wide-effort-the-skies-along-the-northeastern-flank-could-be-in-peril/
2. Baltic News Network. (2018, March 9). Baltics want faster US decisions on the region's air defence. https://bnn-news.com/baltics-want-faster-us-decisions-on-the-region-s-air-defence-181421
3. BNS. (2015, July 23). Baltic states must develop joint air defence system, Lithuanian defence minister says. https://lithuaniatribune.com/baltic-states-must-develop-joint-air-defence-system-lithuanian-defence-minister-says/
4. Cieślak E. (2019). Poland's armed forces in NATO. Two decades of transformation. Polské ozbrojené síly v NATO. Dvě desetiletí transformace. Defence and Strategy, Volume 1/2019,23-38.
5. Cieślak, E. (2021). Unnamed Aircraft Systems: Challenges to Air Defense. *Safety & Defense, 7(1), 72-83*. https://doi.org/10.37105/sd.110

6. Dura M. (2015, October 23). Latvia Upgrades Its Air Defence Capabilities. https://www.defence24.com/latvia-upgrades-its-air-defence-capabilities
7. Harper Ch., Lawrence T., Sakkov S. (2018, May). Air Defence of the Baltic states. ICDS Tallinn. https://uploads.icds.ee/ICDS_Report_Air_Defence_Christopher_Harper_Tony_Lawrence_Sven_Sakkov_May_2018.pdf
8. Klein R. M., Lundqvist S., Sumangil E., Pettersson U. (2019, November). Baltics Left of Bang: The Role of NATO with Partners in Denial-Based Deterrence. Strategic Forum. National Defence University. https://inss.ndu.edu/Portals/68/Documents/stratforum/SF-301.pdf?ver=2019-07-23-142433-990
9. Kulik, T. (2020). Selected Aspects of Contemporary Air Threats. *Safety & Defense, 6(1), 11-21*. https://doi.org/10.37105/sd.47
10. Lorenz W. (2012, September 21). Baltic Air Policing – misja w interesie NATO. Biuletyn Nr 82(947). Polish Institute of International Affairs. https://pism.pl/upload/images/artykuly/legacy/files/11518.pdf
11. Metha, A. (2018, September 12). Estonia eyes mid-range air defense systems to rectify NATO 'oversight'. https://www.defensenews.com/global/europe/2018/09/12/estonia-eyes-mid-range-air-defense-systems-to-rectify-nato-oversight/
12. Ministry of National Defence. Republic of Lithuania (2020, October 30). NASAMS medium-range air defence system officially handed over to the Lithuanian Armed Forces. https://kam.lt/en/news_1098/current_issues/nasams_medium-range_air_defence_system_officially_handed_over_to_the_lithuanian_armed_forces.html
13. NATO (2021). BALTIC AIR POLICING. https://ac.nato.int/missions/air-policing/baltics
14. NATO Standardization Agency (2010). AJP-3.3.1(B) Allied Joint Doctrine for Counter Air
15. NATO Standardization Office (2016). AJP-3.3 Allied Joint Doctrine for Air and Space Operations Edition B version 1
16. NATO. (2019, December 3). Baltic air surveillance network to enhance NATO air posture. https://ac.nato.int/archive/2019/page87502614
17. O'Hanlon M. E., Skaluba Ch. (2019, June 13). Order from Chaos. A report from NATO's front lines. https://www.brookings.edu/blog/order-from-chaos/2019/06/13/a-report-from-natos-front-lines/
18. Ploom I., Sliwa Z., Veebel V.(2020) The NATO "Defender 2020" exercise in the Baltic states: Will measured escalation lead to credible deterrence or provoke an escalation?, Comparative Strategy, 39:4, 368-384, https://doi.org/10.1080/01495933.2020.1772626
19. Republic of Estonia. Ministry of Defence. (2021, May 24). The Baltic states are jointly setting new goals for the development of military capabilities. https://kaitseministeerium.ee/en/news/baltic-states-are-jointly-setting-new-goals-development-military-capabilities
20. Reuters Staff. (2016, March 29). NATO needs to beef up defence of Baltic airspace - top commander. https://www.reuters.com/article/nato-security-baltics-idINKCN0WV1NX
21. Riigiteataja.ee (2019). Agreement between the government of the Republic of Estonia, the government of the republic of Latvia and the government of the republic of Lithuania on the configuration of the Baltic air surveillance network and control system. https://www.riigiteataja.ee/aktilisa/2060/5202/0002/137XIV_Ohuseire_ingl_k_L1.pdf

SAFETY & DEFENSE
ISSN 2450-551X

The Political and Military Aspects of Creating Anti-Access/Area-Denial Systems (A2/Ad): The Example of China and Russia

Konrad DOBIJA

War Studies University, Warsaw, Poland;
k.dobija@akademia.mil.pl , ORCID: 0000-0002-6120-3915

DOI: https://doi.org/110.37105/sd.143

Abstract

Over the last two decades, China and Russia have been developing Anti-Access/Area-Denial (A2/AD) systems mainly based on long-range Air Defense, ballistic and cruise missiles, supported by Electronic Warfare and cyber-attack capabilities. Initially, these systems were used for defense purposes, but over time. it was recognized they could be also applied for imposing military situation in the specific regions and create effective response to NATO countries and their concept of conducting military operations. The main aim of the article is to asses and present the impact of Chinese and Russian Anti-Access/Area-Denial (A2/AD) systems on changes in global political relations and balance of military power. In the course of this study, the author used numerous analyzes, synthesis, comparisons and case studies methods mainly concentrated on presently operating A2/AD systems. This article undertakes the analysis of the Chinese bases located in the South China Sea and Djibouti, Russian A2/AD systems within Russia's borders with particular emphasis on Kaliningrad Oblast, and A2/AD systems in Crimea and Syria created as part of Russian military operations. This research allowed us to conclude that some of the A2/AD systems serve to defend borders, while the rest are created to influence the geopolitical and military situation or to gain an advantage in the area of military operations. It can be also evaluate that the use of these systems allow dominate future conflicts because they enable to establish a full control zones which are completely closed for opponents forces operations.

Keywords:

air defense, anti-access/area-denial, defense, safety, military operations

Submitted: 14.07.2021 Accepted: 16.08.2021 Published: 20.10.2021

1. Introduction

The methods of ensuring world security and the methods of creating military systems directly related to them are the result of threat changes and evolve in each decade. Therefore, we can assume that every new military system is different from the previous one. On the other hand, this is only an assumption, because if we look closely, the general framework, concepts, and purpose of creating safety systems and their military subsystems remain unchanged. Military systems usually have two fixed objectives: defensive and offensive activities. The defensive goals are to preserve sovereignty and deter the enemy from his own territory. The offensive ones are focused on ensuring victory in the military campaign and dominating the enemy at home and abroad. The only thing that fundamentally changes is the weapon and its combat capabilities. Nowadays, as a result of technological development, weapons are more accurate, faster, and could affect the enemy at very long distances with less involvement of own operating personnel. Presently, military systems are able to operate at intercontinental distances in various combinations of environments like land, sea, air, space, as well as in cyberspace. One such operational concept based on the latest military achievements is the concept of Anti-Access /Area Denial (A2 /AD). However, the idea of conducting military operations this way has been known known throughout the history of wars (e.g. Maginot Line or Isolation of Great Britain and its defense in World War II), but its name and character was defined and refreshed again two decades ago. Nowadays, concept of A2/AD is mostly dominated by China and the Russian Federation, countries which in their polities and military activities are in opposition to NATO countries. At the same time, it can be observed that Russia and China, which originally declared that these A2/AD systems serve only to defend their borders, are increasingly developing military capabilities and are creating new A2/AD systems also outside their borders. This raises the main research problem: what is the purpose of creating Anti-Access /Area Denial systems? In order to answer the main research problem, author also asks specific questions: to what extent Anti-Access/Area-Denial zones can play a defensive or an offensive role? What is their impact on military balance and the geopolitics relations in a specific region? What are the real possibilities of using these systems in the military operations? In the course of this study, the author decided to answer all these questions in article and verify his main hypothesis based on the predictions that probably in the future, the dominant way of exerting political influence and gaining military advantage before and during operations will be the dislocation of A2 / AD systems in the key areas.

The idea of Anti-Access /Area Denial (A2 /AD)

In subject literature, the A2/AD concept has various names, including the concept of isolating of the battlefield, the concept of blocking access and counteraction, the doctrine of closing access for the intervention forces. They also have an abbreviated name (anti-access concept) and a colloquial name (anti-access). However, the closest to its essence and purpose is a two-part name: the concept of Anti-Access / Area Denial (A2 /AD). The correct nomenclature is particularly important from the perspective of distinguishing between two activities implemented under the A2 / AD concept. The actions of A2 are completely different from the actions of AD. They use different means of combat, are carried out at different distances and in different areas, and their effects are also different from those obtained by AD means. Anti-Access (A2) and Area Denial (AD) are therefore two essentially different groups of activities carried out ultimately for a common goal, which is to gain an advantage over the opponent in a specific area (Dobija, 2019).

The development of the two-part name makes it possible to understand purposes and tasks which are carried out within this concept. Anti-Access (A2) are activities that use long-range combat measures to prevent an enemy from deploying forces in a Joint Operation Area (JOA). In other words, the enemy's forces are prevented from entering the operational area by actions limiting his freedom of movement. Anti-Access is understood primarily as a set of actions carried out against the enemy, making it difficult to reach the area of operation (JOAC, 2012) . These actions focus on limiting enemy freedom of maneuver in each possible dimension of warfare. They are implemented in the land, sea, air, space and cyber dimensions. Considering above-mentioned activities it should be stated that they will be carried out globally under A2, using the latest combat tools and technological achievements. They will be characterized by higher speeds and greater momentum as well as dynamics of operations, previously unknown from traditional forms of air, land or sea combat. The concept of A2 actions are conducted in order to prevent the enemy's troops (creating a kind of wall) in front of the place of operation and will focus mainly on the disorganization of its movement. Thus, the priority targets for the A2 combat assets will be airports and seaports as well as land communication routes. Permanent supervision over the air corridors and sea routes leading to the area of operation will also be carried out. It should be noted that the concept of A2 activities is not only the involvement of the latest military equipment, ships, planes, submarines, ballistic missiles or satellites, but also information warfare carried out in cyberspace. Nowadays, with the enormous and progressive digitization of all civilization it may turn out that the one who controls cyberspace also controls the enemy's ships, planes and satellites. When ruling in cyberspace, one could control information, decision centers, power plants, command posts and its armed forces (Krepinevich,2003).

On the other hand, Area Denial (AD) covers all activities involving the use of weapons with shorter ranges than Anti-Access ones. The main purpose of AD activities is to limit the opponent's freedom of action in the Joint Operation Area (JOA) (JOAC, 2012). Unlike A2, AD measures are focused on limiting enemy combat activities in the operating area. It is strictly military in nature and is used to conduct direct warfare. The A2 / AD concept considers two possible scenarios in which AD means are triggered. First, when A2 measures fail and the opponent manage to enter the JOA, then AD resources are automatically activated. The second, when A2 means constantly isolate the enemy from Joint Operation Area and at the same time AD means conduct close military operations inside the JOA. Hypothetically, this type of scenario could be played by Russian A2/AD system dislocated in the Kaliningrad Oblast. The A2 part could isolate NATO troops from providing support to the Baltic states and the ranges of the AD systems would allow them to combat and control of the military situation in the Baltic states region. The advantage created in this way would ensure that Russian forces gain local supremacy and separate the rest of the NATO forces. One of the best explanations of the A2/AD idea is presented in the words of Professor Andrew A. Michta: "the A2 / AD concept is a combination of activities that limit the possibilities of military access to an operation area, with activities that limit the possibility of operating in a controlled area" (Michta, 2019). Thus, he further stated that the area around the Anti-Access system does not have to be an area of military operation, but it can be a place where ensuring control will allow for gaining an advantage or even ruling in a selected region of the world.

Taking into account the indicated two basic types of activities of A2 / AD concept, the two groups of means could be use appropriately for their goals. As part of Anti-Access (A2) measures, the following systems could be distinguished:

– long-range reconnaissance systems,
– anti-satellite systems,
– other means which are used for carrying out cyber-attacks against: IT networks, command posts, troop movement control systems, supply networks, elements supporting the resilience of the troops,
– Theater Ballistic Missiles (TBM),
– Cruise Missiles (CM): launched from bomber aircraft -Air Launched Cruise Missiles (ALCM), launched from surface and submarine warships - Sea Launched Cruise Missiles – SLCM, and Ground Launched Cruise Missiles (GLCM),
– intercontinental-range submarines,

On the other hand, for the implementation of the Area Denial (AD) tasks, the following systems are used:
– operational and tactical level of Electronic Warfare (EW),
– reconnaissance measures,
– combat aviation (fixed and rotary-wings aircraft),
– unmanned UAVs,
– air defense systems, including Land and Navy air defense systems,
– short-range artillery,
– anti-ship missiles and torpedoes,
– sea and land mines,
– ground maneuver units,
– and all other measures limiting the enemy freedom of action, used from a distance allowing for the avoidance of direct contact with the opponent (Kreuder, 2013).

The use of the above systems in conjunction with the principle of synergy makes them virtually insurmountable. Such a combination creates a multi-layer, closed protective bubble over a large area and completely paralyzes the enemy's actions. At the same time, the dislocation of such systems directly affects the state security policy, especially in countries whose territories are within the range of systems gathered in such zones.

Anti-Access /Area Denial (A2 /AD) – China and Russia case study

Nowadays, there are two countries in the world that specialize in the A2/AD concept - China and Russia. Although these countries use similar military means under the A2 / AD concept, the purpose of their use differs.

China is first of all concerned with the defense goals of A2 / AD and the preservation of its borders sovereignty. Currently, by dislocating systems in the South China Sea, they are "pushing" the United States out, treating it as a potential aggressor. In recent years, a situation has been observed in which a significant part of the Pacific Ocean, previously dominated by US forces, was lost to the armed forces of the China. This became possible because nowadays, China is not only an economic but also a military power. Economic development allowed China to create new military units and expand them into more and more advanced regions. By assuming a defense policy, China began to make its old aspirations to dominate the seas and oceans more realistic. The waters around Taiwan, recognized by Beijing as its rebel province, and the areas in the South China Sea, where China has so far had territorial disputes with its neighbors (Vietnam, the Philippines and Malaysia) have become a key area.

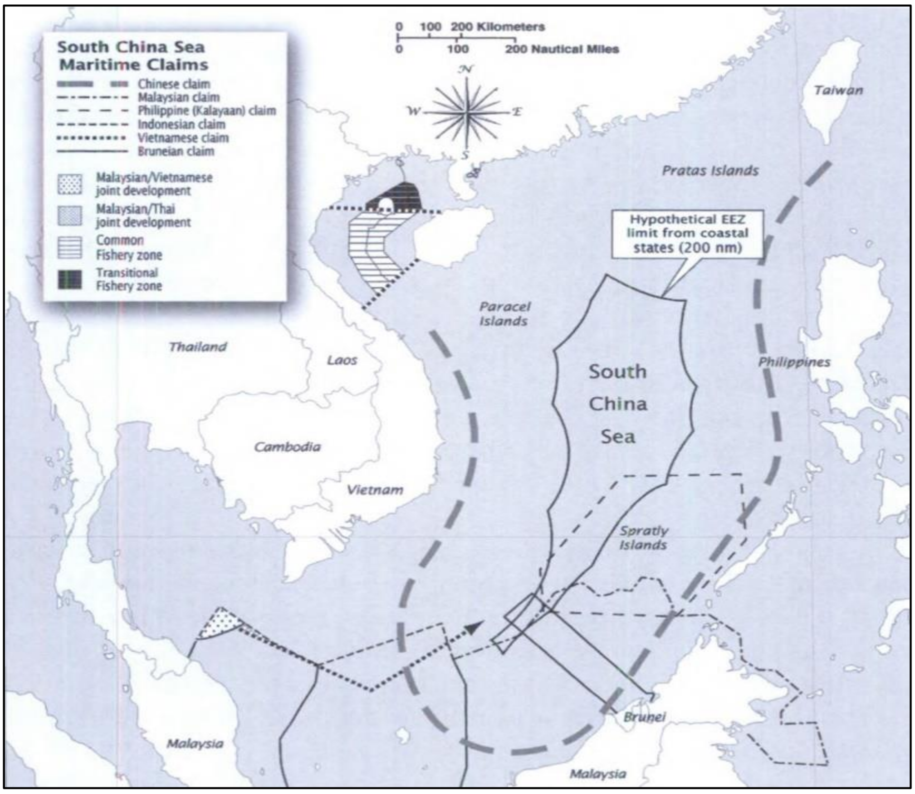


Figure 1. South China Sea claims – marked in dotted line (South China Sea Maritime Claims, Adopted from: National Defense University Press, Public domain, via Wikimedia Commons, 2011, Source: https://commons.wikimedia.org/wiki/File:South_China_Sea_Maritime_Claims.jpg).

Interestingly, China's current dominance in this area is based not on its overwhelming military potential, but on developing strategic strike capabilities within the framework of the A2 / AD systems being developed. These systems make it possible to isolate and maintain potential enemy naval forces (in the intention of the US forces) at large distances from continental borders (Permal, 2014). Keeping the aggressors away from their own territory is possible mainly by dislocating A2 / AD systems on artificial reefs and islands in the South China Sea. The adopted defense concept is based on the use of specialized military means, including reconnaissance satellites, radars, anti-ship and ballistic missiles, anti-aircraft systems and attack aircraft. The concentration of these weapons on artificial islands (rebuilt reefs) located far from the coast of mainland China deprives the US Navy, and above all the US NAVY carrier groups, of gaining an advantage in this region.

Figure 2. Fiery Cross Reef a militarized and controlled by China reef located in the South China Sea (Fiery Cross Reef 2020 jpg., Adopted from: SkySat, CC BY 2.0, https://creativecommons.org/licenses/by/2.0, via Wikimedia Commons, Source: https://commons.wikimedia.org/wiki/File:Fiery_Cross_Reef_2020.jpg)

The implemented scale of the military projects shows growth of China's arms budget. It is the second largest budget in the world just after the US. In 2021, it amounts 1.35 trillion yuan ($ 208.47 billion). Deployment of China's A2 / AD systems in distant territories means that, at least for the moment, the United States do not have the capability of responding and restoring its dominance in the disputed areas. In addition, the latest Chinese anti-ship missiles Donfeng DF-26 with the range 5,000 km could threaten US aircraft carriers, even though they are outside the China Sea (Guizner, 2016).

Therefore, it can be concluded that Anti-Access / Area Denial (A2/AD) systems could diametrically change methods of war conducting. The aircraft carriers perceived so far as the main power on the seas and oceans lost their primacy in the face of the possibility of using long range (thousand kilometers) anti-ship missiles or strike groups of planes located on artificial islands. That is the way the A2 / AD system changed the balance of power in the South China Sea and some parts of the Pacific Ocean. Despite the fact that Chinese A2/AD has a defensive and regional character which is historically associated with the China territories, one cannot exclude that there is a change of military balance in the South China Sea region. What is worrying the most is the scale of expenditure on Chinese armaments and the establishment of the first (in 2017) Chinese military base on another continent in Dzibutti (West Africa). Declared as a logistic base, it was created to ensure the safety of the Chinese merchant fleet. So far, its tasks have been focused mostly on the supply and maintenance of warships. The warships stationed there provide peaceful anti-piracy operations to supervise the China's economic interests in Africa. Nevertheless, experts point out that the location of the base has military and geopolitical importance not only for China but also for the whole world. This is because it is a sensitive and strategic area called the Horn of Africa. From this area China could control the movement of the world's merchant fleet flowing through the

Red Sea and further through the Suez Canal to the Mediterranean Sea. It is also possible that this base will be equipped with A2/AD system later. If that happens, it can radically change military force of balance in the Middle East and China can influence from this place on the North Africa and even South Europe countries.

Summing up, A2 / AD systems currently play a central role in China's military strategy and successfully defend the interests of the world's largest economy. The Chinese economy, which is export-oriented and at the same time dependent on the import of raw materials is largely based on the free use of sea routes. For this reason, escort missions in the Red Sea and a permanent presence in the Indian Ocean are crucial for China. At the same time, the strategy adopted by China is to base the Anti- Access/ Area Denial systems in distance areas, which allows them to move the defense line and prevent potentially hostile warships from reaching their shores. Although these actions are defensive in nature, they de facto allow China to pursue an expansive policy, which is particularly visible in the South China Sea. It should be also noted that the Republic of China is developing its navy at a very high pace, introducing over 100 ships (including 2 aircraft carriers) into its service over the last 10 years. These actions can testify to the further expansion plans and exerting political and military influence beyond the area of the declared Chinese territorial waters. Sensing a weakening position, the USA has started working on new strategies that could break through A2/AD zones domination. One of the proposed concepts is based on a multidimensional attack conducted both in cyberspace, in the electromagnetic spectrum, by rocket artillery, unmanned aerial systems, and hypersonic missiles (Hypersonic Glide Vehicle). This last, previously unknown weapon, will be characterized by high precision, and primarily high speeds, several times exceeding the speed of sound, and the ability to carry any type of combat warheads (NATO, 2011). The purpose of using all the above systems in a coordinated manner is to disrupt and disable the A2 / AD command, thus creating conditions for carrying out the next phase, conventional attacks on the other military systems located inside the zones. The breaches created in this way in the defense zones and, at the same time, the inability to strike at long distances will allow the transition to the 3rd phase of the operation and the introduction of land and sea troops supported by aviation in order to take over the areas previously occupied by A2 / AD forces (Behrendt, 2020).

The US concept of counteracting A2 / AD zones proves their great influence on the process of shaping the geopolitical and military situation in the world. These zones can diametrically affect the movement of air and sea in a selected areas and excluding the possibility of deploying opposing ground forces in their vicinity. Assuming China's further economic development, it cannot be ruled out that in the future A2 / AD systems will also be deployed in new areas of interest far away from the country's continental borders. Let’s hope it will be dictated mainly by the need to ensure the security of the continuity of supplies of raw materials and energy for the Chinese economy, which is currently the largest and at the same time the most expansive in the world.

A slightly different concept of A2/AD is implemented by the Russian Federation. Historically, the Russian Anti-Access/Area - Denial systems were initially created as a network of defensive bastions deployed around the borders of the largest world territory. Thus, the A2 / AD bastions became the solution that allowed for the concentration of forces in selected areas, while maintaining the ability to act at very long distances. As a result of the concept, the Russians have created as many as nine A2 / AD systems, ranging from Vladivostok and Kamchatka, to the western borders of Europe. Over time, they also began to be deployed in sensitive regions in order to dominate the military situation and extend the sphere of influence to opposite border states and their allies. An example of such activities is dislocation of the A2/AD system in the Kaliningrad Oblast, which is a Russian exclave bordering with NATO countries, or the dislocation of A2 / AD systems in areas of military conflicts in which Russia is currently involved (Crimea and Syria). So far, the Russian Federation maintains as many as 11 A2/AD, 9 of which directly serve to defend its borders, while the rest are created to influence the local political and military situation or to gain an advantage in the area of military operations. Below is the list of A2/AD systems as of August 2016:

1. Kaliningrad;
2. Murmansk / Polarnyj;
3. Saint Petersburg;
4. Moscow;
5. Novorossiysk;
6. Vladivostok / Nakhodka;
7. Petropavlovsk/Kamchatka;
8. New Earth;
9. Tiksi;
10. Sevastopol/Crimea;
11. Khmeinin, Latakia/Syria

Figure 3. Dislocation of Russian's A2/AD systems(The authors own work)

A striking example of the creation of the A2 / AD system, which affects the political and military situation in the region, is the one established in the Kaliningrad Oblast which is the most western Russian exclave bordering the NATO countries. The Kaliningrad Oblast is cut off from the rest of the country, borders Lithuania and Poland, and from the north, it has an extensive coastline on the Baltic Sea. In a straight line, the Kaliningrad Oblast is about 250 km away from the borders of the Russian Federation. The distance to be covered by land routes from the Kaliningrad Oblast to the Russian border is 450 km, while the sea route to the nearest Russian port (Saint Petersburg) is estimated at approximately 550 nautical miles. This territory has strategic military and economic importance for the Russian Federation. The process of increased militarization of the oblast began in 2009, when Russia entered the phase of economic crisis and, at the same time, increased its military expansion. In the following years, Russia invested in non-military means of combat, which ultimately led to the transformation of the Kaliningrad area into the Russian A2 / AD zone (Sukhankin, 2018).

A particularly significant increase in spending on the militarization of Kaliningrad and its alienation from Western partners was visible in 2013, during the Ukrainian crisis when Russia took over Crimea and eastern Donbass. This zone is currently the most heavily armed of all A2/AD zones and allows for the supervision over air, land and sea space in Baltic Sea and most of central Europe. It is estimated that about 12-15 thousand soldiers are currently stationed there. They are equipped with:

- combat aircraft (689th Reg Su-27 and 4th Reg Su-24, Su24MR, UAV Squad),
- air defense systems (183rd Reg S-400, 1545th Reg S-300, 22nd Reg Pancyr-S1,),
- long-range reconnaissance and EW systems (142nd EW Battalion, 302nd Reg),
- ballistic missile and winged missile systems (152nd Brig Toczka- U/M, Iskander -M, 244th Brig BM-21, 2A36, Hiacynt-B),
- marine and coastal missile systems (25th Costal Missile Reg Bastion-P),
- submarine and surface warships.

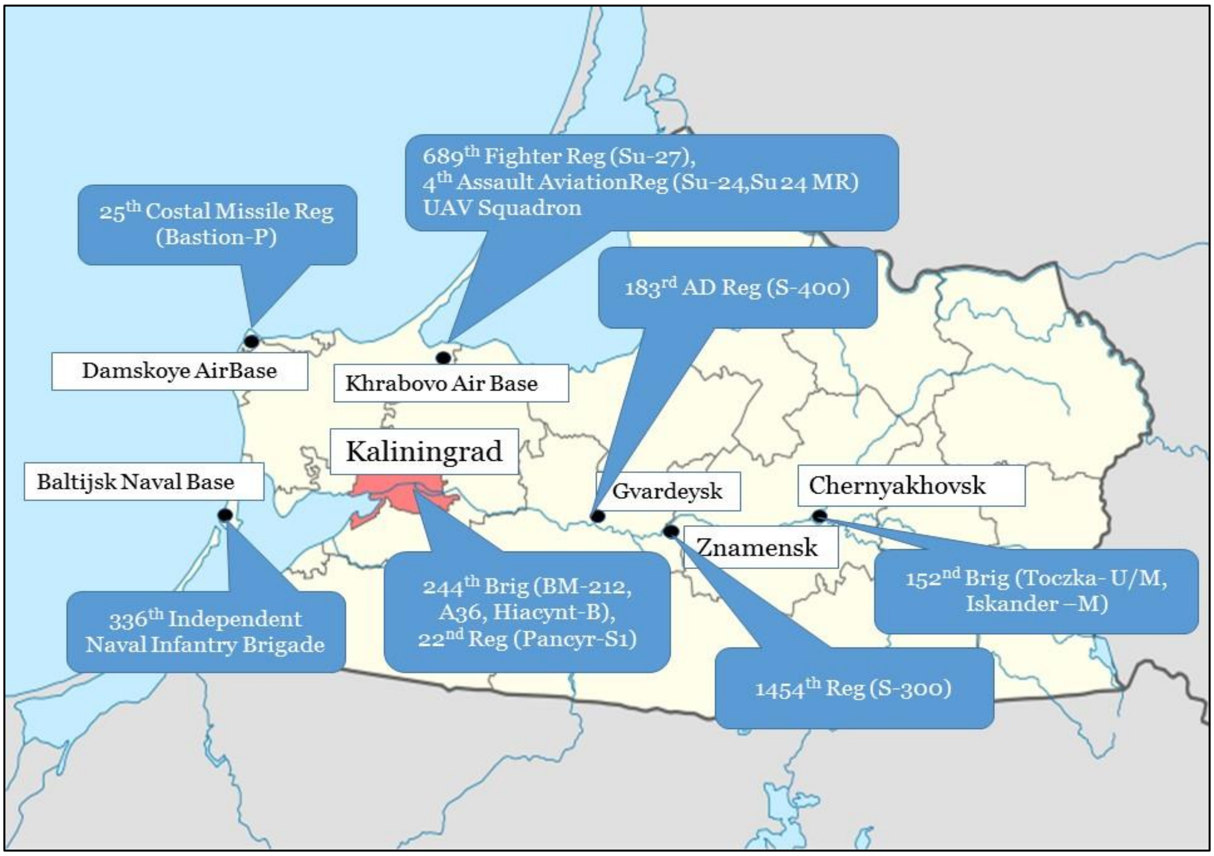


Figure 4. Dislocation of the main forces in the Kaliningrad Oblast A2/AD (The authors own work)

S-300 and S-400 long-range anti-aircraft systems can be distinguished among the most dangerous air defense systems deployed in the Kaliningrad Oblast. Depending on the version and type of missiles, they allow for the destruction of air targets at distances of 150 km (S-300 PMU set with a 48N6E missile), 200 km (S-300 WM set with a 9M82M missile), and even 400 km (set S-400 Triumph armed with 40N6 missile). Of course distances of 400 km are achieved only when air targets are flying at very high altitudes. Therefore, the full ability of the S-400 system to destroy air targets is assumed at distances about 250 km. The S-300 / S-400 systems are multi-channel, thus they can engage several or a dozen targets simultaneously, including ballistic missiles and winged missiles. The dead zones of both of the systems are supplemented (covered) by the following short-range anti-aircraft systems: Pancyr, Tor M-1, Buk and Tunguska.

From the NATO perspective, the A2/AD system deployed in the Kaliningrad Oblast poses a particular threat to European countries. In the event of a possible conflict, Russian troops and weapon dislocated in Kaliningrad allow the Baltic countries to be cut off from the supply and support NATO lines of communication in a very short time. In this regard, the special perception should be focused on the "Suwalki Corridor" called also “Suwalki Gap”. This is a small land located between Kaliningrad Oblast and Belarus, a Russian ally. This area is a 100 km long border between Lithuania and Poland,, and the main route of land communication between the Baltic states and the rest of Europe. The seizure of the "Suwalki Corridor" by Russia would enable a connection for Russian troops from Belarus, while simultaneously cutting off Lithuania, Latvia and Estonia from land communication with other NATO countries. This area is extremely important for ensuring the security of the Baltic states, the former Soviet republics, towards which Russia's policy is conducted from the position of the dominant state. At the same time, US politicians and military commanders point out significant infrastructural, communication and organizational shortcomings that prevent NATO countries from quickly redeploying forces and reacting in this area. It is commonly known that Russia and Belarus would show interest in this area in the event of a potential escalation of conflict with NATO countries. A clear example of these efforts are the joint military exercises carried out close to the Polish and Lithuanian borders. An example of this can be exercise ZAPAD-17 cared oud where Poland and Lithuania were presented as aggressors defeated by the joint forces of Russia and Belarus. During the exercise, the Russians moved air defense systems and tactical Iskander-M ballistic missiles from their bases in Russia in order to strengthen the A2 /AD system in the Kaliningrad Oblast, and then carried out their simulated massive attack on the aggressors. The ZAPAD -17 maneuvers were a kind of offensive war with different combinations of simulated attacks on the Baltic states, air strikes at the Lithuanian border and landing troops at the Estonian - Latvian border. The offensive combat variants were also practiced by Russia in earlier years during the ZAPAD-09 and ZAPAD-13 exercises.

Figure 5. Location of Suwalki Corridor (Gap) and possible Russian military actions (The author own work based on google.maps.com)

The presented actions of Russia and neighboring Belarus allow us to conclude that the "Suwalki Corridor (Gap)" is one of Russia's strategic priorities, after wide access to the Baltic Sea. The main threat to Poland and Lithuania is also the possibility of restricting or blocking access to the ports in the Baltic Sea by naval and missile forces stationed in the Kaliningrad Oblast as part of the A2 / AD system. Affecting trade routes to Gdansk and Klaipeda could result in large economic losses and political destabilization in the Baltic Sea basin. The forces deployed in the oblast (the Russian fleet and costal missile systems) also allow for having an impact on the Scandinavian countries, including neutral Sweden and Finland. There is a widespread belief that Russia's ability to restrict access in the Baltic Sea region may be used to close this basin. This would be aimed at preventing the displacement of naval forces, as well as cutting off the Baltic states from providing land and air military support to their Western allies. Therefore the "Suwalki Corridor" would be the only place from which NATO reinforcements for the Baltic states could arrive. The sea and air routes would be too dangerous to use them in the first phase of conflict due to the strength of the Russian Baltic Fleet and their air superiority in this area.

The dislocation of such a large number of troops in such a small area and the creation the A2 / AD zone has a great impact on European security and the efficient functioning of the Alliance. As a result of that situation, NATO countries decided in 2016 to dislocate four multinational battalion battlegroups with locations in Poland and three Baltic States. The aim of the initiative called Enhanced Forward Presence (eFP), was to increase the defense on the eastern flank of the Alliance bordering the Kaliningrad Oblast. The NATO Battalion Battle Group (BGB) dislocated in Poland started its service on April 13, 2017. The core of the battalion consists of US armored cavalry soldiers. However, it also includes soldiers from Great Britain, Romania and Croatia. The Battalion Battle Group in Lithuania was formed by the German, Belgian, Czech, Dutch, Icelandic, French and Norwegian troops. The Latvian

BGB is made up of allies from Canada, Albania, Montenegro, the Czech Republic, Iceland, Poland, Slovakia, Slovenia and Italy. The Estonian BGB, on the other hand, relies on the support of Great Britain, Denmark and Iceland. Each of the 4 BGBs consists of about 1000-1500 soldiers who conduct a series of training courses to maintain their constant combat readiness. These soldiers operate in a six-month rotation system.

The strengthening of NATO forces as part of the creation of the multinational rotating BGB made the occupation of the “Suwalki Corridor” by Russia to be considered unlikely, mainly due to the unpredictable political consequences and the involvement of many countries in the conflict and due to NATO's military and economic advantage. Moreover, it is believed that the Russian Federation, due to the size of its territory and de facto encirclement by the United States and the presence of China, cannot afford to weaken the A2/AD garrisons in the eastern part of the country. The only method by which Russia could gain an advantage is to divide and deepen disputes between NATO countries using the “Suwalki Corridor” as propaganda to affect Poland and Lithuania and building tension in relations between NATO and Russia.

Looking at the A2/AD system dislocated in the Kaliningrad Oblast, one can conclude that it performs both offensive and defensive functions. Firstly, it allows for military domination and isolation in a sensitive area, while on the other hand, it is a part of the network of defensive bastions on which Russia secures its borders. However, some Russianists argue that it is incorrect to believe that Russia will not start a conflict against NATO, others foresee this possibility. Unfortunately, as recent history shows, what is irrational for Western countries may be logical for Russia (it is so-called mirror imaging phenomenon described as assessing the ways of acting of aggressor from our perspective instead of from aggressor’s position). An example of such thinking by Western countries was the initial ignoring of Russian actions during the annexation of the Ukrainian Crimea or Russia's involvement in the operation in Syria. These actions came as a big surprise to many countries and initially met with their lack of reaction. Presently, the concerns of Europeans related to A2/AD Kaliningrad Oblast are following:

- The possible deployment of a large number of nuclear warhead-capable Iskander-M mobile missile complexes with ranges that cover the entire Baltic Sea and most of Central Europe countries,
- Quick possibility to reinforce A2/AD troops by air or sea military transport which allow to build the Russian military advantage in the region,
- Convenient dislocation of Russian troops to start a hybrid invasion on the former Soviet republics (Lithuania, Latvia and Estonia),
- Borders with Suwalki Corridor – strategic place which can be easily occupied or used as a perfect terrain for force connection with Belarus in order to cut the three Baltic countries off from their NATO allies,
- Conventional long-range strike capabilities against NATO countries using cruise missiles Kalibr and strike bombers,
- A combination of tactical and strategic military exercises named ZAPAD (conducted in an atmosphere of secrecy and non-transparency) as a potential start for Russian military intervention,
- Information and psychological war (specially aimed at Poland and Lithuania) and constant provocations (force present) in the sea and air space,

On the other hand, objectively looking at the map of the Baltic Sea, it can be noticed that NATO controls most of its territory. It should also be noted the actual ranges of Russian missiles are very often smaller than declared, What is more important, Russian forces suffer from a lack of long-range reconnaissance capacity indispensable for effective missile guiding and hitting targets at long distances. Therefore, looking at the A2 /AD systems realistically, one can also notice many other limitations, including:

- There is always not enough air defense systems to protect all of the sensitive assets in the area,
- Long range air defense systems have to be protected by medium or short range AD systems, requiring great efforts and the need of force movement from other unprotected areas,
- Declared AD ranges (300- 400km) are only realistic in terms of targets that are flying at a very high altitude (normally they fly at low levels to avoid radar detection and shooting by AD systems),
- Satellite surveillance gives insufficiently precise guides for Russians maritime and land long rage-missiles. The technology is still underdeveloped and NATO has a reliable anti-satellite weapon,
- A high concentration of forces in a small area makes them an easy target. It is supposed that in future various types of unmanned vehicles, like aerial, sea and land, will be crucial in defeating enemy A2/AD systems.

Despite these limitations, Russia continues to pursue its strategy of deploying A2/ AD systems in the areas of its military and political interest. Since the annexation of Crimea in 2014, it has also drastically increased its presence in the Black Sea region. Russians A2/AD systems have practically covered all of the Black Sea to deny other countries' access and free movement. Within five years, the number of Russians troops increased from the initial 12,000 (before illegally seizing Crimea) to 32,000 aiming to reach 43,000 in 2025. Currently, the following units and A2/AD systems are stationed on the Crimean peninsula:

- 31st Air Defense Division composed of two AD regiments: 12th Air Defense Regiment and 18th Air Defense Regiment (S-300PM and S-400, Pansyr S1) 1096th Reg (SA-8 OSA, Buk),
- 27th mixed aircraft division composed of three fighters regiments (37th, 38th, 39th) equipped with e.g. Su-27SM, Su-30M2, Su-3M2, Su-24M, Su-25, Tu-22M3, Ka-52, Mi-28N, Mi-35M, Mi-8AMT, 43rd Independent Naval Reg (Su-24,Su-24MP, Su-30SM) 318th Independent Mixed Aircraft Regiment (An -26, Ka-27),
- 15th Independent Coastal Artillery and Missile Brigade (1st Bastion-P and Bastion-S Squadron, 2nd Utios Stationary Squadron, 3rd Bal Squadron),
- 475 th Electronic Warfare Center (including the Murmansk-BN high power reconnaissance and jamming system),
- Different classes of submarines (5) and warships (30) with Kalibr missiles.

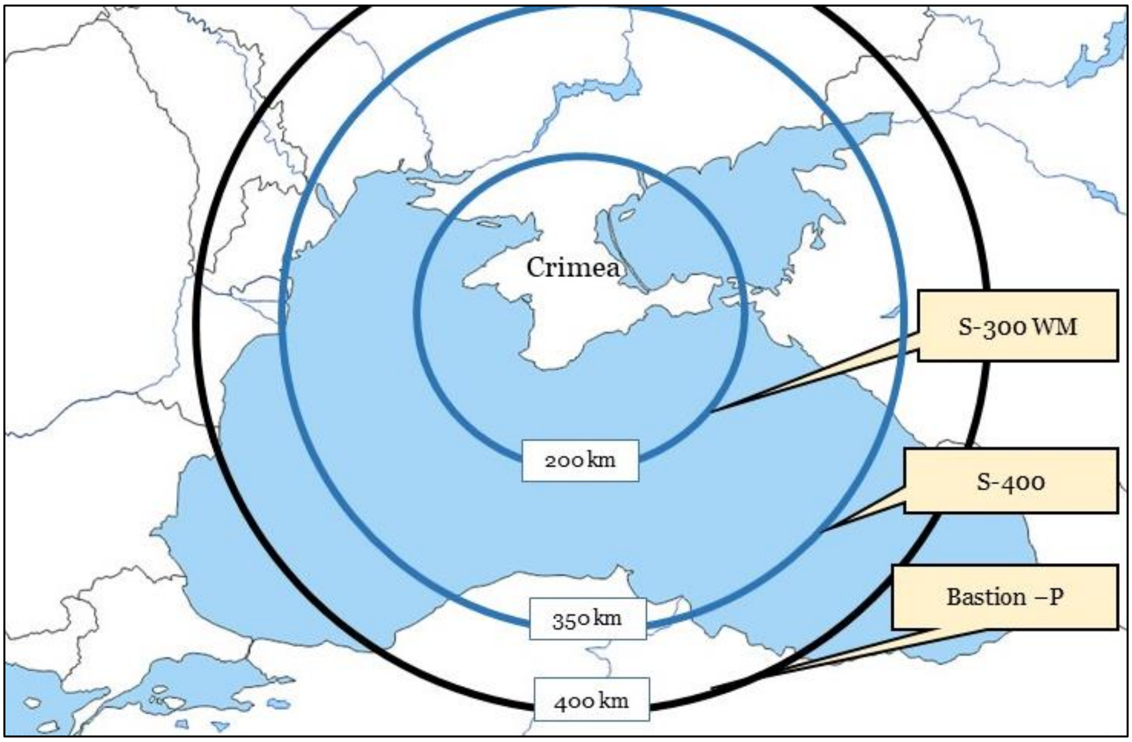


Figure 6. Estimated ranges of selected Russian missile systems located in Crimea A2/AD (The Author own work)

Coastal defense created under the A2/AD system with its Bal and Bastion anti-ship missiles can destroy not only Ukrainian ships, but also Romanian and Bulgarian ones, as well as those located in Turkish ports. In addition, the ranges of the S-400 anti-aircraft systems, supported by the Pansyr S1 and SA-8 OSA systems and Tu-22M3 Backfire bombers cover most of the Black Sea basin. Furthermore, Kalibr missiles, thanks to their ranges, could hit targets in southern and eastern Europe, central Asia and the Middle East. Electronic reconnaissance and electronic warfare facilities located in Sevastopol are also an integral part of this system. They can monitor the movement of all ships not only in the Black Sea but also in the Mediterranean Sea. In this manner, Russia gives a clear sign to Western politicians that they may face clear resistance if they wish to support Ukraine militarily. In addition, in the Black Sea region, Russia constantly conducts psychological activities and demonstrates its strength e.g. by performing low-pass flights close to NATO ships. Russia is also modernizing facilities in Crimea that were used in the past to store nuclear weapons. Therefore, it should be noted that, among others, the mentioned Tu-23M3 bombers, Bastion coastal defense system and Kalibr missiles and submarines have the ability to carry nuclear warheads.

Unfortunately, at the moment, there is no agreement between NATO countries on how to restore the balance of power in the Black Sea basin. The idea of creating a joint Bulgarian-Romanian flotilla as a response of the Alliance countries to the Russian military potential accumulated in Crimea has also fallen. One of the obstacle in restoring the balance of power in the Black Sea is the 1936 Montreux Convention. It limits the tonnage of warships entering the Black Sea and the duration of their stay in this area to 21 days. For these reasons, the US, GB, France and other NATO nations must constantly rotate their warship presence there. Military control of the Black Sea is essential for Russia, giving them access to the Balkans and the Mediterranean Sea. Some observers of the political and military situation claimed that the expansion of the A2 / AD system within Crimea may indicate that Russia still feels insecure in this region, as many countries do not accept the annexation of Crimea and recognize it as an integral part of Ukraine. As it turned later, this system gave the Russians perfect military access to Syria conflict (e.g. Bastion coastal defense system was delivered from Crimea to Syria as part of the local A2 /AD system built up there by the Russians). In addition, during the Syrian conflict, the activities of the Russian troops were supported by ships in the Black Sea that carried out missile strikes against targets in Syria.

The Russian A2/AD dislocated in Syria was established to protect sea (Tartus) and air (Latakia) expeditionary bases. As part of creating this system, the following equipment was brought to Syria:

- 2* S-400 system batteries at Khmeinin, dislocated at Latakia and Masyaf,
- S-300 system battery at Tartus,
- Bastion-P battery in Masjaf,
- EW 1RŁ257 Krasucha-4 system in Khmeini,
- Admiral Kuznetsov Aircraft Carrier with about 30 Su-33,
- Additionally project 21631 Bujan-M missile ships were on duty in the Kaspisian Sea, which, equipped with Kalibr cruise missiles with a range of 2,500 km, attacked targets in Syria.

Figure 7. Ranges of Russians missile systems dislocated at Syrian A2/AD (Author own work)

Initially involving to the Syrian conflict, Russia declared that its military activities would be limited to the combat aviation and would be directed only against the so-called Islamic State (IS). However, the first weeks of the Russian operation in Syria confirmed the earlier assumptions made by many observers that the Kremlin's goal is not to fight with the Caliphate, but to defend the regime of President Bashar al-Assad. Moscow chose not only the very moment of starting its intervention (at the end of September 2015), but also its scope and nature of the military means used, mainly in the form of bombing and aviation assault. As a result of the two weeks of Russian air support for pro-government Syrian ground forces, the opposition formations operated in the provinces of Idlib and Latakia stopped their offensive activities.

Generally involving the Syrian war, Russia has to show its military power and presence in the world. This means this was also an attempt to re-establish Russian Federation activity in this part of the world in a much more "concrete" way than it has been in the past 25 years. Using the A2/AD system, they have protected their expeditionary forces and took control over most of the joint operation area. In addition to the base expansion agreement with Syria, Russia has deployed sophisticated anti-aircraft and anti-ship missile launchers, and strategic bombers. When Russia completed its mission in December 2017, it began slowly to replace the combat air wing in Khmeini with more interdiction assets. The dislocation of A2/AD systems gives Moscow a number of strategic benefits, such as the possibility of using its naval and air military installations with a real influence on the Middle East region while simultaneously countering NATO's relative influence. Such a capability creates considerable political and security challenges for the alliance especially by denying NATO access to the Black Sea, the Baltic Sea, and now to the eastern Mediterranean regions (Paravincin, 2016). Success in establishing an A2/AD zone in the eastern Mediterranean would deny NATO the ability to take "action against Russia or its allies in the region (Georgetown SSR, 2017)." It may be observed that Russia is pursuing this endeavor via three main paths: (1) posturing a credible and present military force; (2) exploiting fissures within US and Western relations with regional allies, to include Egypt and Turkey; and (3) establishing a permanent base agreements (Altman, 2016). Additionally, Russia's access to the region currently relies heavily on positive or at least neutral relations with Turkey, the only state with the power to block Russia's access route from the Black Sea to the Mediterranean Sea.

Summary

In recent years, Since now the military conflicts conducted by regular armies have been based on a pattern in which the main aim of first phase was to win airspace dominance over the theater of operations in order to ensure freedom of action for the navy and army. For many years, this concept has been mainly developed by NATO countries and led by the USA. In response, the Russians and the Chinese began to develop a strategy that NATO planners have started name A2/AD (Anti-Access / Area-Denial). It involves the deployment of long-range missile systems surface-to-air/surface/water, long range radars and radio-electronic jamming systems in the Joint Operations Area (JOA). Thanks to them, Russia and China became able to establish a full control zones which are completely closed to enemy air and sea operations. The size of the A2/AD areas are mostly defined by the ranges of its combat systems. It can also be observed that China and Russia are constantly developing their military technologies and increasing the ranges of their missile systems. Today, they are able to create excluded A2/AD zones with a radius of between 400 and 600 km (depending on the type of missiles located inside zones). Although the strategy based on A2/AD has its previous defensive character, nevertheless it could also be successfully used to achieve the offensive military goals. A2/AD strategy exert political influence on border states, push them out of hitherto areas of influence and make long-term changes in selected regions of the world. This is especially visible in the South China Sea, the Crimean Peninsula and the eastern part of the Mediterranean basin where China and Russia has established their A2/AD zones.

Nevertheless, comparing the Russian A2/AD strategy to the Chinese one, it should be noted that the former is more aggressive. Russia often uses A2/AD systems to provoke strong political and military reactions, especially from NATO countries. This was visible during ZAPAD exercises carried out in the area of Kaliningrad A2/AD zone and the "Suwalki Corridor", especially when Russia deployed Iskander missiles to the Kaliningrad Oblast without prior announcement. In addition, Russia began to use the A2/AD concept for offensive purposes and to dominate in the areas where it conducts military operations. It was especially noticeable during the conflicts in Ukraine and Syria. However, it cannot be excluded that in the future other countries which possess A2/AD abilities will use this offensive strategy too. Its advantage is the possibility of achieving dominance in the air, sea and land in a very short time and effective isolation of the opponent's actions. Summing up, it can be observed that the original defensive character of A2/AD systems has evolved and now they are more often use for offensive purposes and military operations. In the author's opinion, the presented research results allow us to confirm the previously formulated hypothesis. They also point out that the dislocation of A2/AD systems will be the leading concept of future military operations and will have a large impact on world military and geopolitics relations. The briefly described results in the article are also a part of a larger research project entitled: "Functioning of the Anti-Access/Area –Denial (A2 /AD) in operation" in which author has been involved since 2018.

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

References

1. Altman, J., Russian A2/AD in the Eastern Mediterranean: A Growing Risk," Naval War College Review, Winter 2016, 69:1, Available online: https://www.usnwc.edu/getattachment/4ac8b59c-4634-44b3-af06-dee0203d6c67/Russian-A2-AD-in-the-Eastern-Mediterranean—A-Gro.aspx
2. Behrendt, P,. Jak Amerykanie chcą militarnie powstrzymać Chiny, (20.06.2021). Available online https://nowakonfederacja.pl/jak-amerykanie-chca-militarnie-powstrzymac-chiny/
3. Dobija, K. (2019). Uwarunkowania rozwoju system obrony powietrznej Polski, Warszawa: Akademia Sztuki Wojennej.
4. Georgetown Security Studies Review, Containing NATO: Russia's Growing A2/AD Capability in the Mediterranean, (20.06.2021) Available online:https://georgetownsecuritystudiesreview.org/2017/02/21/containing-nato-russias-growing-a2ad-capability-in-the-mediterranean/#_edn10
5. Guizner, M., Clark, B. (2016). Winning the Salvo Competition Rebalancing America's Air And Missile Defenses, Center for Strategic and Budgetary Assessments, Washington.
6. Interim conceptual Ideas, NATO Ground Based Air Defense Operations (2020), Version 0.4, Brusel, April 2011.
7. *Joint Operational Access Concept*, Deparment of Defense, USA, 17 January 2012.

8. Krepinevich, A., Watss, B., Work R., (2003). Meeting the Anti-Access and Area – Denial Challenge, Center for Strategic and Budgetary Assessments, Washington.
9. *Kreuder, G., Lead Turning the flight, (2013),The Joint Operational Access Concept and Joint Doctrine,* JFQ/ *issue 69, 2nd quarter 2013, ISSUE 69, 2nd quarter JFQ, NDU, Washington.*
10. Michta, A., Odpowiedź na rosyjski system A2/AD to wielkie wyzwanie dla NATO, (1.07.2021). Available online https://www.bankier.pl/wiadomosc/Michta-Odpowiedz-na-rosyjski-system-A2-AD-to-wiel-kie-wyzwanie-dla-NATO-3554988.html
11. Paravicini G., New chess game between West and Russia, Politico, July 11, 2016, Available online: http://www.politico.eu/article/natos-struggle-to-close-defence-gaps-against-russia-a2ad/
12. Permal, S., China's Military Capability and Anti-access Area-denial Operations, Maritime Affairs: Journal of the National Maritime Foundation of India, Volume 10, 2014 - Issue 2, Published Online: 10 Nov 2014.
13. Sukhankin S., From ‘Bridge of Cooperation’ to A2/AD ‘Bubble’: The Dangerous Transformation of Kaliningrad Oblast, The Journal of Slavic Military Studies, Volume 31, 2018 - Issue 1, Published Online: 09 Feb 2018.

SAFETY&DEFENSE
ISSN 2450-551X

Global Challenges and Threats of Hypersonic Weapons: The Russian Context

Mirosław BANASIK

Jan Kochanowski University, Kielce, Poland;
miroslaw.banasik@interia.pl, ORCID 0000-0002-9358-1240

DOI: https://doi.org/110.37105/sd.119

Abstract

This article presents the results of research that set out to identify and characterize the challenges and threats to international security posed by the use of hypersonic weapons. The research process mainly employed the critical assessment of the literature, systemic and comparative analyses and generalization. As a result of the research, it was established that hypersonic weapons are an indispensable tool in the conducting of international competition by the Russian Federation and can be treated on par with nuclear weapons. Due to its attributes, it meets the criteria of an offensive weapon and poses certain uncertainties and real threats to the international security environment mainly because, so far, the capabilities to intercept and destroy it in the active phase of flight to the target has not been acquired. The Russian Federation considers hypersonic weapons as an excellent tool for applying pressure and aggression, allowing it to conduct international competition in the gray zone and achieve foreign policy objectives without the need for direct military confrontation. Due to its ability to cause almost immediate operational and strategic effects, it accelerates the dynamics of conflict escalation and rapidly affects the transition from a state of stability to international instability. It cannot be ruled out that in the third decade of the 21st century hypersonic weapons may be the key element determining the Russian Federation's achievement of global dominance.

Keywords

defense, hypersonic weapons, rivalry, Russian Federation, threats

Submited: 28.04.2021 Accepted: 04.06.2021 Published: 20.10.2021

1. Introduction

In late December 2018, Russia successfully tested a missile system Avangard (2018) with a hypersonic glider vehicle. According to press reports, this nuclear-capable strategic glider launched an old Russian SS-19 ballistic missile (Troianovski, 2018) from southwestern Russia flew about 3,500 miles to a target on the Kamchatka Peninsula, reaching speeds of up to 20,000 mph.[1] Russian sources have noted and the U.S. have confirmed that this new maneuverable hypersonic missile cannot be intercepted by existing air and missile defense systems due to its high velocity and unpredictable flight trajectory (Georgiou, 2018). Most of the existing U.S. anti-missile systems are capable of countering medium- and long-range ballistic missiles launched from the Middle East region. A few dozen sets deployed in Alaska and California can intercept classic Russian ballistic missiles, but they are too few to provide effective cover against Russian hypersonic missiles in the future. In fact, the capabilities of the Ground-Based Interceptors (GBIs), are highly limited. Introduced into operational service in 2004, the GBIs were first tested against true ICBM only in 2017 (Homeland, 2017). Furthermore, the first salvo fire, which constitutes the cornerstone of the missile interception strategy, was conducted only in 2019 (Homeland, 2019). This means that the GBI is still in an experimental phase of development, even though it has been operationally deployed. Therefore, it is highly debatable if this weapon can intercept modern Russian MIRVed ICBMs employing a range of penetration aids. One might be tempted to conclude that due to poor technological sophistication, no state in the world currently possesses hypersonic weapons to counter missile capabilities (Woolf, 2020).

The Russian Federation's drive to acquire a large number of hypersonic missiles (Kristensen & Korda, 2021) in the future poses new challenges and threats to international security. This is supported by the following arguments. First, hypersonic missiles are highly maneuverable. Second, it is difficult to precisely identify not only the target of an attack but even the state on which a hypersonic missile will fall, which can lead to alarms being raised in several neighboring states simultaneously. Third, in the situation of a crisis of a political-military nature, active retaliation must be expected (Arbatov et al., 2019). Fourth, there is no technical possibility to distinguish between a hypersonic missile armed with a conventional payload and a missile carrying a nuclear weapon. Fifth, because of the limited time between the detection of a missile and its detonation, as well as ambiguities about the target of an attack, the decision-making process of the attacked party is complicated. Consequently, a state possessing nuclear weapons may be inclined to use them and undertake, large-scale, warning or preemptive strikes due to potential or perceived threats to its civilian or military infrastructure (Arbatov et al., 2019).

The problematic situation thus identified leads to the formulation of the main research problem: What challenges and threats to international security do Russian hypersonic weapons pose? The main research problem was fragmented and the following specific problems were identified:

1) What are the characteristics of hypersonic weapons?

2) What strategic implications does the use of hypersonic weapons entail?

This article presents the results of research that set out to identify and characterize the challenges and threats to international security posed by the use of hypersonic weapons. The solution of the main research problem was possible thanks to the systemic approach, which allowed us to examine the interactions, interdependencies and relationships between the

[1] The range of the glider is up to 6,000 kilometers, the flight time can be up to 35 minutes and the accuracy of hitting the target is 30 meters (Russia, 2019).

threats resulting from the use of the Russian hypersonic weapons and the participants of the international security environment with regard to the present and the future. This article does not provide a catalog of every possible threat, but focuses on a cross-cutting identification of the most significant causes affecting the lowering of the level of security and an indication of the risk for international instability. One of the key factors determining that crises may arise rapidly is the ability of hypersonic missiles to carry nuclear payloads. This results in the complexity of system interactions between the use of hypersonic weapons and the management of the nuclear weapons. The research process mainly employed the critical assessment of the literature and a systemic analysis. Comparative analyses and generalization were also helpful, which allowed us to determine strategic trends in the use of hypersonic weapons and the escalation of crisis situations as well as countering negative phenomena related to their use.

2. Characteristics of hypersonic weapons

The Russian Federation, through the application of new technologies, has succeeded in the sphere of hypersonic long-range precision-guided missiles (Kucharczyk, 2020), which represent new capabilities of strategic and operational importance (Weitz, 2020). They include maneuvering re-entry ballistic missiles, hypersonic guided cruise missiles (HCVs), and boost-glide missile systems (HGVs) (Heinrich & Weiland, 2009, p. 2). The acquisition of precision control devices has made it possible to create maneuverable self-guided warheads (HCVs), at the end of their flight trajectory. In some cases, it is not a reentry maneuver of the vehicle with the warhead, but a controlled flight of the missile itself, which can change its trajectory several times to confuse air defenses, as is the case with the Iskander-M or Kinzhal ballistic missiles. Boost-glide systems (HGVs) represent hypersonic glide vehicles which are delivered to or slightly above the upper atmosphere by carrier rockets traveling at high speeds of about 7000 m/s. At altitudes above 80 km, speeds in excess of Mach 25 are achieved. After separation from the platform, the warhead enters the atmosphere and moves independently at high speed, gradually slowing down. It is essentially a new type of precision-guided weapon with special features, both in terms of the principle of motion and the trajectory of flight. These features make it a special type of offensive weapon, which was not included in the earlier provisions of international agreements. For this reason, it is not subject to the current rules of arms systems control (Arbatov et al., 2019). Hypersonic weapons are at an early stage of development, so there are a number of technical barriers to achieving design maturity. These include the need to cope with extreme temperatures and to have a guidance system that can provide sufficient accuracy under very difficult maneuvering conditions, i.e., while flying at hypersonic speeds. It is also difficult to manage thermal loads due to the fact that the temperature increases with increasing speed and density of the atmosphere. Another problem to be solved is the enormous aerodynamic force that the warhead's delivery must withstand during flight. These variables must be managed not only to maintain the structural integrity of the explosive delivery means, but also to ensure the functionality of the onboard instrumentation (Borrie et al., 2019).

The advantage of hypersonic weapons in comparison with classical subsonic missiles is the relatively short flight time and high resistance to enemy defense systems. At the same time, however, it has no other advantages compared to the latest generation of classical Cruise self-guided missiles, which perform flights at very low altitudes. In contrast, the flight of a hypersonic missile takes place at altitudes of 20 to 30 km, which theoretically increases the possibility of its detection from the ground by 10-20% compared to cruise missiles

(Speier et al., 2017). This means that the detectability, especially in the infrared range, by satellites and reconnaissance aircraft can be practically compensated by the short flight time and penetration capabilities of existing defense systems. The strategic use of hypersonic weapons is judged to be more effective compared to self-guided subsonic missiles, at least in terms of organizing and coordinating a massive, offensive strike or integrating it into a broader retaliatory strike conducted with all weapons at hand. However, a strike by itself would not be capable of leading to strategic instability, although effective tracking and interception of hypersonic missiles requires the construction and deployment of new, expensive surveillance and air defense systems. It should be noted, however, that the actual range of prototypes and procured hypersonic missiles does not exceed 1,000-1,500 km, which is still at least twice the range of modern, subsonic strategic missiles launched from aircraft or submarines. At the same time, hypersonic cruise missiles have the lowest average velocity of all prospective types of long-range hypersonic precision weapons (Arbatov et al., 2019). Boost-glide systems, on the other hand, even with conventional weaponry, can seriously disrupt strategic stability. There are several reasons for this. In addition to its global range and high airspeed of up to Mach 25, the delivery medium has a much smaller profile than a typical missile of comparable range, and much of its trajectory is outside the range of existing missile early warning systems. A launched carrier rocket can be detected by reconnaissance satellites, which are able to spot its streak, but sensors cannot obtain accurate trajectory information and track the flight of the warhead despite its brightness being comparable to thunderstorm lightning (Erwin, 2018). Missiles also cannot be tracked by ground-based radars (Acton, 2015, p. 2). Second, a missile detached from its warhead is able to maneuver during its flight to the target, both in altitude and heading. The ability to make maneuvers of up to several thousand kilometers makes it unclear to the end what the target of the flight is, especially for a single or group strike, in an area of high infrastructural density (Arbatov et al., 2019).

The development of hypersonic weapons is not without impact on other areas of national defense. The limited flight time of hypersonic missiles forces the development of space-based countermeasure systems. It also encourages the development of automated interceptor systems, which are likely to undertake future combat without human intervention. With extremely difficult problems to overcome, once a hypersonic missile is launched, the attraction of pre-emptive strikes to neutralize the remaining missiles before they are used is likely to increase. Finally, Russia's sale of hypersonic systems to states such as India, Iran, Syria, or Turkey, and perhaps even Venezuela or Cuba, cannot be ruled out, which would certainly greatly complicate the international security situation (Cummings, 2019).

One of the key factors in the development of precision-guided weapons will be their capabilities to integrate and share information between reconnaissance, command, and missile systems. The networking of offensive weapons will help close the existing time gap in the cycles of fire interactions. The capabilities to locate, identify and track targets and assess the effects of their flare will be improved, and losses from own fire will be minimized. Networking will provide real-time fire interaction capabilities and battlefield situation assessment based on the most reliable sources (Koudelka, 2005). Linking the physical and virtual worlds together will create new opportunities for the application of hypersonic weapons and increase the likelihood of success in future combat. However, as new missile systems are developed, the proper balance between technology and the ability to create effects in the battlespace must be maintained to prevent over-reliance on the virtual world. Otherwise, cross-linking may become an Achilles' heel in the development of precision-guided weapons (Koudelka, 2005).

3. Strategic implications of the use of hypersonic weapons

Hypersonic weapons, because of their attributes, pose serious threats to international security. Strategically, it can affect rapid changes in stability (Speier et al., 2017). If used in the future against states with limited nuclear response capabilities, it can be assumed with a high degree of probability that major forces will be paralyzed before they can respond in any way. Such a prospect could lead the attacked states to seek to launch their nuclear missiles at all costs, without any warning and rather do so blindly, which could lead to serious emergencies. Second, due to the great difficulty in defending against hypersonic missiles strikes, which are relatively small in scope, they can pose serious threats to force projection, even for those states that possess serious military capabilities. Therefore, hypersonic weapons have a certain value for strategic deterrence (Speier et al., 2017).

The principles of the use of hypersonic weapons in the Russian Federation have not been doctrinally unambiguously clarified (Sheremet & Voloshin, 2016). It is assumed that the capabilities of hypersonic weapons will not always be treated as strategic, but depending on how they are used, they can have strategic effects. One factor complicating its classification as a specific type of weapon is that hypersonic systems can be equipped with both conventional and nuclear warheads. Although in this respect they are no different from many other dual-use systems, such as self-guided cruise missiles or ballistic missiles, the nature of some hypersonic systems and the situations in which they may be used make it difficult to overcome this ambiguity (Woolf, 2020). Uncertainties about the strike target and ambiguities about the warhead armament complicate the correct assessment of the operational situation, especially when the attacker has not communicated his intentions. In addition, because of the limited flight time of the missile and the difficulty in identifying it, reconnaissance systems may not be able to generate reliable warning information in time. Hence, the risk of misunderstanding is very high, especially when considering that neither intercontinental ballistic missiles nor hypersonic missiles have ever been used in combat and it is unknown how both existing early warning and command systems will respond to their use (Borrie et al., 2017). Even if we assume that hypersonic warheads will be detected in time and correctly identified, it will still not be known until the last moment whether the target of the strike will be a conventional or nuclear object. Consequently, this situation could lead to an unintended nuclear escalation (Borrie et al., 2019).

The source of escalation due to uncertainty in most cases is the nuclear capability of hypersonic missiles. Hypersonic systems provide niche capabilities, and a small number of warheads may be in the future sufficient to destroy an adversary's security-critical facilities (Woolf, 2020). Again, it is important to emphasize that it is extremely difficult to eliminate ambiguity about the type of payload that hypersonic systems carry, so the likelihood of miscalculation and escalation of conflict is very high. Even if a particular state knew that a missile fired in its direction was conventionally armed, it might still consider it a strategic weapon, regardless of how it was perceived by the attacking state, and conclude that a strategic response even with nuclear weapons was perfectly reasonable. Again, the short time to make a decision and respond correctly complicates efforts to take control of the escalating conflict (Borrie et al., 2019).

Whether or not hypersonic systems are a destabilizing factor in the international security situation, their operational use in the future contributes to broader contemporary strategic trends. The relationship between the development of weapons capabilities and the ways in which they can be used raises broader concerns, particularly about the ability to defend against hypersonic missiles and provide security for space infrastructure. Nuclear-armed states also appear to be keeping a close eye on new hypersonic strike capabilities, carefully assessing the level of threat to their own nuclear retaliation capabilities. Accordingly, it is possible that doctrinal changes could be made that would expand the range of conditions deemed necessary for nuclear weapons to be deployed. Also, attempts by some states to raise the combat readiness of their nuclear forces in response to a potential adversary acquiring new hypersonic systems cannot be ruled out. Such actions certainly lead to destabilization of the security situation and foster unnecessary international tension (Borrie et al., 2019).

Looking at the issue of the use of hypersonic weapons in a broader sense, one may conclude that their ability to relatively easily defeat air and missile defenses and the relatively short time to react and make the right strategic decision may have a particularly negative impact on the security in regions where the international situation is tense, for example between Iran and Israel or North Korea and Japan. Regional conflicts may evolve to involve superpowers supporting states on opposing sides, which may lead to even greater escalation and negatively affect the stability of international security (Speier et al., 2017). In such a situation, the primary role of external actors would not necessarily change. There would certainly be an equalization of power, but external powers could suddenly find themselves in a state of direct confrontation. Patronage states, on the other hand, would be satisfied with the resulting so-called "leverage" effect. In addition, smaller states threatening hypersonic strikes could gain influence over the world powers, especially if they had the assurance of armed intervention by their supporters. It should also be noted that the destructive effects of hypersonic weapons could lead to a lowering of the threshold for initiating conventional military activities. On the other hand, the powerful destructive capabilities of hypersonic weapons can have strategic effects and make the acquisition of hypersonic technology a desirable political goal for many states (Speier et al., 2017).

The Russian Federation may use precision-guided weapons, which include hypersonic missiles, in local, regional, and global conflicts in both offensive and defensive actions. Since 2012, however, it is believed that precision weapons will become a means to achieve decisive victories in conflicts, especially those of a global nature. Marshal N. Ogarkov predicted that precision-guided weapons would improve the destructive capabilities of conventional weapons by at least an order of magnitude, but by no means did he predict that they would become crucial in achieving victories. In the last decade, there has been a tendency to make Russian precision weapons strategic (Gormley, 2016, p. 6), especially since the acquisition of hypersonic capabilities, on the grounds that they can prevent an adversary from using nuclear or satellite weapons, as well as neutralize so-called anti-access capabilities (Acton, 2013). However, it seems that the emergence of new hypersonic weapons primarily means a change in the whole approach to military force as a foreign policy instrument. According to Alexei Ivanovich Podberezkin, the military-technical revolution, consisting in the creation of new types of precision weapons, has not only caused major changes in the balance of military and political power in the world, but also contributed to radical changes in the art of war. By this, the armed forces become useful again, both in small and large conflicts (Podbieriezkin, 2013). The author predicted that due to the availability of precision-guided weapons, the use of armed forces to conduct international competition will become common again and its importance will increase, due to the high effectiveness of hypersonic weapons in conducting regional and local conflicts (Podbieriezkin, 2013). Unfortunately, such a view contradicts the opinions of most Russian experts who believe that the role of armed struggle in achieving political goals is limited. Others believe that in seeking to impose one's will on the opponent, with the use of hypersonic weapons, it is easier to execute strikes against key civilian and military targets deployed throughout the opponent's territory. Since conquering territory and maintaining it is now becoming increasingly difficult, it is anticipated that future wars using hypersonic weapons will focus on forcing a specific adversary's behavior, with political objectives being more limited in nature. If the attacker chooses not to use ground troops and the armed struggle is limited to air strikes, then certainly by eliminating all important facilities, conditions will be created to end the conflict. However, the political objectives will, after all, inherently have to be limited (Mahnken, 2013).

There are two key dilemmas in conducting a hypersonic weapons campaign. First, whether the priorities of fire shock should be directed at military or civilian targets, and whether these should be stationary or perhaps mobile targets Vladimir Slipchenko believed that the main priority in future war would be stationary civilian targets, as they could have an even greater impact on the political will of the opponent than military targets (Slipchenko, 2002). In contrast, Sergei Chekinov and Sergei Bogdanov (2013) emphasized that this can be done selectively against both civilian and military infrastructure. However, mobile targets present a much more difficult challenge than stationary targets. Effectively destroying them requires the networking of both the means of warfare and the elements protecting them (Watts, 2013). However, it seems that a completely different criterion should be followed, namely the criterion of the effects achieved. It is particularly concerned with causing negative cascading effects throughout the defense system of the attacked state. The final criterion for the use of hypersonic weapons against specific objects should be to estimate the impact of their destruction on the possibility of escalating effects, thus creating a specific level of psychological coercion that will convince the enemy of the futility of undertaking further resistance. Of course, targets of strikes can and likely will include those facilities that have both a deterrent effect and practical military value (Burienok, 2013). This means that there is a group of objects that have dual importance. The objects of strategic importance are considered to be those, the destruction of which leads to significant material losses in the economy of the state. They can be, for example, objects of key importance for military production, or those in which hazardous substances are located, and nuclear or hydroelectric power plants. Strikes against them are carried out in order to intimidate and cause fear in a potential adversary and to convince it of the high costs involved in continuing a confrontation with the Russian Federation (Burienok, 2013).

4. Conclusion

As a result of the research, it has been determined that hypersonic missiles are capable of moving at tremendous speeds and maneuvering altitude, reaching a ceiling much lower than classical missiles and making them virtually undetectable to radar. Currently, no country in the world has an effective protection system against a hypersonic missiles attack, which sounds alarming considering that hypersonic weapons will be able to attack any point on the Earth's surface in less than 60 minutes. The attributes possessed by hypersonic weapons render nuclear weapons resources useless, as they can be destroyed at any time. Moreover, due to its high speed and maneuverability, it is impossible to predict the direction of the missile's flight. Admittedly, the closer to the target of the attack, the predictability of the flight path increases, but also the time to react significantly decreases, which makes it practically impossible to take effective preventive action in time.

The Russian Federation has long believed that precision-guided weapons are an indispensable element of modern international competition and warfare, which is why, after the illegal annexation of Crimea, acquiring them to the fullest extent possible was considered the main priority of Russian military modernization. At present, it is the subject of constant experimentation and discussion in Russian political and military circles regarding its role and significance in achieving the goals of international competition. According to military theorists, its integration with other types of weapons and the activities of special forces, , can bring the greatest benefits, in line with the needs of the operational environment.

Based on an assessment of doctrinal documents (Military, 2014; National, 2015), it can be concluded that large-scale strikes with precision weapons can be executed against a variety of infrastructure facilities already in the initial phase of a conflict, especially those whose destruction will create strategic effects. These may include, for example, oil refineries, nuclear power plants, fuel and toxic material storage facilities (e.g., chlorine and ammonia), and many other critical state infrastructure facilities. In addition, hypersonic weapon strikes can be conducted to deny access to an area of strategic importance and to force the opposing party to behave as expected by the affecting party. It should also not be forgotten that precision-guided weapon systems can be armed with nuclear warheads, which have specific security implications for both militaries and civilians. It should also be noted that modern strategic ballistic missiles are as unstoppable and powerful as hypersonic weapons, but they are already deployed in great numbers. Surely, for some missions, the *Avangard*-like missiles would be better than conventional intercontinental ballistic missiles. But in most cases, like massive countervalue or counterforce strikes, the already existing missiles would serve as effectively as hypersonic. The same goes for non-strategic use of hypersonic weapons. Moreover, the blurring of the boundaries between conventional and nuclear weapons will foster the creation of favorable conditions for the Russian Federation to achieve the goals of international competition. In a situation of rapid technological change seriously affecting the new capabilities of offensive weapons, which undoubtedly include hypersonic weapons, questions arise about the future of strategic stability between the world's major nuclear powers.

Based on the research, it can be concluded that hypersonic weapons, when applied in the future on a large scale, could lead to a revolution in the conduct of international competition and armed struggle in the future. The mass production and widespread use of modern and reliable designs of precision-guided weapons means that these weapons no longer represent a niche capability directed against a limited number of highly profitable targets. In the Russian Federation, hypersonic weapons are treated on a par with nuclear weapons. It is believed that due to its attributes it is an excellent tool for applying pressure and aggression. It is estimated that hypersonic weapons will allow international rivalry to take place in a gray area and achieve foreign policy objectives without the need for direct military confrontation. The capabilities of hypersonic weapons to have near-instantaneous operational and strategic effects may realize concerns about the stability of the international security environment. Modern hypersonic weapons can create crisis situations, accelerate the dynamics of conflict escalation, and rapidly transition from a state of stability to international instability.

The high effectiveness of precision-guided weapons makes it necessary to make doctrinal changes and to adjust the strategy of their use in the future. It may also be a key element in determining whether the Russian Federation will achieve global dominance in the third decade of the 21st century.\

Acknowledgments
This study was supported by the Jan Kochanowski University in Kielce (Minigrant No. 542/2020).

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

References

1. Acton, J.M. (2013). *Silver Bullet? Asking The Right Questions About Conventional Prompt Global Strike*. Carnegie Endowment for International Peace. https://carnegieendowment.org/files/cpgs.pdf
2. Acton, J.M. (2015). Supplement to Hypersonic Boost-Glide Weapons, *Science & Global Security, Volume 23* (Issue 3), 1-23. https://doi.org/10.1080/08929882.2015.1087242
3. Arbatov, A., Oznobishchev, S., & Bubnova, N. (Ed.). (2019). *Russia: Arms Control. Disarmament and International Security*. Primakov national research institute of world economy and international relations Russian academy of sciences. https://doi.org/10.20542/978-5-9535-0558-1
4. *Avangard system is tested, said to be fully ready for deployment*. (2018). http://russianforces.org/blog/2018/12/avangard_system_is_tested_said.shtml
5. Borrie, J., Caughley, T., & Wan, W.F. (2017). *Understanding Nuclear Weapon Risks*. The United Nations Institute for Disarmament Research. https://www.unidir.org/files/publications/pdfs/understanding-nuclear-weapon-risks-en-676.pdf
6. Borrie, J., Dowler, A., & Podvig, P. (2019). *A Challenge and Opportunity for Strategic Arms Control*. United Nations Office for Disarmament Affairs & United Nations Institute for Disarmament Research. https://www.unidir.org/sites/default/files/publication/pdfs/hypersonic-weapons-a-challenge-and-opportunity-for-strategic-arms-control-en-744.pdf
7. Burienok, W. (2008). *Wojennaja biezopasnost´ Rossii - problemy i rieszenija*. Vozdushno-kosmicheskaya oborona. http://www.vko.ru/strategiya/voennaya-bezopasnost-rossii-problemy-i-resheniya
8. Chawryło, K., Wiśniewska, I., Rodkiewicz, W., & Menkiszak M. (2018). *Orędzie Putina: obietnice dla Rosjan, szantaż wobec Zachodu*, Ośrodek Studiów Wschodnich. https://www.osw.waw.pl/pl/publikacje/analizy/2018-03-01/oredzie-putina-obietnice-dla-rosjan-szantaz-wobec-zachodu
9. Chekinov, S.G., Bogdanov, S.A. (2013). The Nature and Content of a New-Generation War*, Military Thought, Nr. 4, 12-23*. http://www.eastviewpress.com/Files/MT_FROM%20THE%20CURRENT%20ISSUE_No.4_2013.pdf
10. Cummings, A. (2019). *Hypersonic Weapons: Tactical Uses and Strategic Goals*, War on The Rocks. https://warontherocks.com/2019/11/hypersonic-weapons-tactical-uses-and-strategic-goals/
11. Erwin, S. (2018). *U.S. would need a mega-constellation to counter China's hypersonic weapons*, Spacenews. https://spacenews.com/u-s-would-need-a-mega-constellation-to-counter-chinas-hypersonic-weapons/
12. Georgiou, A. (2018). *Russia Successfully Tests Weapon That Travels 27 Times Speed of Sound and Renders Missile Defense Systems 'Useless'—Officials*, Newsweek 27.03.2018. https://www.newsweek.com/russian-new-weapon-mach-27-avangard-hypersonic-glide-vehicle-intercontinental-1273729?utm_source=Twitter&utm_campaign=NewsweekTwitter&utm_medium=Soci
13. Gormley, D.M. (2016). The Offense/Defense Problem: How Missile Defense and Conventional Precision-Guided Weapons Can Complicate Further Deep Cuts in Nuclear Weapons, *eep Cuts Working Paper No. 6, May 2016*. Institut für Friedensforschung

und Sicherheitspolitikan der Universität Hamburg (IFSH). https://deepcuts.org/images/PDF/DeepCuts_WP6_Gormley_UK.pdf
14. Heinrich, R. & Weiland, C. (2009). Selected Aerothermodynamic Design Problems of Hypersonic Flight Vehicles, Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-540-89974-7
15. *Homeland Missile Defense System Successfully Intercepts ICBM Target*. (2017). Missile Defense Agency. https://www.mda.mil/news/17news0003.html
16. *Homeland Missile Defense System Successfully Intercepts ICBM Target* (2019). Missile Defense Agency. https://www.mda.mil/news/19news0003.html
17. Koudelka, B.F. (2005). *Network-enabled Precision Guided Munitions*. Air University, Air War College, Center for Strategy and Technology, Maxwell. https://apps.dtic.mil/dtic/tr/fulltext/u2/a463458.pdf
18. Kristensen, H.M. & Korda, M. (2021). Russian Nuclear Weapons 2021. *Bulletin of the Atomic Scientists, 2021, vol 77, no. 2, pp. 90-108*. https://doi.org/10.1080/00963402.2021.1885869
19. Kucharczyk, M. (2020). *Broń hipersoniczna to hit minionego roku. Czy jest rewolucją, jak by tego chcieli Rosjanie?* Gazeta.pl. https://wiadomosci.gazeta.pl/wiadomosci/7,114881,25556406,taka-ciekawostka-bron-hipersoniczna-to-hit-minionego-roku.html
20. Mahnken, T.G. (2013). *The Growth and Spread of the Precision-Strike Regime*. https://doi.org/10.1093/acprof:osobl/9780199895946.003.0004
21. Miasnikov, E. (2009). *Long-Range Precision-Guided Conventional Weapons: Implications For Strategic Balance, Arms Control And Non-Proliferation*. https://www.armscontrol.ru/pubs/en/em090918.pdf
22. *Military Doctrine of the Russian Federation* (2014). *Rossiyskaya Gazeta-Federal Edition № 298(6570)*. https://rg.ru/2014/12/30/doktrina-dok.html
23. *National Security Strategy of the Russian Federation* (2015). https://rg.ru/2015/12/31/nac-bezopasnost-site-dok.html
24. Podbieriezkin, A.I. (2013). *Jewrazijskaja WKO: rol stratiegiczeskich niejadiernych wooružen̆ij*. Wozduszno-kosmiczeskaja oborona, 29-37. https://mgimo.ru/files/236035/podberezkin_avia.pdf
25. *Russia showed the US a hypersonic nuclear missile called Avangard*. (2019). Geekweek.pl. https://www.geekweek.pl/news/2019-11-27/rosja-pokazala-usa-hipersoniczny-pocisk-jadrowy-o-nazwie-avangard/
26. Sheremet, I.B. & Voloshin R.V. (2016). A new look at parrying threats to Russia's national security. In applying the enemy precision weapons in conditions of combat operations on the basis of a single global information and communication space. Science. Society. Defence (noo-journal.ru). - 2016. – No 3(8). https://doi.org/10.24411/2311-1763-2016-00020
27. Slipczenko, W. (2002). *Wojny szestogo pokolenija. Orużyje i wojennoje iskusstwo buduszczego*. https://velesova-sloboda.info/archiv/pdf/slipchenko-vojny-shestogo-pokoleniya.pdf
28. Speier, R.H., Nacouzi, G., Lee, C.A., & Moore, R.M. (2017). *Hypersonic Missile Nonproliferation. Hindering the Spread of a New Class of Weapons*. Rand Corporation. https://www.rand.org/content/dam/rand/pubs/research_reports/RR2100/RR2137/RAND_RR2137.pdf

29. Troianovski, A., & Sonne, P. (2018). *Russia is poised to add a new hypersonic nuclear-capable glider to its arsenal*, The Washington Post. https://www.washingtonpost.com/world/europe/russia-is-poised-to-add-a-new-hypersonic-nuclear-warhead-to-its-arsenal/2018/12/26/e9b89374-0934-11e9-8942-0ef442e59094_story.html
30. Watts, B.D. (2013). *Precision Strike: An Evolution. The world once thought guided munitions were the future of warfare. The truth has been more complicated*, The National Interest. https://nationalinterest.org/commentary/precision-strike-evolution-9347
31. Weitz, R. (2020). *Managing Multi-domain and Hypersonic Threats to NATO*, ICDS w Estonii. https://icds.ee/en/managing-multi-domain-and-hypersonic-threats-to-nato/
32. Woolf, A.F. (2020). *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, Congressional Research Service. https://fas.org/sgp/crs/nuke/R41464.pdf

SAFETY & DEFENSE
ISSN 2450-551X

Warfare Use of Unmanned Aerial Vehicles

Janusz KARPOWICZ

Military University of Aviation, Dęblin, Poland;
j.karpowicz@law.mil.pl, ORCID 0000-0002-5002-9384

DOI: https://doi.org/10.37105/sd.135

Abstract

This article contains a summary of the research conducted in the Military University of Aviation concerning the problems of warfare use of unmanned aerial vehicles. It indicates the operational needs of the air force at the modern and future battlefield and the resulting requirements for unmanned aerial vehicles. The present paper outlines the areas of the potential applications and types of unmanned platforms useful for these tasks. It presents the technical and operational requirements and indicates the directions of future research necessary to expand the combat capabilities of these machines. It defines the potential groups of combat and support tasks that may be performed by unmanned aerial vehicles in the future. Conceptual solutions for the use of unmanned platforms at the battlefield and the problems of introducing new means of destruction and extending the autonomy and viability of the platforms are also presented in the present article.

Keywords

battlefield of the future, combat tasks, defense, surveillance and reconnaissance, unmanned aerial vehicles

Submitted: 24.06.2021 Accepted09.08.2021 Published: 20.10.2021

1. Introduction

The air force has entered an era in which unmanned aerial vehicles (UAVs) have become not only acceptable but even essential. An example of this reality the case of long-duration observation and reconnaissance operations.[1] When addressing the issue of the use of UAVs in combat operations, the assumption was made to define the needs of the air force, define the technical requirements, develop the principles and concepts of operational tactics during the war and the integration of UAVs in the civil and military environment, i.e. in the common airspace. The first stage of research concerned the theoretical basis of the use of UAVs in combat operations. The research covered five areas:
1) platforms (airframe, propulsion and flight control systems);
2) on-board mission equipment and systems (sensors, data processing and communication);
3) on-board weapons (kinetic and non-lethal weapons and attack systems);
4) mission control systems – human factor (ground/air control, human-machine interfaces and training);
5) operational problems (BM/C4I – Battle Management/Command, Control, Communication, Computers And Intelligence, integration of forces, roles and missions, and new concepts).

In the second stage, on the basis of the accepted theoretical considerations regarding strike aviation support, an attempt was made to define the concept of using UAVs for the suppression of enemy air defenses (SEAD).

The research covered selected battlefield support tasks:
– patrolling and observing areas, gathering intelligence;
– reconnaissance (radar, optical, electro-optical);
– recognition and indication of attack targets (laser beam illumination of targets);
– electronic warfare (including interfering emissions, suppression of the elements of the army command);
– support for search and rescue operations (SAR, CSAR);
– confusing the reconnaissance system and the air defense system, covering the manned aviation missions (UAV as decoys).[2]

The research tasks included the potential combat tasks and those already being carried out with the use of armed UAVs:
– air supremacy combat tasks with the use of air-to-air weapons;

---

[1] In the research, the term "unmanned aerial vehicle" (UAV) was used. It is a vehicle designed specifically to operate without an operator on board or an aircraft intended to be manned, converted to perform unmanned operations, capable of performing tasks of observation, reconnaissance and attacking or other support tasks in the air (for example, disturbing or jamming the transmissions of the opponent).

[2] Supporting the implementation of tasks in the theater of combat operations includes:
– Intelligence Preparation of the Battlefield (IPB),
– Situation Development,
– Battle Management (BM),
– Battle Damage Assessment (BDA) and
– Rear Area Security (RAS).

Based on: (Wezeman 2007)

– combat tasks related to hitting surface targets with and without the use of kinetic weapons.

The first three tasks are part of the aviation activities defined in NATO as intelligence, observation, targeting, ISTAR (Intelligence, Surveillance, Target Acquisition and Reconnaissance). The research was based on methods of problem and comparative analysis: technical descriptions of equipment and weapons, as well as documents and reports from combat operations. In relation to combat operations and future concepts of warfare, the method of case study and prognosis was used.

2. UAV classification adopted in the research program

From the point of view of the air force, information security and other types of support for aviation operations must cover the area of tactical operations, i.e. 30-50 km from the military demarcation line. Within this space, the tasks of direct support of fighting troops (CAS - Close Air Support) are carried out, and the depth of the enemy territory, where aviation conducts isolation of the combat operations area (AI- Air Interdiction) up to the depth of 500-800 km. For these reasons, there is interest in using UAVs whose technical characteristics allow them to be operated in such a defined space. In the first case, it concerns UAVs classified as tactical of short and medium-range, and in the second, MALE and HALE UAVs forming groups of operational and strategic UAVs. The criteria for classification and characteristics of the exemplary structures adopted in the tests are presented below.

1. Tactical UAVs – short range/low altitude (50-150 km/max. 4,500 m), payload up to 100 kg. Flight duration over 1 hour.
2. Tactical UAVs – medium range/medium altitude (200 km/6,000 m), payload up to 150 kg. Flight duration up to six hours (this group includes the tactical UAV PGZ-19R Orlik).
3. Operational UAV MALE (Medium Altitude, Long Endurance) type – long range, medium altitude (200 km/10,000 m), payload up to 300 kg, flight duration more than six hours, (the research included the MQ-9 Reaper and RQ-170 Sentinel UAVs) (Abraszek, 2009, pp. 60-64).
4. Strategic UAV of the HALE (High Altitude, Long endurance) type – long range and high altitude (range over 1,000 km/altitude over 10,000 m), payload over 300 kg (Wezeman, 2007, p. 16). Flight duration over six hours (Predator C Avanger and RQ-4 Global Hawk UAVs were selected for the tests) (Joint Doctrine Publication 0-30.2. 2017).

The research, conducted mainly by the method of case studies of military operations in two decades of the 21st century, focused on the use of UAVs for the following tasks:

– detection of weapons of mass destruction, mobile tactical and operational ballistic missile launchers, other important mobile military targets and directing manned aviation to these targets;
– observation and recognition of aircraft detection and air traffic control system (radar stations, radiolocation posts) and the military communication and command system;
– destroying ground targets with the use of guided kinetic weapons;
– destroying air targets as part of the air supremacy fight;
– tactical confusion and disruption of communications, command, airspace control and navigation systems.

Within the research, descriptions and other available documents of the above-mentioned air operations were analyzed in terms of operational capabilities and the possibility of using supporting technologies (UAV). As part of the preliminary research, it was found that the leading programs with the use of unmanned platforms, in which the air force may be interested, include:

- electronic interference and aviation activities support within the integrated SEAD operations;
- detection, precise location and neutralization of radio signal transmitters emitted by the enemy at frequencies disrupting own systems;
- image detection and location as well as destroying stationary and moving targets with the use of armed reconnaissance and strike UAVs;
- suppression of enemy air defense for securing the manned aviation operations;
- communication and navigation support of aviation activities;
- deconfliction of airspace management.

The possible range of UAV applications was considered taking into account the following factors:

- the possible scenarios of wars and conflicts;
- types of operations and combat tasks of aviation and their tactical alternatives;
- the relative risk and costs of introducing new UAVs;
- UAV technology maturity and development perspectives.

Initial research allowed for the specification of the main UAV attributes in a comparative analysis with manned aircraft. They were divided into four groups. The first, related to the ability to survive in a hostile environment and significant resistance to countermeasures, results in such operational and tactical advantages as:

- ongoing supervision and information support;
- constant deterrence;
- reduction of the required number of manned units in the theater of operations;
- operating as communication relays in the command system;
- standalone and cooperative operation, including cooperation with manned platforms;
- mission cost decreased.

The lack of crew on board the UAV allows obtaining such features of the UAV and operational benefits as:

- the continuity of operations with a smaller number of platforms, elimination of the fatigue factor of the platform crew;
- the ability to operate in high risk environments (e.g. contaminated environments, air defense zones);
- the ability and profitability of using UAV in a provocative role (decoy),
- potentially simpler construction and reduced cost of purchase and operation;
- reduced need for crew training and combat protection;
- lower reliability factor and less accurate safety test required;
- potential use for a suicide mission;
- less extensive support and protection of the mission than in the case of manned aircraft.

The benefits resulting from automation and autonomy of the unmanned platform include the following:

- less complex, less costly training for operators than that of the manned aircraft pilots;
- no safety systems and tests for the crew, no protection and rescue systems required;
- simpler design of the programming and control interface for unmanned aircraft;
- reduced physical requirements for operators.

The UAV's ability to operate at high altitudes and depths favors the exposure of such operational features as:
- the ability to far-detect objects in the air and on the ground;
- wide viewing angle of Doppler and SAR radars;
- large range of data transmission from the UAV board and retranslation of external signals or emissions;
- favorable geometry for Tactical Ballistic Missiles (TBM) destruction missions (Worch, et al, 1996, pp. 3-4).

Figure 1. Remote Piloted Air System (RPAS) MQ-1 Predator, used by the American military. Predator's payload consists of for or eight Hellfire Missiles AGM-114C or AGM-176B Griffin (INS / GPS + semi-active laser guidance) with a weight of approximately 15 kg with a range of 8 to 20 km; and two Paveway II laser guided bombs GBU-39B, GBU-58 or GBU-44/B Viper Strike. Adopted from: "Amerykańskie Reapery w bazie w Mirosławcu". Radar rp.pl, by Z. Lewitowicz, Copyright 2019 by the Publisher. *https://radar.rp.pl/wojsko-polskie/13633-amerykanskie-reapery-w-bazie-w-miroslawcu*

3. Missions and operational tasks concepts

The research covered a review of the current air support tasks performed for the benefit of other types of troops, and it was determined which of them can be performed instead of or supported by unmanned aerial vehicles. The possible contribution of the currently available UAVs to the typical strike aviation tasks on the battlefield was also considered.

Three basic types of strike aviation activities were selected for the research – strategic air activities against leadership, the armed forces and the economy, and activities against land forces, including direct air support and strikes against troops and objects in the tactical zone, as well as a group of air isolation tasks and within its framework, attacks on troops and objects outside the tactical zone. The activity of strike aviation against the enemy air force was also considered. This activity includes the fight against the enemy air force on the ground by striking airplanes and air bases, as well as fighting enemy air defense system facilities by performing strikes against defense measures as well as missile and radar systems (Karpowicz, 2008, p. 248).

A number of factors were taken into account in the assessment of UAVs capabilities. They included the characteristics of the platform, the degree of vehicle/flight autonomy, management, reliability, airspace planning procedures, survival procedures, deployment (dislocation) requirements, combat capabilities (impact with kinetic and non-destructive weapons), information support, communication systems (information), survivability, command and control (C2), autonomy and the human factor.

The research covered three main types of aviation combat operations: actions against enemy land forces, actions against air force and air missions in the form of a strategic attack.

When it comes to the combat aviation needs, the following aspects were adopted as critical aviation tasks within the framework of the above-mentioned types of activities: combating weapons of mass destruction; searching and destroying ballistic missiles and self-guided missiles; destroying important permanent and mobile military targets in the tactical and operational zone; suppressing enemy air defense; intelligence, surveillance and target acquisition (ISR); electronic warfare; securing communication; positioning and indicating targets for air strikes and missile forces.

The listed key tasks of aviation find practical and technological solutions in tactics, and UAVs bring significant potential to strengthen the capabilities of the Air Force by supplementing the existing structure of forces and combat capabilities (Zieliński, 2010).

Combating weapons of mass destruction is high on the list of tasks for unmanned aviation. The ability to locate and destroy weapons of mass destruction (WMD) can determine the success of a campaign. The operational concepts include the use of UAVs for observation, recognition and tracking, as well as in the positioning of mobile means of delivery of these weapons. Basically, the task of destroying the detected targets belongs to the manned aviation, but equipping UAVs with precision weapons allows it to take over these tasks.

Modern sensors and UAVs reconnaissance capabilities predispose a group of operational unmanned reconnaissance aircraft to the tasks of determining the possession, production, storage and movement of nuclear materials, materials and devices for the production of biological and chemical weapons (NBC) by opponents. UAVs can effectively complement other forces in carrying out this difficult and complex task by taking advantage of their long-term presence in close proximity to the sought targets.

It is also possible to destroy such materials by UAVs with dual equipment (multispectral sensors and kinetic weapons) or reconnaissance UAVs in conjunction with weapon carriers. Making a decision to use precision penetrating weapons or specialized kinetic charges will require an assessment of the side effects of such an attack in terms of environmental impact (combat damage assessment).

The tasks of searching for and destroying mobile ballistic missile launchers and cruise missiles (Theater Missile Defense - TMD and Theater Ballistic Missile - TBM) is the second significant task of aviation in the struggle for supremacy on the battlefield. Considering the durability and resistance of UAVs in counteracting enemy air defense measures in the tactical zone and beyond it, such platforms are even predestined to take over this important mission from the manned aviation, especially when it is not possible to temporarily or permanently suppress the enemy's air defense. The effectiveness of the UAVs support for the manned aviation results from their ability to stay over the enemy's territory for a long period of time, penetrate both the tactical zone and the back of the fighting troops, while being resistant to the enemy's air defense system. Additionally, high-altitude armed UAVs with the characteristics of impaired detectability may supplement the shortage of manned systems counteracting ballistic and self-guided missiles.

The implementation of this task has so far been based on an independent (without external support) visual search for important targets, e.g. ballistic missile launchers by the crews of airplanes and/or helicopters in designated zones. This method is called Combat Air Patrol (CAP). Due to the high degree of risk, this method was used after gaining air supremacy. It was a particularly risky task, as the crews were exposed to attacks from the enemy's unneutralized air defense measures. The use of UAVs is not subject to the mentioned tactical limitations. This task can also be performed together with the manned aviation during other types of air operations, e.g. as part of the isolation of the battlefield.

The tasks of tracking, recognizing and fighting command centers with the use of UAVs may include both electronic disruption of the operation of military command and control systems, as well as destructive influence of armed UAVs on the sensitive elements of these systems. Experience in the field of counter-terrorism allows to assume that reconnaissance and strike UAVs can be used to identify and even physically eliminate important people from the opponent's leadership.

Generally, such tasks are to be carried out as part of an air-based strategic attack, in which aviation, acting alone, will strive to reduce the enemy's defense capabilities and their will to fight, as well as during combined air-ground (sea) operations.

As part of air operations against land forces, UAVs can be involved in supporting the manned aviation during the implementation of air isolation tasks and direct support for troops.

Combat UAVs can be used to attack fixed surface targets of high value during aviation operations as part of strategic air attack (SA), close air support (CAS) and isolation of the combat area (Air Interdiction - AI). Direct aviation support mainly covers the fight against operational reserves, but may also be used to neutralize material resources (ammunition and fuel depots) and structural resources (command and control network, communication network).

The place and tasks for UAVs will be taken into account during the planning and implementation of all forms of tactical aviation strike groups, i.e. *Force Flow* and *Force Package*, both during mass and selective strikes.[3] As part of selective strikes with the use of precision means of destruction, UAVs will be particularly able to provide information and fire support to the manned aviation.

As part of these types of operations, armed UAVs can, apart from suppressing the enemy's air defense, perform the following tasks: recognizing and marking important targets in a group of fighting troops, such as command posts, artillery, missile and armored units, and air force of the land forces. An important task for these UAVs will be to detect and mark objects in the back of the fighting troops, such as: army groups, armaments warehouses, reserves, airports and airstrips as well as air bases. The manned aviation using this information and the support of the UAVs will be able to carry out the task of supporting the troops operation effectively.

---

[3] The *Force Package* option enables the use of single, fully autonomous tactical groups, formed by strike and support aircraft, intended to combat individual objects or groups thereof in a limited area. The *Force Flow* option uses a large number of strike groups to combat a wide range of impact targets.

As part of support for strike aviation activities, UAVs will perform image reconnaissance (composition, arrangement, sensitive elements of the target), GPS positioning and other targeting data, e.g. about targets, masking, weather in the area of the strike targets, by providing information about the targets of the planned strikes,.[4] The data from the UAV, delivered in advance and updated during the mission, will eliminate the need for direct reconnaissance and will make it possible to reduce the size of the COMAO combat group. The condition is that the strike aircraft are adapted to receive various forms of information directly from the board of these planes. Unmanned aerial vehicles will also be used to control the results of the impacts. If there are no such possibilities, the reconnaissance is carried out by aircraft from the tactical group (Karpowicz, 2008, pp. 250-251).

Fighting against fixed and mobile targets by manned aviation in the tactical and operational zone with precise means of destruction, from medium and high altitudes, outside the fire zone of short-range artillery and missile air defense systems, may be supported by unmanned aerial vehicles. Attack from high altitude with guided means of destruction requires special targeting equipment and good weather conditions because the planes remain at a considerable distance from the targets, and it is difficult to detect them and identify the prescribed hit points. For these reasons, the indication of targets or the directing the guided means of destruction to targets is more and more often performed by reconnaissance unmanned aerial vehicles equipped with appropriate equipment (e.g. laser target/hit point pointer) and groups of special forces, including relevant specialists.

High-altitude and high-endurance operational and tactical UAVs in this type of operations can provide long-time observation as well as image and electronic reconnaissance of the part of the enemy territory of key importance for the manned aviation mission. Connected in a C2 network architecture, HALE reconnaissance UAVs can provide information about impact objects to the air command stations or directly on board of manned platforms during their flight to the destination. If it is not possible to suppress the enemy's air defense, the missions of searching for and destroying fixed and mobile targets on the battlefield or in the back room may be taken over by armed UAVs (Brzezina & Chojnacki, 2008).

Intelligence, Surveillance, Reconnaissance – ISR. Acquiring information about the enemy and the potential air strike targets is carried out in the air force by conducting observations and air reconnaissance. The collection of data obtained by the air force is used to determine the intentions of the potential opponents, to detect and select targets for impact, and to possibly determine the effects of actions taken by own forces (Intelligence, Survey, Target Acquisition and Reconnaissance – ISTAR Operations).

Aerial observation consists of continuous or systematic observation of a selected segment of the airspace, land or sea surface to detect changes taking place there. It is not assumed in advance what objects are to be observed. However, the location and period of time the observation should be carried out and what constitutes the object of the observation in general are determined. In the case of aerial reconnaissance, the action is aimed at detecting, locating (defining the position by measurement or other means) and determining the state or activity of a predetermined reconnaissance object.

The technical and tactical properties of the UAV perfectly meet the needs of a relatively safe stay over the enemy territory, approaching targets being objects of interest to the troops and long-term observation, and tracking and recognition of their activity. This al-

[4] Targeting is the process of selecting targets, prioritizing them, and selecting and implementing an appropriate method of impacting these targets, taking into account operational (tactical) requirements and possessed possibilities. See: *USAF Intelligence Targeting Guide*. Air Force Pamphlet 1998, access 21.04.2021 [in:] https://fas.org/irp/doddir/usaf/afpam14-210/index.html

lows for precise determination of the location of the detected objects and any changes in this range. These UAV capabilities are generally defined as: "the ability to provide the necessary and up-to-date intelligence data from anywhere in enemy territory, day or night, regardless of the weather, for military purposes".

Electronic warfare (IW/EW) is defined as military operations involving the use of electromagnetic energy, including Direct Energy (DE), to use and dominate the electromagnetic spectrum or to attack an enemy (AJP-3.3, 2016) This type of warfare includes the interception and identification of electromagnetic emissions, the use of electromagnetic energy to limit or prevent the use of the electromagnetic spectrum by the enemy, and actions ensuring the effective use of the electromagnetic spectrum by own troops (forces).

UAVs can operate at high altitudes for a long time (even 24 hours) without refueling, and thanks to their low detectability, they can avoid threats from enemy air defense systems. Due to their considerable payload, they can carry electronic support measures (ESM) and electronic counter measures (ECM) on board.

The considerable flight endurance allows for electronically covering both single impact missions and large COMAO formations over a large area. In another support concept, jet UAVs equipped with electronic warfare systems could lead a COMAO formation providing jamming of radar stations tracking and guiding systems of enemy air defense missiles and other recognized electronic means.

Jamming UAVs can also play the role of decoys in a formation, which, replicating the signature of a manned aircraft, would engage the enemy's guidance and anti-air defense systems.

Suppression or destruction of enemy air defenses (SEAD / DEAD) is any activity that neutralizes or temporarily disrupts surface anti-aircraft defense by overwhelming or destructive use of air defense measures (Joint Pub 3-01.4, 1995).

For manned aviation, overcoming air defense countermeasures during the flight over the line separating troops and combat operations zone is a complex tactical task. The flight itself has an increased degree of risk (Worch, 1996). In addition to manned aircraft with reduced detectability (stealth), UAVs can be engaged in the tasks of suppressing the enemy's anti-aircraft defense as part of comprehensive electronic fire destruction of the elements of the air defense system. In the fight against air defense, the elements of the radar reconnaissance, command and destruction subsystem may be the object of the UAV's influence. The main form of influencing these measures is fire and electronic strike. Support in this matter can be provided by UAVs equipped with electronic warfare systems and combat means of destruction. It is assumed that while performing tasks over the enemy's territory, UAVs should remain outside the firing zone of small arms and anti-aircraft artillery (Worch, 1996).

The UAVs used for SEAD tasks should be able to fly safely over areas defended by integrated ground-based air defense systems. The stealth features of the BSP platform are required in this respect. In addition, the UAV must be able to provide the operator in the control center with a real-time image of the tactical situation, collected by the observation radar and optical recognition system (TV, Video), which is necessary to make an attack decision. The UAV armament must be capable of self-guiding to the source of electromagnetic emission of the missile guidance station or at the indicated hit point of the recognized target. It should have a range of min. 5 NM, as it is assumed that this distance allows for the recognition of most small-sized mobile targets with weak unmasking characteristics (Joint Pub 3-01.4, 1995).

UAVs can detect the enemy's electronic air defense system's emission means and transmit the emission characteristics and precise location data to the SEAD aviation command posts. This will allow stealth strike aircraft equipped with SEAD/DEAD weapons to plan and safely execute their attacks (Worch, 1997). Many circumstances indicate that in the near future, these tasks will be fully taken over by unmanned platforms (North, 1997).

Securing retranslation in command and reconnaissance networks

An unmanned platform can be used to carry out multi-range unmanned communication relays securing the connection and data transmission between the ground command posts of the troops fighting and moving over a large area.

The value of such support is manifested in most offensive phases of operations when the tactical communication network is limited in keeping up with fast moving forces, not only in physical speed but in power, frequency, throughput, available channels and avoiding enemy interference. Separated and widely dispersed land forces are often out of sight and thus also out of the reach of VHF communication. Thanks to UAV retranslation, they would receive effective support.

Communicating reconnaissance information over appropriate networks, including fighting troops, also often requires amplifying or re-translating emissions.

Air supremacy combat in the form of Offensive Counter Air/Deffensive Counter Air combat is defined as an air activity directed against offensive and defensive means of the enemy air force in order to obtain and maintain the desired degree of air supremacy. The combat can be offensive or defensive.

Offensive actions include: countering enemy aviation at airports and in the air; destroying elements of the enemy's air defense system; destroying elements of the aviation command system and anti-aircraft defense; and fighting down elements of the enemy's air force support subsystem (infrastructure and resources). Offensive actions rest with strike aviation, which is assigned the task of destroying the enemy's air force on the ground and bases located on its territory. Defensive actions are the responsibility of air defense ground system and fighter aviation.

BSP can be engaged in defensive and offensive air supremacy combat. It is envisaged that unmanned aerial vehicles armed with air-to-air missile weapons will be used to fight the enemy aviation at forward borders, even over enemy territory. Armed UAVs that remain beyond the capabilities of radar detection can create advanced ambushes and surprise attacks on single planes and combat formations with air-to-air weapons. It is also planned to use fighter UAVs for offensive air combat, basing the success in combat on maneuverability significantly exceeding the parameters of manned aircraft, extended autonomy and self-guiding short-range weapons.

Unmanned aerial vehicles will also fulfill the functions of manned aviation support in these activities by direct recognition of attack targets and indicating targets for precision ammunition strikes, incapacitating or destroying air defense means of the impact targets and re-translating communication in aviation command networks.

4. Factors for assessing the capabilities of the UAV combat applications available to the air force

Several of the characteristics of UAVs deserve special attention: operational height, combat readiness and continuity of operations, technical reliability and durability, operational compatibility.

The above-mentioned tactical and technical properties of UAVs, which are desired for future applications, generate new technological challenges for UAV platforms. Research has shown that the following areas can be included:

a) enhancing the stealth properties of the airframe and on-board (outboard) weapons;
b) image recognition and data collection and processing;
c) the technology of adaptive-autonomous control systems;
d) the development of propulsion system technology in order to reduce fuel consumption and increase flight endurance, reduce unmasking thermal and acoustic emissions (noise reduction) and electromagnetic emissions;
e) new types of weapons dedicated to UAV – low weight and dimensions, self-guiding (fire and forget) and guided (laser beam, TV, IR), modular control and shock heads (kinetic, electromagnetic).

The general direction of technological changes of on-board systems is to maintain the current level of efficiency, while radically reducing the size, mass (weight), energy consumption affecting flight endurance and costs (construction, maintenance, operation, purchase).

5. New weapon systems dedicated to the UAVs

With regard to operational needs, phased development works on new missiles with modular warheads were initiated, allowing for the future fulfillment of the spectrum of UAV and manned aircraft combat missions. The key is a number of innovative, modular warhead technologies ensuring the achievement of extensive capabilities in the field of targeting and kinetic impact in small-size and low-mass UAV-compatible weapons.

The family of weapons developed for the UAV is adapted to the new potential combat tasks envisaged in the operational concepts.

1. Rocket weapons required to intercept a ballistic missile during the launch (climb) phase (Boost Phase Intercept – BPI). A hyper-fast projectile with a kinetic charge and an infrared warhead.
2. Penetrating missile with a modular warhead (kinetic for destroying permanent targets and SEAD tasks; penetrating (flechette) for striking reinforced targets; microwave HPM capable of disrupting and destroying electronics and radio devices).
3. Low-cost, small-size subsonic cruise missile, guided by GPS/INS, with modular warheads, for various UAV missions, as part of the Low Cost Autonomous Attack System (LO-CAAS) capable of autonomous search, classification and destruction of the target.
4. Low-mass tactical missiles armed with High Power Microwaves (HPM) warheads.

Air-to-air missile. The current concepts of UAV combat applications provide for their use in actions against the enemy air force, as part of offensive and defensive air supremacy combat. Air-to-air UAV functions are currently limited by the level of autonomy and the payload size and weight of the available air-to-air missiles, as well as the detection range of UAV sensors (radar). Therefore, the Sidewinder (AIM-9) and AMRAAM (AIM-120) missile families are expected to be suitable weapons for short and medium range applications.

Figure 2. MQ-9 armed with the AIM-9X Block 2 missile. Adopted from: “MQ-9 Reaper new weapons test”, US Air Force, by A.H. Stevens, Copyright 2021 by the Publisher https://www.konflikty.pl/wp-content/uploads/2021/02/200903-F-UA265-1057.jpg

Implemented precision-guided munitions programs (PGMs) Air-Launched: Paveway Laser Guided Bomb, Joint Direct Attack Munition (JDAM), Small Diameter Bomb, Small Diameter Bomb II, Hellfire Missile, Joint Air-to-Ground Missile, Joint Air-to-Surface Strike Missile (JASSM), Long Range Anti-Ship Missile (LRASM), and Advanced Anti-Radiation Guided Missile (Precision-Guided Munitions .., 2021).

Small-sized ammunition adapted to unmanned platforms:

a) guided missiles: AGM-176 Griffin (Raytheon) JAGM (Joint Air to Ground Missile) (Lockheed Martin) – platforms: MQ-1 Predator, MQ-8B Fire Scout, MQ-9 Reaper;

b) small-size guided bombs: Hatchet (ATK); ADM (Air-Dropped Guided Mortar) (General Dynamics); SABER (Small Air Bomb Extended Range) (MBDA); (GBU-44/B) Viper Strike (MBDA); platforms: MQ-5B Hunter, RQ-7 Shadow, MQ-1 Predator, MQ-9 Reaper (Glajzer, 2016).

6. Limitations of extending the autonomy of UAVs

Airborne Lethal Autonomous Weapon (ALAW), or Autonomous Air Weapons System (AAWS), is a type of unmanned air-to-air combat system that can independently search for targets and attack them based on programmed characteristics and constraints.

Currently, the autonomy of such systems is limited in the sense that a human gives the final command to attack – although there are exceptions for some "defense" systems.

It is controversial to delegate more military tasks and potentially some key decisions to computers and algorithms installed in weapons capable of violent action against humans. The most ethically contested capabilities of the new autonomous systems lie deep in the software code. The autonomy of the system means that it can make some decisions by itself. Theoretically, advanced software could allow the new UAV to decide on its own whether to attack an enemy plane, destroy the enemy's missile launchers or radar, or bomb a convoy of vehicles or a factory. Due to legal and ethical issues, it is likely that no autonomous system will ever be left to make such decisions. Any future autonomous air systems will be under the control and command of highly qualified ground or air operators, who will also be able not only to remotely pilot the unmanned aerial vehicle, but also to decide about its combat functions.

7. Final conclusions

In the very near future, unmanned aerial vehicles will not only be able to collect data on the target's location but also – due to the increasing autonomy granted to them – use weapons to destroy them.

Fighting tasks with the use of air-to-air weapons are being intensively developed among the UAV combat applications. In the superiority and supremacy combat, UAVs can be engaged in defensive operations, providing information support (detection of air targets) to the anti-aircraft defense system and fighter aviation, and for offensive operations independently in the form of an air ambush or in joint formations with fighter aviation (increasing range of detection and destruction of fighter aviation).

Concepts of using UAVs as a swarm of subordinate wingmen, guided from a manned platform, occupying positions on extended borders, in order to detect and attack an air enemy early, well beyond the detection range of ground-based radars, are being tested. The idea is to allow a single pilot-operator to run several semi-autonomous, artificial intelligence, and unmanned aerial vehicles from their own cockpit. In this way, the role of a human would change from a fighter pilot-operator to a system mission commander.

The concepts of using UAVs for strike tasks with the use of precision ammunition, in operations over the enemy territory, in high-risk areas, in the form of air patrols, operating autonomously in designated areas (kill boxes), independently searching for and fighting against the ordered, saved in the memory of the on-board computer and detected targets.

It is necessary to envisage extending the combat tasks of the UAV after completing work on the new types of weapons and ammunition dedicated to the UAV.

Declaration of interest - The author declares that he has no known competing financial interests or personal relationships that could have appear ed to influ16 ence the work reported in this article

References:

1. Abraszek, P. (2009). MQ-9 Reaper - półtora roku operacji bojowych, *Nowa Technika Wojskowa*, 5, pp. 60-64.
2. AJP-3.3. (2016). *Joint Air And Space Operations Doctrine*. Edition B Version. Published by the NATO Standardization Office (NSO), Brussels.
3. Brzezina, J. Chojnacki, Z. (2008). Bezzałogowe statki powietrzne w ostatnich konfliktach, *Przegląd Sił Powietrznych*, 9.
4. Brungess, J.R. (1994). *Setting the Context. Suppression of Enemy Air Defenses and Joint War Fighting in an Uncertain World*, AU Press, AFB.

5. Eggleston, R.G. (1998). *Machine intelligence and crew-vehicle interfaces*. [in:] Heer, E. Lum, H. (Eds.), *Machine Intelligence and Autonomy for Aerospace Systems*. American Institute of Aeronautics and Astronautics, Washington, DC.
6. Flach, J.M. (1998). *SEAD and the UCAV: A Preliminary Cognitive Systems Analysis*, United States Air Force Research Laboratory, Wright-Patterson AFB.
7. Glajzer, M. (2016). Uzbroić BSP - lotnicza amunicja małogabarytowa dla bezzałogowych statków powietrznych. *Nowa Technika Wojskowa*, 7, pp. 88-93.
8. Joint Pub 3-01.4. (1995). *JTTP for Joint Suppression of Enemy Defenses (J-SEAD),* Joint Chiefs of Staff, Air Force Publications Distribution Center, Baltimore.
9. Joint Doctrine Publication 0-30.2. (2017). *Unmanned Aircraft Systems*. Development, Concepts and Doctrine Centre, Wiltshire.
10. Karpowicz, J. (2008). *Podstawy taktyki lotnictwa SP*, Wydawnictwo WSOSP, Dęblin, pp. 248-251.
11. North, D.W. (1997). U.S. Military weighs future of SEAD. *Aviation Week & Space Technology*. June 16, pp. 151-154.
12. *Precision-Guided Munitions: Background and Issues for Congress*. Congressional Research Service. June 11, 2021. https://fas.org/sgp/crs/weapons/R45996.pdf
13. Precyzyjna i małogabarytowa amunicja powietrze-ziemia. *Przyszłość, Uzbrojenie i Wyposażenie*, 04/06/2011. https://eshelon.wordpress.com/2011/06/04/precyzyjna-i-malogabarytowa-amunicja-powietrze-ziemia/
14. Rasmussen, J. Vicente, K.J. (1989). Coping with human errors through system design: Implications for ecological interface design. *International Journal of Man-Machine Studies,* 31.
15. *USAF Intelligence Targeting Guide*. Air Force Pamphlet 1998, access 21.04.2021 [in:] https://fas.org/irp/doddir/usaf/afpam14-210/index.html
16. Wezeman, S. (2007). *UAVS and UCAVS: Developments in the European Union*. Policy Department External Policies, Security and Defence, Brussels, p. 16.
17. Worch, P. Borky, J. Gabriel, R. Heiser, W. Swalm, T. Wong, T. (1996). *UAV Technologies and Combat Operations,* tom 1, Department of the Air Force, US Air Force Scientific Advisory Board, Washington, DC, pp. 3-4.
18. Worch, P. (1997). *SEAD mission profile*. *Presentation at Workshop on Human Machine Issues in UAVs*. George Mason University, Fairfax, VA.
19. Zieliński, T. (2010). *Operacyjne i taktyczne możliwości zastosowania bezzałogowych systemów powietrznych w operacjach ekspedycyjnych*, Akademia Obrony Narodowej, Warszawa.

SAFETY & DEFENSE
ISSN 2450-551X

Suborbital Rockets in Safety & Defense Applications

Tomasz NOGA

Łukasiewicz Research Network – Institute of Aviation, Warsaw, Poland;
tomasz.noga@ilot.lukasiewicz.gov.pl, ORCID: 0000-0002-4093-6749

DOI: https://doi.org/10.37105/sd.146

Abstract

This paper presents benefits from using suborbital rockets in safety & defense applications. The paper describes suborbital rockets and their contribution to modern science, research and technology development. A historical view of suborbital rockets and their applications in safety & defense roles is discussed. Chosen research & development activities, military exercises and air defense systems' tests performed using suborbital rockets in various countries are listed and described based on a literature review of publicly available sources. The paper presents capabilities of Łukasiewicz Research Network – Institute of Aviation in the field of suborbital rockets. A development of ILR-33 AMBER 2K rocket reaching flight speeds over Mach 4 and optimized to reach 100 km altitude is described with comment regarding its applicability in safety & defense applications supported by flight simulations.

Keywords

rocket, safety & defense systems validation, sounding rocket, suborbital launch vehicles

Submitted: 20.07.2021 Accepted: 16.08.2021 Published: 20.10.2021

1. Introduction

The “suborbital launch vehicle” or “suborbital rocket” is defined by the Office of Commercial Space Transportation (part of the FAA – Federal Aviation Administration) as “a vehicle, rocket-propelled in whole or in part, intended for flight on a suborbital trajectory, and the thrust of which is greater than its lift for the majority of the rocket-powered portion of its ascent. The Suborbital trajectory is defined as the intentional flight path of a launch vehicle, reentry vehicle, or any portion thereof, whose vacuum instantaneous impact point does not leave the surface of the Earth” (Electronic Code of Federal Regulations, 2021). This definition clearly separates suborbital rockets from orbital launch vehicles which are often confused by non-specialists. While orbital launch vehicle provides with at least orbital speed and allows its payload to enter the orbit, suborbital rockets can only lift its payload to high altitudes - sometimes much higher than LEO orbits – but an orbit insertion is not possible. Such vehicles are often referred to as “sounding rockets”, however, in this paper the term “suborbital rocket” is used as a general nomenclature for such vehicles. Clearly, FAA definition as stated here with no context encompasses missiles, however, term suborbital rocket is used in a framework of rockets with no warheads and no direct combat roles.

An ability to fly above the Kármán line, achieved speeds, accelerations and other flight parameters make suborbital rockets useful for numerous applications in science, technology development and safety & defense. Civil applications of suborbital rockets were discussed by (Christie et al., 2016) with an emphasis on the activities in the United States. More general overview of suborbital rockets and their payloads was given by (Noga & Puri, 2020).

Civil applications of suborbital rockets are well described in the literature and in the public domain. On the contrary, safe & defense applications are often lacking technical description in sufficient level and were not described holistically. The goal of the paper was to attempt to close this gap and to preliminary verify a Polish potential contribute to safety & defense applications of suborbital rockets. The main research problems of the paper presented were ~~was~~ to:

1) Determine how suborbital rockets are used in safety & defense applications
2) Extract mission requirements and verify preliminary how Polish suborbital rocket with the highest Technology Readiness Level – ILR-33 AMBER 2K – can respond to these requirements.

The methodology to address research problems included a detailed literature review of civil and safety & defense applications of suborbital rockets. The review was limited to publicly available sources and included books, conference proceedings, scientific papers and press. Analysis of the data gathered in a literature review - especially use-cases – allowed to determine and to examine applications of suborbital rockets and corresponding mission requirements. Simulation data allowed to compare ILR-33 AMBER 2K mission parameters with derived requirements. In section 2 a construction of a typical rocket is detailed and typical applications in the civil sector are outlined. Section 3 presents numerous applications of suborbital rockets in safety & defense and – where applicable – briefly describes specific, historical missions. In section 4 technologies related to suborbital flights that are being developed in the Łukasiewicz Research Network – Institute of Aviation (Ł-IoA) are described with emphasis on ILR-33 AMBER 2K rocket. Paper’s findings are concluded and future work is proposed in section 5.

2. Suborbital launch vehicles – their construction and applications in civil sector

While most of the historical suborbital rockets utilized solid rocket motors such as military surplus motors (NASA, 2019), modern solutions often make use of liquid propellants as is the case for Nucleus (Faenza et al.,2019), MIURA-1 (Francisco et al., 2018), ILR-33 AMBER (Marciniak et al., 2018) and New Shepard (Blue Origin, 2019). The latter is an interesting example of a rocket with a demonstrated reusability and ability to land using its propulsion system – similarly as is done with Falcon 9 launch vehicles. Regardless of the propulsion systems onboard, such rockets usually have an experiment module where various types of experiments can be flown and a service module which includes avionics (flight computer, power system, communication system etc.). A parachute recovery module is often employed as well.

Rockets with high performance in terms of altitudes achieved and masses of payloads usually employ staging – in a manner similar to launch vehicles. An example of a rocket with exceptionally high performance is the Black Brant XII-A which utilizes 4 stages and can deliver over 90 kg of payload to an altitude of over 1600 km. The altitude of a suborbital rocket is driven by a total impulse of the propulsion system, its thrust curve (optimization of which is the objective of the famous Goddard Problem (Goddard, 1919)), a payload mass and an elevation angle. The latter is dependent on various factors, most notably wind conditions at launch. An example performance graph showing altitudes achieved when varying an elevation angle and a payload mass is shown on a Figure 1. It is worth noting that the impact range can be significant – even for a relatively small Improved Orion rocket the impact range can be over 100 kilometers. This drives requirements for thorough safety analysis including statistical computation of impact points and other methods (Wilde, 2018). Figure 2 presents an example trajectory and flight-events of a suborbital rocket. The rocket launches from a launch rail using its rocket propulsion system – cold launches are most often not implemented. Once one or more stages have finished thrusting the rocket decelerates and its altitude is increasing until the vertical component of the velocity is zero. When this happens, the rocket is starting to fall down. Some segments (especially rocket motor stages) separate during ascent, however, at times separation can occur during the descent. So-called flat spin phenomenon is utilized to reduce the speed of the rocket during the descent. A two-staged parachute is often employed to further slow-down parts of the rocket intended to be recovered. Recovered parts are most often the experiment and service module. New Shepard rocket demonstrated ability to recover the whole vehicle.

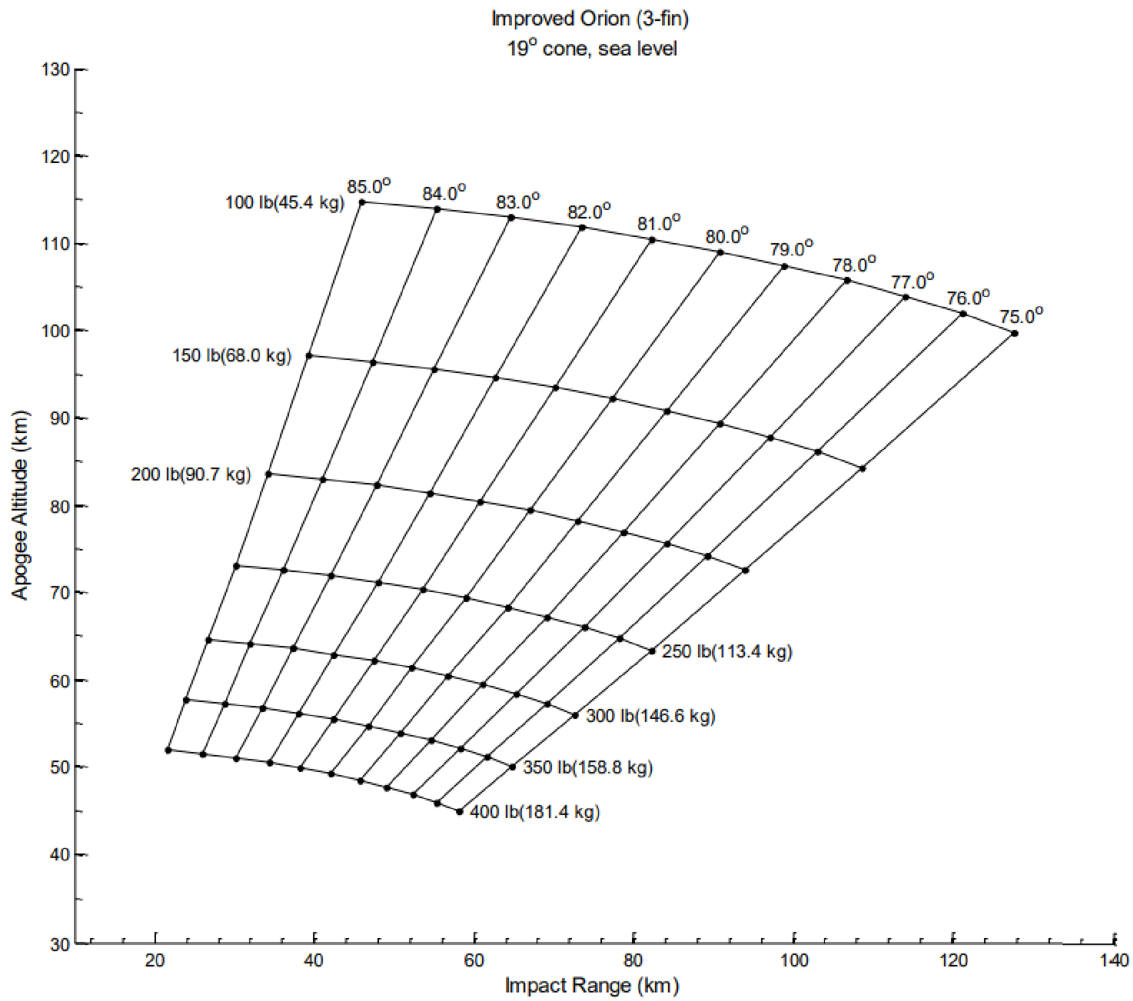


Figure 1. Performance Graph for Improved Orion . Adopted from: "NASA Sounding Rockets User Handbook" by NASA. Copyright 2015 by NASA.

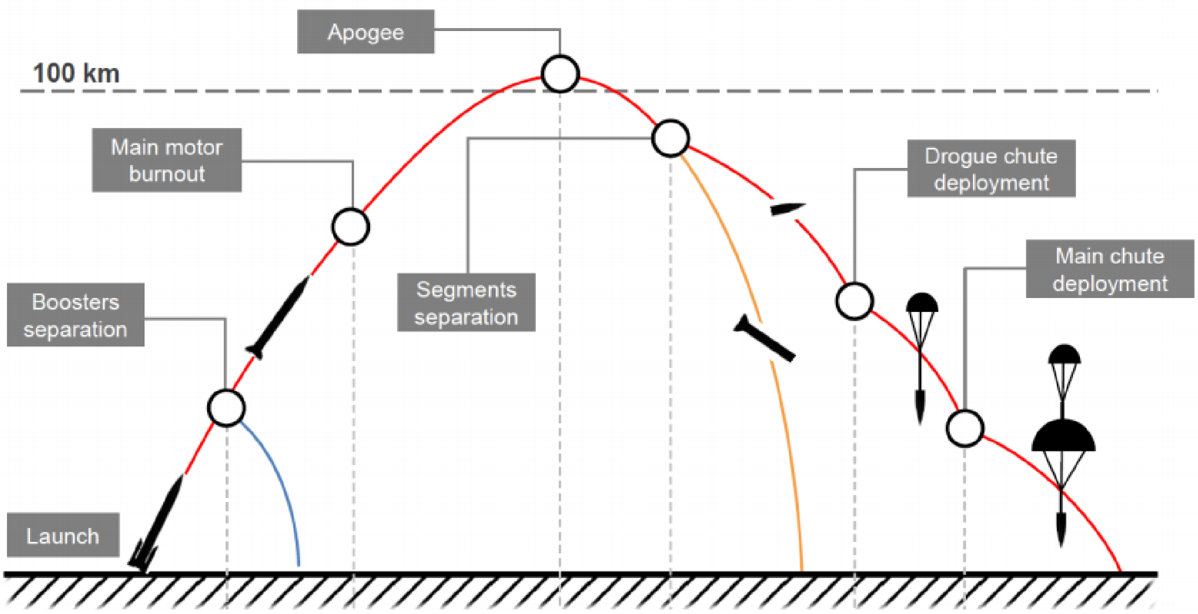


Figure 2. Trajectory of ILR-33 AMBER 2K rocket. Ł-IoA own work.

Suborbital rockets are usually launched from spaceports that include launch rails, integration halls, ground stations, mission control rooms, meteorological equipment, and more (Noga & Puri, 2020). Some entities demonstrated ability to launch the rocket with a mobile ground infrastructure – example being Ł-IoA launching AMBER rocket from military test grounds in Poland.

Suborbital rockets have seen service as early as in 1946 when a captured German V2 rocket was launched from the White Sands facility (Demets, 2011) to perform research on effect of brief space travel (an apogee of 187 km was achieved) on a fungus. Research was continued with more complex species and new research fields were studied. Biology and astrobiology is an important topic of suborbital research to date. Atmosphere sounding has started in 1947 and to this day it provides data regarding structure and processes of the Earth's atmosphere (Noga & Puri, 2020). Suborbital rockets are the only vehicles that can gather the in-situ atmosphere data in a feasible manner at ranges from approximately 40 kilometers (upper limit of stratospheric balloons) to 200 kilometers (lower limit of satellites). This type of suborbital research was especially popular in 1950's and 1960's (Seibert, 2006).

Another type of a suborbital research is a microgravity research. Microgravity conditions are experienced inside the suborbital rocket for some part of a flight ranging from 2 minutes for small rockets to even 15 minutes for larger vehicles. Suborbital rockets provide microgravity conditions of much better quality than aircraft and for higher durations than drop towers and aircraft. While a spacecraft can offer microgravity of comparable or higher quality and for much longer duration, suborbital rockets offer lower experiment price, faster turn-around and ability to recover the payload which is a driver for many types of missions (Noga and Puri, 2020). For instance, microgravity onboard suborbital rockets is used to precisely measure thermophysical properties of liquid metals (Egry, 2009) or to study response of living organisms to a gravity stimuli (Demets, 2011).

Suborbital rockets are platforms that can enable astronomical observations above the Earths' atmosphere. Observations above the atmosphere are vital as certain wavelengths of EM spectrum cannot go through it and any light reaching the observer on the ground is obscured. Astronomical observations from suborbital rockets are especially popular in the United States, and such observations allow to use cutting-edge observation technology which is not possible in case of spacecraft due to their cost and long mission preparation phase. At times, new detectors are flight tested onboard suborbital rockets before being used on spacecraft (NASA, 2019).

Astronomy is not the only field in which technology development can benefit from an environment onboard suborbital rockets. Such environment can be used to increase *Technology Readiness Level*, most notable in a space sector. Examples include tests of flight environment monitors, surveillance broadcasting, navigation sensors, avionics and other technologies dedicated for rocket vehicles – orbital and other. Entry, descent and landing technologies (i.e. for Martian Earth Return Capsule) were tested using suborbital rockets as well. In China, a number of commercial cubesats were launched onboard a suborbital rocket as part of test campaign. Space technologies related to liquid management in microgravity are another notable example (Noga & Puri, 2020).

It is also worth noting that suborbital rockets proved to be optimal platforms for education purposes. Educational programs in USA enable students from all levels of education to fly experiments of their designs onboard suborbital rockets.

An emerging type of suborbital flights is related to a space tourism. Suborbital flights can offer experiencing microgravity and being present above the edge of space for several minutes for a fraction of cost of an orbital flight. At the moment of writing such capability was demonstrated by Blue Origin and Virgin Galactic companies (Masanuga & Mendez, 2021).

3. Suborbital launch vehicles applications in safety & defense

As in case of purely civil applications of suborbital rockets, safety & defense applications take advantage of environment provided by such rockets. Review of publicly available information regarding safety & defense applications of suborbital rockets allowed to summarize them into following categories for the purposes of this paper:

1) <u>Missile attack simulation</u>
   Suborbital rockets are in many ways similar to missiles – a classic suborbital rocket shares similar propulsion system and aerodynamical shape with a missile. A well-known example that proves the similarity is so-called “Norwegian rocket incident” caused by a Black Brant XII rocket launched from the Andøya Rocket Range to study aurora borealis over Svalbard. The rocket was detected by a Russian early-warning radar station and appeared to the station crew as a Trident missile. This caused full alert on Russian side and nuclear weapons were prepared to attack. Fortunately the mistake was detected (EUCOM History Office, 2012). In 2011 a rocket target based on Oriole rocket system was launched to simulate a missile attack as part of the Atlantic Trident military exercises (NBC News, 2011). Another example reported Macdonald, 2016) is an American Terrier-Orion two-stage rocket which was launched from the United Kingdom in October 2015, and it was the first vehicle ever launched from the United Kingdom to reach the outer space. The rocket was launched to simulate a missile incoming to warships being exercised. According to press, the “missile” was successfully detected and shot down by the USS Ross. It was reported in press (defence24, 2019) that in 2019 a small suborbital test rocket developed by a Polish company Space Forest was detected and tracked by during testing campaign of a passive radar technology APART-GAS (Active Passive Radar Trials – Ground-based, Airborne, Sea-borne) on a Polish military ground.
2) <u>Technology development and validation</u>
   As in the case of a technology validation for a space sector, safety & defense applications can benefit from the environment provided by suborbital rockets. Whereas in case of space sector a microgravity onboard the rocket is a widely used asset, it is the resemblance to actual missiles that proves useful in case of safety & defense applications. There are numerous examples of such tests, mostly form the United States. Sounding rockets enable tests of new missile systems components, such as sensors or releasing of simulating warheads for system tests (Martin & Law, 2002). An example of such flight is a Hypersonic Test Vehicle-2A flown for the US Department of Defense in 2010 (Federal Aviation Administration, 2011). A HOT SHOT in the USA programme, which included a rocket launch in 2018, aims to enable flight tests of missile systems onboard a relatively cheap flight vehicle, “filling a gap between ground tests and a final flight test” (Rummler, 2018). More recent example is a Terrier-Oriole launch carrying an experimental research payload for the Air Force Research Laboratory in March 2021 (Strout, 2021) – see Figure 3**.** The US Air Force has provided a grant to study using suborbital rockets to test materials, sensors and flight controls at hypersonic speeds (Reim, 2020). It is also speculated that a French V-Max vehicle demonstrating maneuvering during a hypersonic gliding would utilize a sounding rocket for its initial flight test (Trevithick, 2021).

Figure 3. Launch of a Terrier-Oriole sounding rocket, carrying an experimental research payload for the US Air Force Research Laboratory. Adopted from *(C4ISRNET, 2021)*, Copyright 2021 by NASA

3) Peaceful utilization of surplus missile motors
Utilization of surplus military equipment, especially explosives and energetic materials is of major concern. Proper utilization prevents hazards and illicit transfers of weapons. Suborbital rockets often use surplus military motors as propulsion (NASA, 2019), and as such they contribute to safe utilization of surplus military materials. Example of such motors are Terrier MK12 or MK70 boosters (NASA, 2015).
4) Remote sensing
A report aiming to forecast a growth of suborbital flights' market (Tauri Group, 2012) predicts that suborbital rockets could be utilized for remote sensing purposes in military applications. Suborbital rockets could offer high resolution observations with swath widths with hundreds of square kilometers with an almost on-demand revisit time (provided the vehicles are available). They could ascend in friendly airspace and achieve views into hostile territory without violating airspace restrictions or exposing the vehicle to the treat of engagement. No actual flight demonstrations of this concept have been found in the literature review.
5) Other
There are more potential applications of suborbital rockets. For instance, aforementioned report (Tauri Group, 2012) foresees that price reduction of suborbital flights could result in new, unforeseen applications – especially military. It is worth noting that suborbital rockets use technologies and processes close to ones used in military rockets, regardless of their intentional usage. According to (NASA Sounding Rockets User Handbook, 2015), in the United States of America "Sounding Rockets are considered Significant Military Equipment (SME) and are listed on the ITAR US Muni-

tions List (USML)". Safety procedures are required for any foreign national to be involved in experiment design and testing or field operations related to suborbital rockets

Requirements for a rocket to meet mission objectives can only be made for purposes number 1), 2) and 4). Purpose 3) – peaceful utilization of surplus missile motors describes how suborbital rockets can contribute to disarmament, and one could take it into account when designing a new vehicle (if one has access to such surplus motors). Purpose 5) is too general, however, it is noted that decreasing price may open new safety & defense applications. Main mission requirement for missile attack simulation purposes are to resemble a "real" missile in terms of radar cross section, trajectory, acceleration, speed, etc. – this requirement ensures that suborbital rocket used to emulate a missile will be "close enough" to an actual threat. This requirement is applicable to technology development and validation as well, as it also requires the suborbital rocket to resemble the missile – only this time it is a "friendly" missile. It is noted, however, that this requirement is strongly dependent on the missile one wants to emulate. Another requirement is that the suborbital rocket has to be much cheaper than an actual missile, otherwise it is not feasible and economical to introduce new type of rocket to tests. In case of remote sensing purpose, it is required to provide fine stabilization of the rocket during the observation. It is also desired to increase duration of observation, which probably means that capability to hover on high altitude would be desired.

4. Łukasiewicz Research Network – Institute of Aviation's suborbital launch vehicles and related technologies

Łukasiewicz Research Netowrk – Institute of Aviation is a research and development center dedicated to aeronautical and space engineering. Ł-IoA participates in European research programs which includes rocket propulsion projects for the European Space Agency. Projects involve development of aluminum-free solid motors for spacecraft deorbitation (Nowakowski et al., 2017a), hydrogen peroxide thrusters, bi-propellant engines for geostationary spacecrafts (Surmacz et al., 2017), throttleable rocket engines, and propulsion systems components such as catalytic beds (Surmacz et al., 2019), tanks (Gut, 2020) and valves. Ł-IoA has experience in development and utilization of sounding rocket systems. This experience includes both hardware and software used for design and development and for mission planning and safety analyses. Several rocket flight campaigns have been performed allowing the team to gain hands-on experience in safe rocket flight planning. Historically, 269 Meteor-family sounding rockets have been launched for technology development or atmosphere research purposes between 1963-1974. IoA was responsible for design and testing of the rockets and for launch campaigns' preparation and execution. In 2019 IoA has performed a flight campaign of a cold launch demonstrator with gasodynamic reaction control system. In total 13 flights took place – most of them successful.

ILR-33 AMBER rocket is a technology demonstrator developed by Ł-IoA. The development process started in 2014 which included optimization efforts (Okninski, 2018; Okninski et al., 2018). The rocket is propelled by environmentally friendly hybrid motor with polyethylene as fuel and +98% High-test Peroxide (oxidizer), what makes it the first rocket utilizing HTP at such high concentration. Two solid strap-on boosters are used during the first flight phase (Nowakowski et al., 2017b). The first flight took place in 2017 at CSWL Drawsko. Two more tests took place in 2019, one in Drawsko (Pakosz et al., 2019) and second in Air Force

Training Centre Ustka (Okninski et al., 2019). The rocket render with all modules shown is presented on Figure 4.

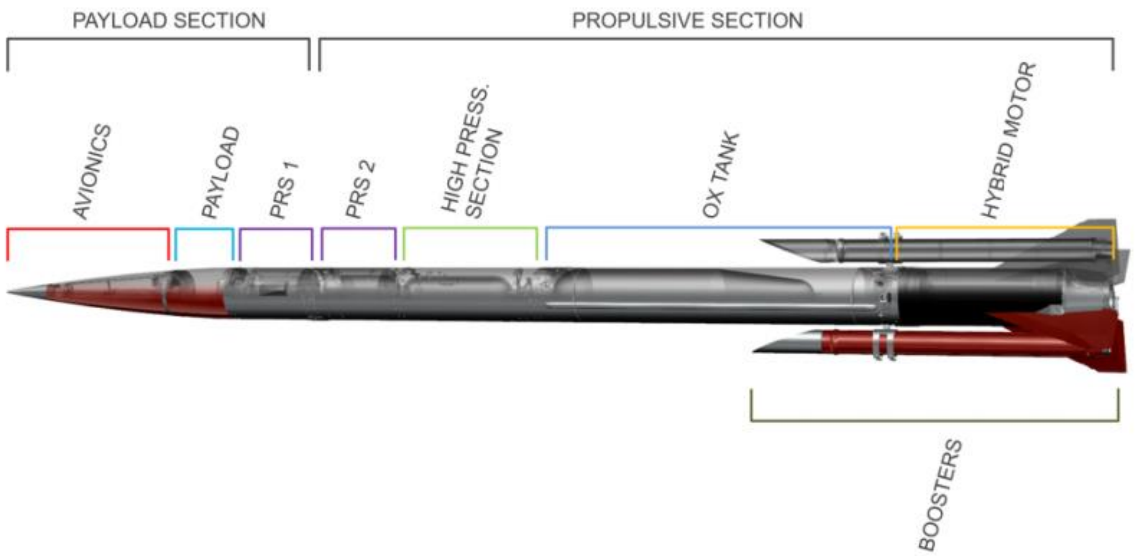


Figure 4. ILR-33 AMBER rocket. PRS 1 and 2 stands for – Payload Recovery System. A rocket configuration from 2017 with two recovery systems is shown. Own work of Ł-IoA.

Flight tests allowed to validate rocket's systems as well as ground infrastructure used during the flight tests. Altitudes of 15, 11 and 23 km were achieved, respectively. The rocket was able to reach altitudes of 60 km, however, the flight ceiling during all the three tests had to be limited due to legal reasons (limited airspace – 15 km) and safety aspects (small size of allowed impact zones, rocket dispersion increase due to the winds). Rocket velocity of 615 m/s, at Mach number 2.05 was achieved as the top value up to date. The maximum ascent acceleration was ~12.5 g_0. Photographs from the latest (at the time of writing) flight test are shown on Figure 5.

Figure 5. ILR-33 AMBER rocket flight test. Top-left – rocket's ascent, note strap-on boosters still attached to the rocket. Top-right – the moment of strap-on boosters separation. Bottom-left – rocket in passive phase of the flight. Bottom-right – recoverable section of the rocket waiting for sea recovery. Own work of Ł-IoA.

The successor of the ILR-33 AMBER rocket is the ILR-33 AMBER 2K (Figure 6). The rocket is being prepared for a flight above the Kármán line with 10 kg of experiment. Due to the COVID-19 pandemic its first flight was postponed form 2020 to 2021. The rocket was also optimized with constraints to provide with at least 120 seconds of 10^{-4} g_0 microgravity environment, to have a maximum acceleration of at most $15g_0$, a wet mass of below 300 kg and a 1σ impact point dispersion of no more than 20 km (Pakosz et al., 2020).

Figure 6. A rendering of ILR-33 AMBER 2K, a successor of ILR-33 AMBER ~~rendering~~. Own work of Ł-IoA.

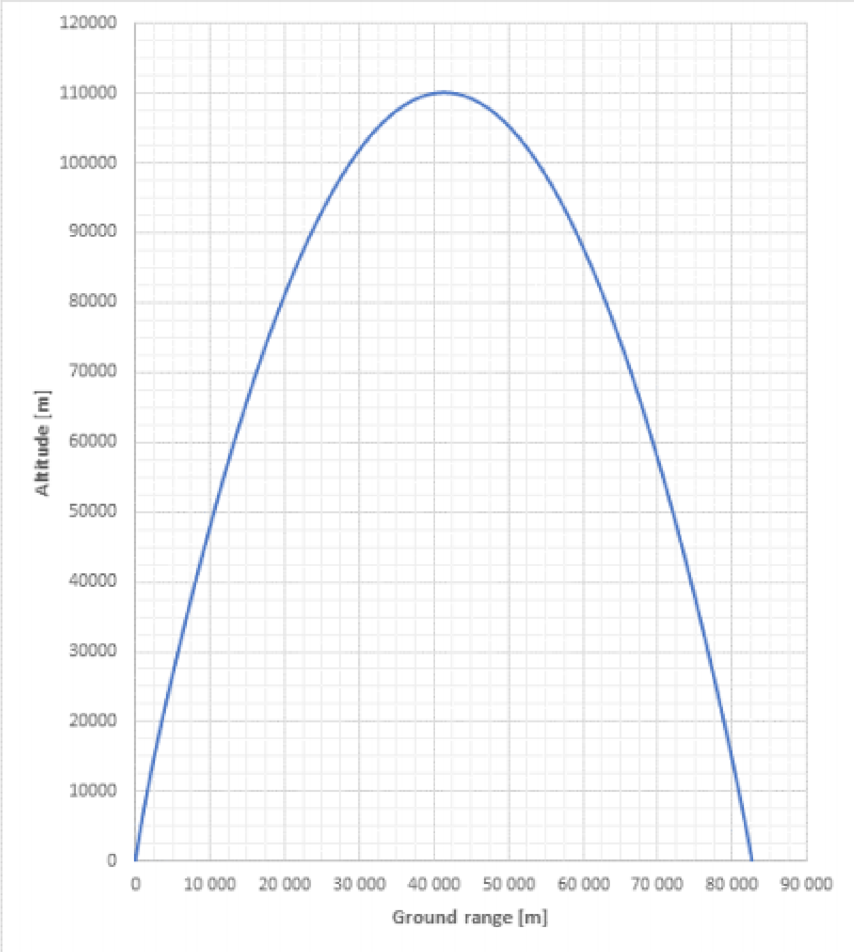


Figure 7. ILR-33 AMBER 2K trajectory. Own work of Ł-IoA.

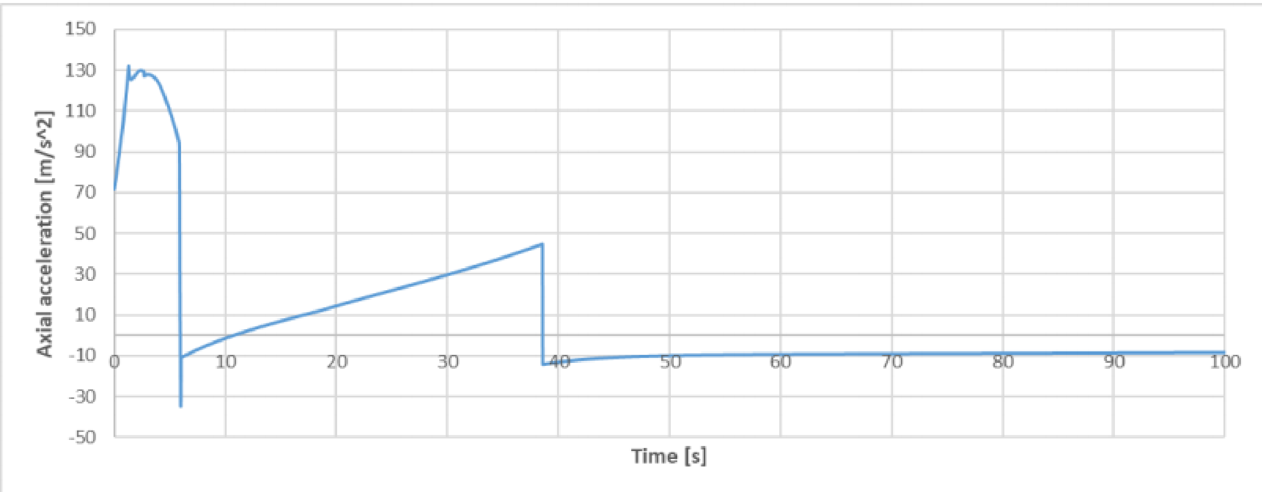


Figure 8. ILR-33 AMBER 2K acceleration profile. Own work of Ł-IoA.

Rocket's trajectory and acceleration profile during the ascent are calculated using a 6 DoF simulation are shown on Figure 7 and Figure 8. Simulations show that the trajectory is resembling ballistic trajectories of missiles. In the simulated flight with hybrid motor delivering its full performance and launch pad elevation angle of 83°, the rocket reaches 110 km apogee, and the distance from the launch pad to the impact point is 82 km. Acceleration of the rocket during is ascent is the highest shortly after launch and reaches over $13g_0$. When boosters finish thrusting and are ejected, the acceleration drops significantly and is then increased again until it reaches approximately $4.5g_0$ when the hybrid motor finishes thrusting. After that, the rocket is decelerated due to an atmospheric drag and a gravitational acceleration. The atmospheric drag is getting lower as rocket ascends and microgravity conditions occur for approximately 2 minutes of rocket's flight. The rocket in current configuration is capable of achieving speeds above Mach 4 in a nominal flight.

5. Conclusions

Based on the study it is concluded that there are numerous use cases for suborbital rockets in the field of safety & defense. The most mature applications that can be offered by modern suborbital rockets are technology validation and missile simulation. There exist potential for other mission types. ILR-33 AMBER 2K rocket has capability to be used in safety & defense applications as it can mimic missiles for both technology validation and serve as a missile simulation to test air defense systems. Reaching high altitudes, Mach 4, high accelerations and having a ballistic trajectory it meets preliminary requirements for such applications. It is also relatively small sounding rocket and it has been cost-optimized. Its modular design will allow easy adaptation for various missions. Reaction control system is being developed that could stabilize the rocket during potential remote sensing (Noga, 2021). As pointed out in Section 3, mission requirements for safety & defense applications are highly case-specific. It is certainly part of the future work to attempt to simulate specific missions, i.e. to emulate a ballistic attack, however, such simulation should include data regarding missile to be simulate, which is not publicly available.

Acknowledgements

The author would like to thank all colleagues from the Łukasiewicz Research Network – Institute of Aviation, Space Technologies Department. It is the whole team that makes Ł-IoA research and development related to rocket technologies possible – which includes this paper.

Declaration of interest - The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

References

1. Blue Origin. (2019, September). *New Shepard Payload User's Guide revision F.* Blue Origin. NSPM-MA0002.
2. Christie, S., Zeiger, B., Pfaff, R., & Garcia, M. (2016). Introduction to the Special Issue on Sounding Rockets and Instrumentation. *Journal of Astronomical Instrumentation, 5(1),* https://doi.org/10.1142/S2251171716020013
3. defence24. (2019, September 16). *NATO testuje radary pasywne w Polsce (NATO is testing passive radars in Poland)*. Defence24. https://www.defence24.pl/wojska-radiotechniczne-sprawdzaja-nowe-rozwiazania-technologiczne
4. Demets, R. (2011). BIOLOGY ON SOUNDING ROCKETS: HISTORY, REQUIREMENTS, RESULTS AND SCIENTIFIC INTERPRETATION. *20th ESA Symposium on european rocket and Balloon Programmes and Related research*. Hyeré, France. https://ui.adsabs.harvard.edu/abs/2011ESASP.700...63D/abstract
5. Egry, I. (2009). Containerless Processing of Liquid Metals in Microgravity. *19th ESA Symposium on European Rocket and Balloon Programmes and Related Research.* Bad Reichenhall, Germany. https://www.semanticscholar.org/paper/CONTAINERLESS-PROCESSING-OF-LIQUID-METALS-IN-Egry/b54776a0723cd4835b6c3645a9c2ea7805fbaf39
6. Electronic Code of Federal Regulations. (2021). Title 14 Aeronautics and Space CFR 401.7. https://www.ecfr.gov/cgi-bin/text-idx?SID=539e9fb58a1472264819f971bb46eebc&mc=true&node=pt14.4.401&rgn=div5
7. EUCOM History Office. (2012, January 23). *January 25, 1995 -- The Norwegian Rocket Incident*. United States European Command https://web.archive.org/web/20160105033448/http://www.eucom.mil/media-library/article/23042/this-week-in-eucom-history-january-23-29-1995
8. Faenza, Martina; Boiron, Adrien; Haemmerli, Bastien; Verberne, Onno. (2019). The Nammo Nucleus Launch - a Showcase for Hybrid Sounding Rockets. *24th ESA Symposium on European Rocket and Balloon Programmes and Related Research*. Essen, Germany.
9. Federal Aviation Administration. (2011). *2011 U.S. Commercial Space Transportation Development and Concepts: Vehicles, Technologies, and Spaceports*. Federal Aviation Administration. https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2011%20DevCon%20Report.pdf
10. Francisco, G., Nuermberger, M., Torres, R., & Crespo, J. (2018). ARION 1 Reusable Sounding Rocket: New Microgravity Platform in Europe. *69th International Astronautical Congress (IAC),* Bremen, Germany. IAC-18,A2,IP,10,x48327
11. Goddard, R. (1919). A method of reaching Extreme Altitudes. In *Smithsonian Miscellaneous Collections 71(2)* (Vol. 71). City of Washington: Smithsonian Institution.
12. Gut, Z. (2020). Using Electrical Capacitance Tomography System for Determination of Fluids in Rocket and Satellite Tanks. *Transactions on Aerospace Research, 1*(258), 18-33, https://doi.org/10.2478/tar-2020-0002
13. Macdonald, K. (2016, February 3). *Hebrides rocket launch: The space milestone we almost missed*. BBC. https://www.bbc.com/news/uk-scotland-highlands-islands-35482244
14. Marciniak, B., Okninski, A., Bartkowiak, B., Pakosz, M., Sobczak, K., Florczuk, W., . . . Wolanski, P. (2018). Development of the ILR-33 “Amber” sounding rocket for microgravity experimentation. *Aerospace Science and Technology, 73,* 19-31, https://doi.org/10.1016/j.ast.2017.11.034

15. Martin, J., & Law, G. (2002). *Suborbital Reusable Launch Vehicles and Applicable Markets*. The Aerospace Corporation. https://www.space.commerce.gov/wp-content/uploads/2002-10-suborbital-LowRes.pdf
16. Masunaga, S. & Mendez, A. (2021, July 20). *Jeff Bezos launches new era of space travel with Blue Origin ride*. Los Angeles Times. https://www.latimes.com/business/story/2021-07-20/jeff-bezos-launches-blue-origin-new-shepard
17. NASA. (2015). *NASA Sounding Rockets User Handbook*. NASA Goddard Space Flight Center, Wallops Flight Facility. https://sites.wff.nasa.gov/code810/files/SRHB.pdf
18. NASA. (2019). *NASA Sounding Rockets Annual Report 2019*. Wallops Island: National Aeronautics and Space Administration, Goddard Space Flight Center, Wallops Flight Facility. https://sites.wff.nasa.gov/code810/files/Annual%20Report%202019_web.pdf
19. NBC News. (2011, January 25). *Kratos Supports Critical Aegis Ballistic Missile Defense (BMD) Test -- Atlantic Trident 2011*. NBC News https://www.nbcnews.com/id/wbna41249257
20. Noga, T (2021). Hydrogen Peroxide RCS on a Sounding Rocket – a Milestone Towards Launch Vehicles and Satellite Platforms' Applications, *Space Propulsion 2020*, Estoril, Portugal. SP2020_#00373
21. Noga, T., & Puri, R. (2020). Microgravity, atmosphere sounding, astronomy, technology validation – an overview of suborbital rockets' missions and payloads. *Int. J. Space Science and Engineering,* *6*(2), 179-208, https://www.doi.org/10.1504/IJSPACESE.2020.110365
22. Nowakowski, P., Okninski, A., Pakosz, M., Cieslinski, D., Bartowkiak, B., & Wolanski, P. (2017b). Development of small solid rocket boosters for the ILR-33 sounding rocket. *Acta Astronautica 138*, 374-383, http://doi.org/10.1016/j.actaastro.2017.06.007
23. Nowakowski, P., Pakosz, M., Okninski, A., Kaniewski, D., Marciniak, B., Surmacz, P., . . . Wolanski, P. (2017a). Design of a solid rocket motor for controlled deorbitation. *53rd AIAA/SAE/ASEE Joint Propulsion Conference*. Atlanta, USA, https://doi.org/10.2514/6.2017-5083
24. Okninski, A. (2018). On use of hybrid rocket propulsion for suborbital vehicles. *Acta Astronautica 145*, 1-10, https://doi.org/10.1016/j.actaastro.2018.01.027
25. Okninski, A., Kindracki, J., & Wolanski, P. (2018). Multidisciplinary optimisation of bipropellant rocket engines using H2O2 as oxidiser. *Aerospace Science and Technology, 82-83*, 284-293, https://doi.org/10.1016/j.ast.2018.08.036
26. Okninski, A., Pakosz, M., Bartkowiak, B., Nowakowski, P., Noga, T., Matyszewski, J., Wolanski, P. (2019). The ILR-33 AMBER 2K ROCKET – dedicated access to suborbital experimentation. *70th International Astronautical Congress (IAC)*. Washington, IAC-19,D2,6,8,x50868
27. Pakosz, Michał; Majewska, Ewa; Matysek, Krzysztof; Noga, Tomasz; Nowakowski, Paweł; Ptasinski, Grzegorz. (2020). Design Modifications for Performance Enhancement of a Suborbital Rocket ILR-33 AMBER 2K. *71st International Astronautical Congress (IAC)*. The CyberSpace Edition. IAC-20,D2,6,7,x60735
28. Pakosz, Michał; Noga, Tomasz; Kaniewski, Damian; Okninski, Adam; Bartkowiak, Bartosz. (2019). ILR-33 AMBER Rocket - Quick, Low Cost and Dedicated Access to Suborbital Flights for Small Experiments. *24th ESA Symposium on European Rocket and Balloon Programmes and Related Research*. Essen, Germany. https://www.researchgate.net/publication/346243972_ILR-33_AMBER_ROCKET_-QUICK_LOW_COST_AND_DEDICATED_ACCESS_TO_SUBORBITAL_FLIGHTS_FOR_SMALL_EXPERIMENTS

29. Reim, G. (2020, April 1). *US Air Force looks at using small sounding rocket for hypersonic testing*. FlightGlobal. https://www.flightglobal.com/fixed-wing/us-air-force-looks-at-using-small-sounding-rocket-for-hypersonic-testing/137660.article

30. Rummler, T. (2018, October 25). *Sandia delivers first DOE sounding rocket program since 1990s*. Sandia National Laboratories. https://www.sandia.gov/news/publications/labnews/articles/2018/26-10/hot_shot.html

31. Seibert, G. (2006). The History of Sounding Rockets and Their Contribution to European Space Research. ESA Publications Division. https://www.esa.int/esapub/hsr/HSR_38.pdf

32. Strout, N. (2021, March 4). *Space Force launches experimental research payload*. C4ISRNET. https://www.c4isrnet.com/battlefield-tech/space/2021/03/04/space-force-launches-experimental-research-payload/

33. Surmacz, P., Kostecki, M., Gut, Z., & Olszyna, A. (2019). Aluminum Oxide–Supported Manganese Oxide Catalyst for a 98% Hydrogen Peroxide Thruster. *Journal of Propulsion and Power, 35*(1), 1-10, https://doi.org/10.2514/1.B37359

34. Surmacz, Paweł; Sobczak, Kamil; Rarata, Grzegorz; Bartkowiak, Bartosz; Okninski, Adam; Kublik, Dominik; Wolanski, Piotr; Valencia, Ferran. (2017). Early Studies and Fire Tests of a Green Liquid Apogee Engine Based on Decomposition of 98% Hydrogen Peroxide. *68th International Astronautical Congress*. Adelaide, Australia, https//doi.org/10.13140/RG.2.2.28847.43686

35. Tauri Group. (2012). *Suborbital Reusable Vehicles: A 10-Year Forecast of Market Demand*. FAA and Space Florida. https://www.faa.gov/about/office_org/headquarters_offices/ast/media/Suborbital_Reusable_Vehicles_Report_Full.pdf

36. Trevithick, J. (2021, April 26). *Warnings Posted For A Peculiar French Ballistic Missile Test In The Atlantic*. THE WARZONE. https://www.thedrive.com/the-war-zone/40334/warnings-posted-for-a-peculiar-french-ballistic-missile-test-in-the-atlantic

37. Wilde, P. D. (2018). Range safety requirements and methods for sounding rocket launches. *The Journal of Space Safety Engineering 5(1), 5*, 14-21, https://doi.org/10.1016/j.jsse.2018.01.002

SAFETY & DEFENSE
ISSN 2450-551X

The Tactical and Technical Functioning Conditions of the S-200C Vega Missile System on the Modern Battlefield

Jan PIETRASIEŃSKI[1], Dariusz RODZIK[2*], Witold BUŻANTOWICZ[3]

[1] Military University of Technology, Warsaw; jan.pietrasienski@wat.edu.pl, ORCID: 0000-0002-4825-3803
[2] Military University of Technology, Warsaw; dariusz.rodzik@wat.edu.pl, ORCID: 0000-0003-1697-8874
[3] Military University of Technology, Warsaw; witold.buzantowicz@wat.edu.pl, ORCID: 0000-0002-4737-4857
* Corresponding author

DOI: https://doi.org/10.37105/sd.160

Abstract

The Polish armed forces have used the S-200 Vega surface-to-air missile (SAM) system since the middle of the 1980s. In the early 21st century, it was upgraded to a digital version and adapted to the reality of air combat at the time. After almost twenty years of service since its upgrade, it remains the only long-range SAM in the armament of the Polish Air Force. Today, this SAM system is undergoing a major modification, again, to maintain its long-range anti-air attack potential and the required combat functionalities.
The objective of this paper is to identify the technical and tactical functioning conditions of the S-200 family of SAM system on the modern battlefield. In order to achieve this goal, the authors used theoretical methods of research. As a result of the conducted analyzes, this paper presents the operational experience gained so far and a justification for the continued service of the Vega SAM system.

Keywords

air defense, defense, S-200C Vega, SA-5 Gammon, surface-to-air missile system.

Submitted: 24.08.2021 Accepted: 20.09.2021 Published: 20.10.2021

1. Introduction

The results of analyses of armed conflicts at the end of the 20th century and the beginning of the 21st century clearly demonstrate a growing trend in the significance of air attack technical assets in combat. The noticeable technical progress in air attack engineering results in a natural drive towards an intense development of air and anti-missile defense measures. The interdisciplinary scientific and engineering nature of air defense systems and the need for their adaptation to the extreme conditions of the battlefield make these technical assets extremely expensive to develop and manufacture, and the consequences of their introduction to military service span decades forward. On the other hand, due to scientific and technical progress, it is impossible to keep SAM systems technically up to date without follow-up retrofitting. This mainly concerns long-range SAM systems, which belong to most complex armament types. The systematic increase in the combat capabilities of air force and the changes of air attack tactics necessitate the continuous adaptation of SAM systems to modern air combat – cf. e.g. (Pang *et al.*, 2019; Bużantowicz & Pietrasieński, 2018; Turinskyi & Skoryk, 2020; Pomohaiev *et al.*, 2020). This is especially true for older generations of the SAM system, which were designed for different operating conditions than those prevailing now.

An example is the S-200 family of long-range SAM systems (NATO code: SA-5 Gammon), which – despite their age – remain in active military service in many parts of the world. The vast majority of the S-200 SAM systems have undergone at least three or four extensive retrofits, which allowed for a marked improvement of its tactical and technical performance (Openko *et al.*, 2020). Some of the S-200 SAM systems undergo periodic retrofits and overhauls, depending on the technical advancement of their operator countries. These efforts are either carried out by specialists from the Russian Federation, or through domestic resources (Bużantowicz, 2021). In the case of Poland, it was decided in 2018 to perform another overhaul of the in-service S-200C SAM system retrofitted at the beginning of the 21st century, combined with a modification of the system's instruments. There is much evidence to assume that the S-200C Vega SAM system will remain in service in the Polish armed forces for at least a dozen or so years.

The objective of this paper is to identify the technical and tactical functioning conditions of the S-200 family of SAM system on the modern battlefield with particular focus placed on the cumulative operating experience gained with the Polish version of the S-200C Vega system. In order to achieve this goal, the authors used theoretical methods of research such as analyzing the literature and selected tactical and technical parameters of S-200 missile system family as well as generalization and comparison.

As a result of the conducted research, this paper presents the operating experience gained so far and a justification for the continued service of the Vega SAM system.

2. Development outline of S-200 SAM system family

Considering their operational range, the SAM systems of the S-200 family are classified as long-range surface-to-air weapons. The development of the S-200 SAM system concept began in 1957 and continues to remain strictly connected to the evolution of air force tactics.

The specific tactics worth noting include air strikes with electronic masking provided by aircraft operating outside of the operational range of the SAM systems of the era, high-distance and high-altitude operations of early warning and command and control (C2) aircrafts.

The original requirements specified that the S-200 SAM system was to ensure defense against aerodynamic targets operating at a maximum flight speed of 3500 km/h, at a maximum distance of 100 km and a maximum altitude of 35 km. The S-200 mission priorities included capabilities beyond the short and medium-range SAM systems: defeating early warning and C2 aircraft, radar jamming carriers, and medium to long-range surface-to-surface missiles and air-to-surface missiles.

The chief design engineer of the S-200 was A.A. Raspletin (later replaced by B. Bunkin), while the design work on the S-200 radar systems was directed by A. Basistov and V. Sinelnikov. The S-200 missile design was developed by the design office МКБ Факел headed by P.D. Grushin. In May 1959, the KB-1 design bureau submitted a preliminary design providing the rationale for the general structure, operating principle, and key features of the S-200 SAM system concerning an improved operational range and effective altitude. The USSR authorities approved the primary tactical and technical specifications of the S-200 system in 1959. The first experimental S-200 missile launch was conducted on July 27, 1960. Between 1962 and 1966, a number of combat launches were performed as a part of live-fire range tests and the alignment of the S-200 system firing channel elements (i.e. the launcher, the target illumination radar, the predictor systems and the SAMs). In 1967, the S-200 SAM system was introduced into the service of the USSR air defense forces under the name S-200A Angara. Just two years later, a modified version, named S-200W Vega, was introduced into service and became the baseline for the export version of the system, the S-200WE Vega-E. Two S-200WE version SAM systems were delivered to Poland in 1986. It should be noted that in the late 1970s, development work began on a partially digitalized version of the S-200D Dubna system, which – due to the collapse of the USSR and the intensive development of the S-300 SAM system family – was introduced into the service in the USSR air defense forces in a limited extent.

Table 1 lists a comparison of the selected tactical and technical parameters of the S-200 SAM system versions A, W, WE, WM, and D.

Table 1.
Selected tactical and technical parameters of S-200 missile system family

	S-200A Angara	**S-200W Vega**	**S-200WM Vega-M**	**S-200WE Vega-E**	**S-200D Dubna**
Year of commissioning	1967	1969	1974	1980	1987
Operational range [km]	160	180	300	255	400
Maximum flight altitude [km]	35	35	40	40	40
Maximum target velocity [m/s]	< 1000	< 1000	< 1200	< 1200	< 1200
Number of target/missile channels	1/2	1/2	1/2	1/2	1/2
Probability of hitting the target	0.45-0.98	0.7-0.98	0.7-0.99	0.66-0.99	0.72-0.99
System readiness time [min]	5-7	5-7	3-7	3-7	3-5

Source: own work

The S-200WE SAM system version specified for the Polish armed forces included a common part consisting of the K9 command cabin, the K7 control tower and power supply equipment, plus two proper semi-active guidance systems, comprising the K1 transmitter-antenna cabin, the K2 instrumentation cabin, the K3 launch control cabin, six launchers and a complement of SAMs. The K1 and K2 cabins and the K7 control tower form an important functional component of the SAM system referred to as the target illumination radar (TIR).

The TIR is an advanced radar system because of the implemented modulation and signal processing methods, namely the radar transmitter, which operates in a continuous radiation mode with frequency synthesis; the transmitted signal phase modulation and phase-switching functions providing optimum circular codes; the frequency transformation process which has four iterations, and the signals correlatively processed by a multi-channel receiver with mono-pulse determination of angular coordinates. The original distance measurement is done with a multi-step vernier as the target progresses through the rejection zone, the transmitted radiation is frequency-modulated, and the target tracking is fully automatic in terms of angular coordinates, speed, and distance. The TIR features an additional observation receiver to facilitate target acquisition for tracking and monitoring the signal environment during the target tracking phase.

The primary mission of the TIR is to detect and continuously illuminate an aerial target, , determine the target coordinates for the semi-active homing seekers of the SAMs in the pre-launch cycle, and determine the time of the SAM launch.

When reflected by a target, the signal transmitted by the TIR carries the target positioning information for the SAM receiver channels at the stage of homing. To ensure a stable reception of the target-reflected signals by the SAM homing seekers, the transmission antenna system radiates a circular-polarity EM wave. This requirement has resulted in the conversion of the K1 cabin receiver antenna for the purpose of receiving circular-polarity signals. In order to provide the optimum operating conditions of the target angular coordinate mono-pulse determination systems, a depolarizing unit is installed in the K1 cabin receiver antenna.

The TIR is largely based on electron tubes with rudimentary digital technologies only, which have become obsolete. The advantage of the electron-tube based solution is the highly dynamic performance of tube-driven receivers, which is adapted to the signal change ranges on the receiver line inputs of the SAM system.

It should be noted that the S-200WE system uses continuous radiation. Unlike pulsed transmitter operation, continuous transmitter operation provides a stable load on the microwave transmitting hardware, which dramatically improves its reliability.

The primary disadvantage of the TIR is its complex antenna system, which, in order to ensure the maximum operational range, through increasing the power of the transmitter and sensitivity of the receiver equipment, requires the Tx and Rx antennas to be isolated with a high-quality metal screen. This reduces the energy of crosstalk between the Tx and the Rx antennas.

The K3 launch control cabin of the S-200WE system is a part of the relay of the command outputs from the K9 command and control cabin and of the signal outputs from the K2 cabin to the SAM launchers and on-board instruments. The K9 command and control cabin executes air situation information processing, assignment of fire missions to individual TIRs, target indication, TIR target tracking quality feedback, launcher and missile health assessment and SAM launch initiation.

A Vega SAM system missile is a 7-ton dual-thrust missile with a regular aerodynamic scheme and a semi-active homing seeker system. The first stage consists of four solid-fuel strap-on rocket boosters installed on the second stage.

3. S-200WE retrofitting to S-200C

In the 1990s, the Polish armed forces operated an extensive air defense system, technically based on short and medium-range SAM systems and two long-range S-200WE SAM system sites with their service life ranging several and 25 years. At the time, the cognizant management was aware of the ageing SAM systems and the necessity of retrofitting of the in-service armament. With the positive experiences from retrofitting the S-125 Neva SAM system, works were initiated to ascertain the feasibility of retrofitting the Polish Air Defense s latest SAM system, i.e. the S-200WE. The feasibility studies considered the SAMs in stock, the warehousing infrastructure, the engineering expansion of the launcher positions and technical facilities. It was decided that the combat capabilities would be restored by retrofitting the S-200WE.

It should be noted that the immense effective coverage of this SAM system was larger than half of the territory of Poland. The main drawback was the lack of the autonomous combat mission capability of the S-200WE, which prevented the territorial separation of the individual SAM system sites.

There were constraints considered to be imposed by analogue signal processing by the legacy generation of the SAM system, where the design of electronic instruments of the SAM guidance station was largely based on an energy-inefficient electron tube technology. Moreover, the natural wear and tear was compounded by the operational obsolescence of the SAM guidance station, a result of the reduced capability for its adaptation to complex and evolving prerequisites for defeating aerial targets. This factor reduced the combat effectiveness of the in-service S-200WE SAM system so deeply that its further use became unjustified.

The retrofitting work on the S-200WE was carried out between 1999 and 2002. The deep retrofit was performed by the personnel of the Military University of Technology headed by Professor Jan Pietrasieński and Wojskowe Zakłady Uzbrojenia (Defense Weapons Manufacturing) in Grudziądz. The deep retrofit was designed to separate and provide the SAM system (the targeting channels) with autonomous operational capabilities. Once retrofitted, the S-200WE re-entered service in 2003 under the designation S-200C Vega (where the character 'C' denoted the digitalization of the system).

The essence of the retrofitting project was intended to provide technical conditions which facilitated autonomous operation of both Vega SAM squadrons, enhanced combat capabilities, effectiveness of command, fire control and combat detail cooperation, and improved cost-benefit and operating characteristics through the application of modern functional, design, and technological solutions. The leading idea behind the retrofit of the S-200C Vega system was its maximum adaptation to modern conditions applicable to defeating aerial targets.

Due to technological, provisioning, cost-benefit and utility considerations, the retrofit of the SAM system included upgrading the instrumentation to meet the following objectives:

- the separation and autonomous operation capability of the SAM system sites;
- the preservation of the existing time-frequency, energy, and spatial performance of the radar signals output by the SAM system;
- the modernization of the signal processing lines;
- the replacement of hardware-processed functionalities with software procedures;
- the improvement of target indication and acquisition for tracking;
- the replacement of low-availability components with modern, high-availability components;
- the development of the new control tower version, the K7C;
- the automation and simplification of the SAM system operating procedures;
- the reduction of the technical staffing for the system;
- the reduction of the combat group size.

As a result of the retrofit, the K9 command cabin was removed from the SAM system. Its functions were moved to the fire control operator's post installed in the K2 cabin, which ensured the following: air situation imaging and analysis based on three coordinates, on-launcher SAM state evaluation, determination of parameters to aid fire command decisions, an indication of targets to track and SAM launch initiation. In connection with the extension of its anti-air combat control tasks, the K2 cabin was re-designated as the 'K2 command, control and instrumentation cabin'. The K2 cabin had more than 90% of the electron-tube instruments removed and replaced with modern, analogue and digital systems, with a considerably greater extent of software-based solutions.

The central piece of the retrofitted SAM system is a three-station command and control console installed in the K2 cabin. The functions provided by the command and control console and its design solutions are driven by the established organization of operational work and the tasks performed by each SAM combat group. The three stations of the console include the fire control operator station, the guidance control station and the target acquisition station. The SAM system operating management and fire control are initiated and determined at the fire control operator station. Target detection, acquisition, and tracking, as well as the TIR management, are initiated and operated at the guidance control station and the target acquisition station. The command and control console instruments manage the tasks with software and hardware. The developed imaging on the displays and the layout of the operating consoles greatly improved the work ergonomics of the SAM system combat group.

The process of target detection and of the guidance of the tracking systems to the target-reflected radar signal requires monitoring the air situation in the entire range of the target speed handled by the homing seeker system. Hence, the TIR functions were expanded to include continuous observation of the full range of target speed, facilitating acquisition for tracking and monitoring of the air situation during target tracking.

Particular attention was given to improving the SAM system's immunity to various electronic jamming strategies by applying effective digital methods for signal processing. Each retrofitted SAM system was equipped with training instruments, combat operation logging instruments and system instrument health self-testing capabilities.

4. Operating experience with the S-200C SAM system

Following the retrofit to the S-200C version, its operation revealed that the technical performance was markedly improved, resulting in the enhancement of combat characteristics of the SAM system.

The replacement of the electron tube instruments significantly improved the operating precision of the EHF hardware with a marked increase in reliability. Moreover, the functionally complex software of the system solutions was performed without fail. Based on the observation of combat operations and thousands of completed target acquisition and tracking operations, it was a valid conclusion that the retrofitted S-200C Vega instruments performed optimally in all types, modes, and conditions of operation. It was noted that during 17 years of operation of the S-200C Vega SAM system, the computers implemented with extensive digital data processing packages never suffered a freeze or a failure.

The digital data processing methods implemented by the retrofit produced very effective target distance measurement and calculation. During combat operation, the maximal target tracking distance was found to reach the maximum range of the TIR.

The counter-jamming measures implemented in the S-200C were proven to be effective. The S-200C Vega SAM system was deployed in many allied exercise missions, where it would counter hours-long air attacks in the presence of very strong and diverse jamming interferences without a single failure.

After many years of operation of this SAM system, the applied ergonomic solutions were rated very highly by the operator. Combat operations became more effective. The automatic test and diagnostic instrument solutions efficiently identified the locations and root causes of discovered faults. This greatly simplified and streamlined the maintenance of the S-200C Vega.

The organization of the operation of the SAM system combat group was modified due to the retrofit of the S-200C Vega version. The line-up of the technical personnel and the size of the combat group were significantly reduced.

To recapitulate, the post-retrofit S-200C provided the SAM system with autonomous operation; combat capabilities improved with the effectiveness of command, fire control, combat group cooperation, and improved maintenance and cost-benefit characteristics.

5. The functioning of the S-200C Vega SAM system on the modern battlefield

Since the Second World War, it is known that sustaining air superiority leads to victory in any military conflict. In order to counteract the complete control of the enemy in air operations, offensive and defense capabilities in the field of reconnaissance, communication, air and missile defense, termed as an Integrated Air Defense System (IADS) are organized. According to P.M. Mattes (2019), modern IADS "*is far more complex than a singular SAM battery (...)*" and it is "*the structure, equipment, personnel, procedures, and weapons used to counter the enemy's airborne penetration of one's own claimed territory*". Therefore modernized the S-200 C Vega should be the one of key elements of the defensive IADS for defeating air and missile threats that may be taken on the land, in the air, at sea, and in cyberspace and even space.

In the case of the S-200C Vega, current modernization should be provided to integrate within the Polish IADS at the appropriate functional, operational and structural level, similar to the requirements defined in FM-3-01 (2020). Additionally, it should be noted that according to the thesis of A. Radomyski (2016), quoting: *"In order to be able to join a collective defence effort conducted alongside NATO member states involving air defence assets, Poland has to adapt its air defence system to the functional requirements of NATO Air and Missile Defence System, NATINAMDS."*. Following the considerations of the same author (Radomyski, 2016): *"Development plans for the Polish air defence system should be convergent with the concept of NATO's integrated anti-aircraft and anti-missile warfare or counter-air defence concept that specifies in detail the Alliance air defence capabilities and organization."*. Therefore, the currently modernized S-200C Vega should be adapted to the above-mentioned plans for the development of Polish air defense system and constitute a temporary element of the Polish IADS for the next several years, until it is replaced by the new SAM system, acquired as part of the WISŁA program.

More and more new types of air threats appear on the modern battlefield. Their operating environment and method of use are properly described in Chapter III of F3-01 (2020). The S-200C Vega has limited capabilities in this regard. However, some analytical and simulation studies were conducted in order to investigate the possibilities of countering ballistic missiles (Pietrasieński, et al., 2006). The current modernization of the S-200C Vega does not significantly change its purpose in terms of the impact on selected types of air threats according to its originally designed capabilities. However, to some extent, it optimizes the crew's combat work and the process of air targets engagement.

As far as detailed analyzing tactical and technical functioning of the S-200C Vega SAM system on the modern battlefield is concerned, the fire effect capabilities deserve attention first. The S-200C Vega can effectively cover an area larger than half of the territory of Poland.

The leading idea behind the development of the S-200 Vega system was to ensure the maximum adaptation to the modern requirements in terms of combating airborne targets in the presence of high-intensity electronic jamming, SAM evasion maneuvers and attacks with anti-radiation missiles. In terms of its radar jamming immunity, the S-200C Vega is one of the best rated SAM systems used by the Polish armed forces.

The S-200C Vega SAM system has been suitably adapted to and integrated and into the Polish Air Force command system with unobstructed access to the air situation data output by higher levels in the chain. This largely simplified the functioning of individual components of the SAM system. For example, the system's target tracking circuit is formed by the SAM and target assembly, whereas the use of the TIR can be limited to target illumination only.

Another aspect to be highlighted is the high design and manufacturing quality of the missiles for the S-200C Vega, which continue to enjoy good technical condition thanks to proper storage and maintenance. Over many years of operation, the mechanical components of the SAMs were found to age at a negligible rate, and this is particularly true of the propulsion and aerodynamic components.

Other factors crucial for the functioning of the S-200C Vega SAM system on the modern battlefield include the inventory stocks of the missiles, an optimum warehousing infrastructure and engineering facilities consisting of launch bunkers and firing sites, or the technical facilities, which include missile assembly equipment as well as test and inspection stations. Thanks to the modern training instruments, it is possible to train and harmonize SAM system operating teams under near-lifelike conditions, like practice and combat operations in diverse scenarios of engagement of real airborne targets with strong radar jamming interferences, complete with simulated SAM launches and guidance to targets.

Finally, the last important aspect to be highlighted in terms of security is the necessity to establish specific and covert properties which are critical to the efficient functioning of the entire SAM system: a set of radar signals, encryption of radio control commands, or the operating conditions for the SAM on-board instruments. These properties were achieved by "proprietary Polish conversion" of the key retrofit solutions, making certain sensitive performance parameters of the S-200C Vega known to the Polish military and defense sector only.

6. Discussion and final remarks

The S-200C Vega SAM has a striking range of 250 km, which is the longest of all anti-aircraft systems used by the Polish Air Force. The S-200C Vega is intended to combat strategic targets or targets of tactical value (including air-to-surface missile carriers, electronic warfare and C2 aircraft, early warning and strike aircraft guidance stations, or flying tankers), operating at up to 1,200 m/s (in approach) and up to 300 m/s (in departure), at altitudes between 300 m and 41 km.

The example of the above described S-200C Vega SAM system clearly demonstrates that the procurement of technically complex armament usually entails consequences for decades, as this results from the military technology design standards. On the other hand, due to scientific and technical progress, it is impossible to keep SAM systems technically up-to-date without follow-up retrofitting. The need for countermeasures preventing the obsolescence of weapons have been increasing at an even higher rate What is considered to be the state-of-the-art today can become within obsolete several years into the future, and this fact is not always dependent on technical considerations, as military equipment may fall prey to espionage or exposure of its sensitive or secret specifications.

Due to the above obvious reasons, procurement of armament should entail the initiation of domestic retrofitting projects or participation in international research programs aimed at the modernization of the purchased weapons. Otherwise, the effect of the novelty will irreversibly expire in a matter of several years. The contractual clauses for armament sourcing should include requirements for disclosure of the data essential for facilitating modification and improvement of the weapons.

In an ideal scenario, equipment scheduled for overhaul is retrofitted simultaneously, as is the case with the current S-200C Vega SAM system. Some may say that a good way to modernize armament and make a technological leap forward is to purchase the relevant license. This is true provided suitable financial and organizational conditions are provided for its development and updating. Manufacturing alone is essential to economic growth, yet it is generally of little relevance to advances in science and engineering.

It should be also noted that a fundamentally negative aspect of importing armament is that all its tactical and technical parameters, and, by the same token, its combat advantages and weaknesses are known to the original manufacturer and the parties (legal or otherwise) in possession of the armament. For understandable reasons, it is prudent to assume that other parties interested in specific armament know this information too. This is primarily true in the case of complex weapon systems, particularly where the primary information about the object to be destroyed is carried by means of electromagnetic waves. This category of weapons includes SAM systems, which operate by radar to determine the target and missile trajectories coordinates. Therefore, there is an undisputed conclusion for the defense sector that absolute reliance on extremely advanced imported armament solutions is not advised. For this reason, certain areas of defense technologies require “proprietary Polish engineering”, which should be understood as endowing an armament solution with specific covert properties. These properties are necessary to ensure the mission capability of weapons in the complex conditions of the modern battlefield. This applies specifically to parameters of the radar signals transmitted by a SAM system, the encryption of its radio control commands and the operating conditions of the SAM on-board instruments.

Modern advanced hardware and software solutions are sensitive to remotely triggered operating interferences, which, even though they often remain unnoticeable, they have a severe impact on their combat performance. For example, to ensure correct operating conditions for target detection systems, the target thermal and sound signatures must be systematically updated to reflect the design modifications and modernization of the attack measures. In order to ensure the high effectiveness and long life of weapons, these updates cannot be outsourced from third parties.

In most cases, the loss of the effectiveness and the obsolescence of weapons is caused by a failure to allocate funds to retrofit programs. While Poland is not capable of developing and manufacturing a new SAM system, we are ready for retrofitting its critical components in terms of our domestic manufacturing and engineering capabilities. The advantage of the current state of affairs is that retrofitting the SAM systems in service in the Polish armed forces does not require a very high budget. There are no other methods to preserve the essential air defense capabilities which would offer better cost-effectiveness. The main argument here is the good technical condition of the SAMs' mechanical components and the hardware, which ensures many years of service life following the retrofitting of the SAM system instruments.

It should be noted that blocking domestic solutions and excluding Poland from the technological race is a mistake, even more so that due to fundamental and obvious reasons, the Polish specialty in armament retrofitting should be the implementation of proprietary Polish solutions.

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.

References

1. Bużantowicz, W., & Pietrasieński, J. (2018). Dual-control missile guidance: A simulation study. *Journal of Theoretical and Applied Mechanics*, *56*(3), 727-739. DOI: 10.15632/jtam-pl.56.3.727
2. Bużantowicz, W. (2021). *Potok technologiczny rakiet 5W28E. Podręcznik dla obsług pododdziałów technicznych*. Wojskowa Akademia Techniczna.
3. FM 3-01 (2020). *U.S. Army Air and Missile Defense Operations*. HQ Department of the Army, 22 December 2020.
4. Mattes, P., W. (2019). What is a Modern Integrated Air Defense System, *Air Force Magazine*. Retrieved from https://www.airforcemag.com/article/what-is-a-modern-integrated-air-defense-system/, 08.09.2021.
5. Openko, P., Tkachev, V., Maystrov, O., Drannyk, P., & Krasikov, O. (2020). Military-historical aspect of creating and improving the surface-to-air missile system S-200. *The Scientific Heritage*, *46*, 30-37.
6. Pang, C., Shan, G., Ma, W., & Xu, G. (2019). Sensor radiation interception risk control in target tracking. *Defence Technology*, *16*(3), 695-704. DOI: 10.1016/j.dt.2019.10.014
7. Pietrasieński, J., et al., (2006). *Analiza możliwości zwalczania rakiet balistycznych przeciwlotniczym zestawem rakietowym dalekiego zasięgu S-200C Wega*. Final report No PBG 205/2004, Military University of Technology.
8. Pomohaiev, I., Tarshyn, V., & Skoryk, A. (2020). Improved method of semi-active homing of surface-to-air missiles with measuring target-missile range. *Science and Technology of the Air Force of Ukraine*, *4*, 95-101. DOI: 10.30748/nitps.2020.41.11
9. Radomyski, A. (2016). *What are the development options of air defence capabilities of the Polish Armed Forces?*, Chapter III [In:] The future of the Air Forces and air defence units of Poland's Armed Forces, Report of Casimir Pulaski Foundation, pp. 62-74.
10. Turinskyi, O., & Skoryk, A. (2019). Design method of surface-to-air missiles using the object-oriented approach and electronic launch technology. *Science and Technology of the Air Force of Ukraine*, *2*, 133-142. DOI: 10.30748/nitps.2019.35.17

SAFETY&DEFENSE
ISSN 2450-551X

The Multi-Criteria Method for the Evaluation of Combat Capabilities of Surface to Air Missile Systems for the NAREW Program

Tomasz KULIK

Military University of Aviation, Dęblin, Poland;
t.kulik@law.mil.pl, ORCID: 0000-0003-4062-2552

DOI: https://doi.org/10.37105/sd.162

Abstract

The selection of weapon systems involves a number of activities to choose the best system in relation to the predefined operational requirements and other vital criteria. In the case of surface to air missile systems competing for the NAREW program, attempts are being made to obtain an asset that will be capable of engaging a spectrum of air threats, under specified conditions, with a predefined high degree of probability. In order to make the right choice, it is necessary to analyze information on performance and combat capabilities. Thus, the aim of this article is to develop a preliminary method of evaluating the capabilities of surface to air missile systems offered under the NAREW program. The theoretical foundation of the empirical study was provided by the method of literature content analysis. Using the methods of comparison and generalization, the author obtained data on the combat capabilities of surface to air missile systems expressed through their tactical and technical parameters. Among the empirical methods, the author applied the algorithm of a multi-criteria analysis and an assessment of the capabilities of surface to air missile systems based on the use of matrix calculus. The diagnostic survey, conducted by means of the questionnaire technique, made it possible to prioritize the adopted evaluation criteria and, consequently, to conduct proper research. The formulation of the final conclusions and establishing the links between the theoretical and empirical part of the study was achieved by means of a synthesis. The results obtained in such a manner may constitute a valuable information database, showing the directions that should be considered when selecting a short-range surface to air missile (SAM) system for Poland. The evaluations and suggestions included in this study can be used for prospective solutions and research conducted in a similar area.

Keywords:

air defense, combat capabilities, multi-criteria analysis, NAREW program, surface to air missile (SAM) system

Submitted: 29.08.2021 Accepted: 27.09.2021 Published: 20.10.2021

1. Introduction

The majority of surface to air missile systems operated by Polish armed forces are obsolete. The post-Soviet systems, although modernized, are not capable of effectively engaging contemporary air threats. High speeds, low observability, altitude changes or resistance to electronic interference have become standards for modern air and missile threats (Bużantowicz & Pietrasieński, 2018). This can be seen in the hypersonic missiles, developed by such military powers such as Russia, China India and the United States (Lee, 2019). With the ability to change their flight path or with speeds exceeding the speed of sound multiple times, surface to air missile systems are able to penetrate even a well-organized, multilayered air and missile defense in a relatively short time. It is assumed that in the event of a high-intensity conflict on NATO's eastern flank, a potential aggressor may use a range of unmanned and manned aircraft performing combat, reconnaissance and support tasks for its own long-range missile and artillery assets. It is to be expected that at least some of them, such as Grom, Piorun or Poprad, will launch stand-off attacks, outside the effective range of the Polish very short-range air defense systems (Cieślak, 2020).

Bearing in mind the urgent defense needs of the state, on September 17, 2013, a multiyear program was established by a resolution of the Council of Ministers,[1] in which priority tasks of technical modernization were defined under separate programs. It included essential expenditures and key tasks that were intended to provide the Polish Armed Forces with the required and desired operational capabilities in the long run. From the perspective of air defense operational requirements, the program for the development of the Polish air defense system, the implementation of which is due by the year 2022, is worth noting. The program called for fielding medium-range surface to air missile systems under WISŁA program, which would be capable of engaging both air and tactical ballistic missile threats. Another important element of the modernization program was the plans to aquire short-range surface to air missile systems under the NAREW program. The modernization of the air defense systems was also meant to introduce the Poprad vehicle-mounted surface into air missile systems, Grom/Piorun man-portable air defense systems (MANPADS), along with short-range anti-aircraft missile and artillery systems for the PILICA program. The program also includes the plans for the deployable Soła/Bystra 3D radars.

While the majority of the above-mentioned plans are being implemented without major disruptions, the NAREW program has been significantly delayed, and the Polish military is still working on the concept of developing a short-range air defense system. The problems related to the NAREW program seem complex, with a number of concerns related to technology transfer, cooperation with the Polish Armaments Group, or compatibility with existing and prospective air defense command, control and communication systems.[2]

Bearing in mind the aim of this article, the author aims at developing a preliminary method for assessing the capabilities of surface to air missile systems competing for the NAREW program. The article includes the findings of research carried out with various research methods. The theoretical methods included analysis, synthesis, generalization

[1] Resolution No. 164 of the Council of Ministers of 17 September 2013 on the establishment of the multiannual program *"Priority Tasks of Technical Modernization of the Armed Forces of the Republic of Poland within the framework of operational programs"*, Warsaw, 4 October 2013, p. 7.
[2] such as the proposed Polish C2-class command system or the American IBCS (Integrated Air and Missile Defense Battle Command System).

and inference. Within the empirical methods, the algorithm of a multi-criteria analysis based on the use of matrix calculus and the method of a diagnostic survey based on the questionnaire technique was applied.

2. The combat capabilities of surface to air missile systems

In order to determine the ability of a given component to perform a task and to achieve predefined objectives in combat, it is necessary to determine the combat capabilities of air defense units and assess the performance of weapon systems. A number of indicators are used for this purpose in air defense troops so as to relate an air defense system / forces (weapon systems, battery, battalion, regiment) to a space and time framework while assessing the effectiveness of their combat employment. The Lexicon of Military Knowledge (1979) defines combat capabilities as a set of quantitative and qualitative indicators characterizing the ability of a unit (subunit) to perform tactical tasks. Spatial indicators determine the environment in which combat tasks can be executed. Time indicators refer to the intensity and duration of the operations. Combat effectiveness indicators provide information on the ability to cover troops and facilities and to engage aerial threats. The main tangible indicators of combat capabilities relate to reconnaissance, fire and mobility (Kuriata, 2005).

The elements of combat capabilities that are considered to be the most important while assessing a particular surface to air missile system include the zone of engagement, and for various tactical scenarios, degree of mobility and ability of conducting autonomous operations (Andruszkiewicz & Głowiński, 2008). Bearing this in mind, it may be concluded that the combat capabilities of air defense troops will largely depend on the tactical and technical characteristics of the reconnaissance, command and fire control, and effector subsystems of their surface to air missile systems, along with skills of their operators. Moreover, available literature on the subject discusses other factors that influence the combat capabilities of air defense units, such as tactics applied by air threats, the strength of their own air defense troops in accordance with the tables of organization and equipment (TOE), and combat service and combat service support available.

The combat capabilities of troops equipped with surface to air missile systems are expressed by their ability to conduct combat operations and defend against air threats in various tactical scenarios (Zdrodowski et al. 1996). Depending on the adopted criteria, they may be expressed by air reconnaissance, fire capabilities, mobility and logistic capabilities.

Air reconnaissance capabilities are defined as the ability to obtain information about air threats and analyzing and processing it. They define the ability of a surface to air missile system as detecting, assessing, identifying and tracking an aerial object. They are conditioned by air reconnaissance elements of the surface to air missile system, the means of relaying information and the ability to obtaining information from other sources. An important factor that affects air reconnaissance involves the technical characteristics of radiolocation and optoelectronic sensors.

Fire capabilities are defined by the ability of an effector component of a surface to air missile system to perform the task of engaging an aerial threat within a specified time and space using a dedicated number of missiles. Some of the most important indicators describing fire capabilities are firing efficiency and combat effectiveness. It is assumed that the parameters expressing the firing effectiveness are such determinants as the probability of engaging aerial threats (kill probability) and the expected number of destroyed air threats. On the other hand, combat effectiveness characterizes the ability of a surface to air missile system (subunit) to perform its tasks. It is expressed by the ratio (quotient) of the number of targets engaged (the expected number of air threats) to the number of targets entering the engagement zone of a surface to air missile system (subunit). Fire capabilities of a surface to air missile system might also be assessed by calculating a segment of air-space protected against enemy air attacks. It may be defined as the radius around protected assets in which there is a possibility of continuous fire. Employing surface to air missile systems in this manner allows for engaging of aerial threats before they can execute their mission. Assessing the fire capabilities of a surface to air missile system (subunit) takes into account time needed for combat readiness expressed by the time required to start firing sequence. It is characterized by the readiness to fire at a target at maximum range, taking into account the delay in obtaining information from air reconnaissance sources. Mobility is characterized by the ability of surface to air missile systems (subunits) to move from the march to firing position (or vice versa), mobility on the roads and in a specific area, and the ability to engage other air targets (maneuver by fire). The logistic and combat supply capabilities of a surface to air missile system (subunit) are defined by, among others, the ability to carry a specific stock of missiles at a required time and place and in a specified state of readiness.

3. The methodology of a multi-criteria analysis and evaluation of combat capabilities of surface to air missile systems

The analysis and evaluation of the combat capabilities of military equipment consists of a number of activities aimed at selecting the best weapon option for the assumed operational capabilities. These capabilities result from specific operational needs. The operational requirements may result in modifying tactical employment of weapons systems or acquisition of new ones. The selection process of a new weapon system can be divided into four basic phases:

1. Analyzing and defining threats;
2. Analyzing and defining the operational capabilities to be achieved by the armed forces;
3. The way in which operational capability is achieved by the armed forces;
4. Evaluating and selecting a weapon system (Miszalski &Mitkow, 2011).

Phase four is the most extensive part related to the selection of a weapon system. As a result of this phase, a final selection of a specific system is made to facilitate a specific operational capability and thus to give the armed forces and the military security system the ability to respond to a specific threat. In the case of surface to air missile systems, a crucial element of this stage is an analysis of tactical-technical parameters characterizing the indicated combat capabilities (Figure 1).

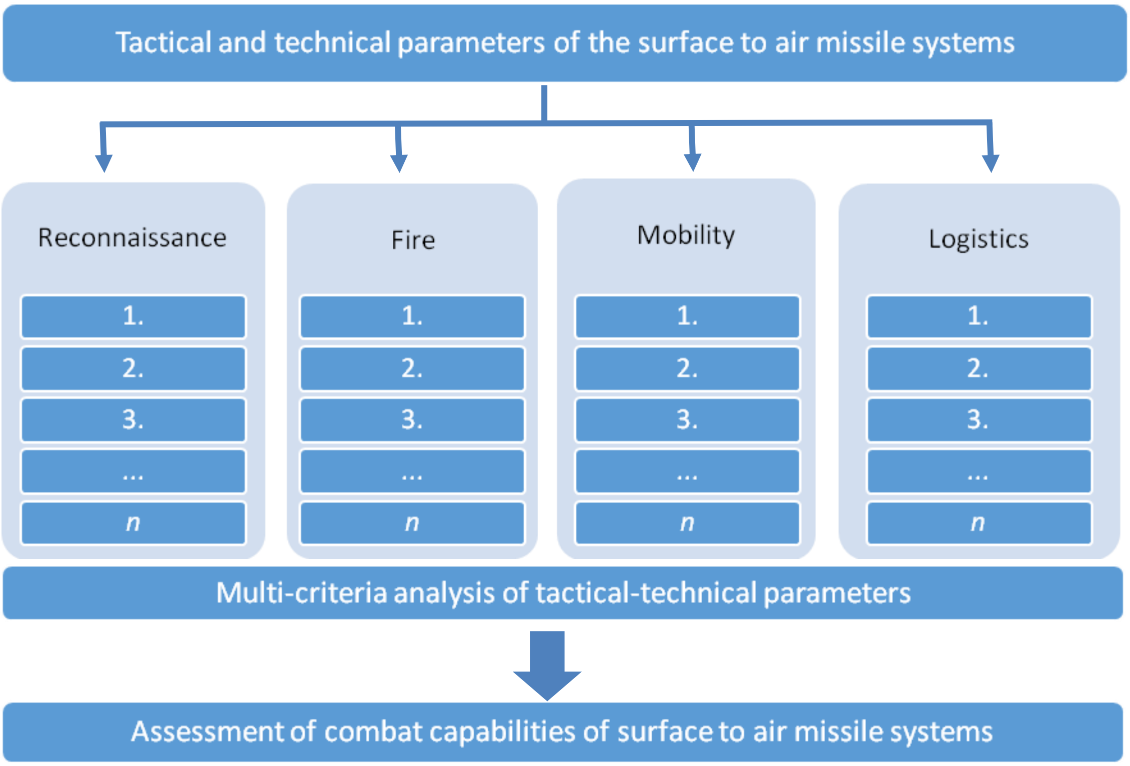


Figure 1. The multi-criteria analysis and evaluation of combat capabilities of surface to air missile systems. Author's own work adapted from: "Analiza wielokryterialna w procesie wyboru dostawcy systemu uzbrojenia" by S. Mitkow. Copyright 2013 by Polskie Wydawnictwo Ekonomiczne.

A multi-criteria approach was used to analyze and evaluate the combat capabilities of surface to air missile systems. When analyzing any issue, in the first place, the objectives of the analysis are defined, which can be described by means of corresponding criterion functions, in short - criteria. When making a comparative analysis of a selected type of armament, many decision-makers are guided by an assessment of the tactical and technical parameters that characterize their combat capabilities. Given a choice of several similar surface to air missile systems, it is difficult to immediately identify the best one, as even the simplest decisions involve several criteria. Quite frequently, the decisions taken are conflicting, as the indication may not fully meet the initial objectives. A multi-criteria discrete optimization may resolve this type of a problem.

Making a decision is usually associated with accepting a compromise on achieving the formulated objectives. It is usually not possible to make a decision so that the best values are achieved simultaneously for all of the criteria considered. It is assumed that in view of the practical impossibility of finding an optimal solution simultaneously for all criteria (i.e. a dominant solution), a multi-criteria solution is accepted as the one which is non-dominated. A non-dominated solution is one for which there is no decision variant, in which the value of a criterion could be improved without the necessity to reduce a value of another criterion. A set of non-dominated solutions forms a boundary efficiency.

Multi-criteria comparative analysis methods are designed to compare (evaluate) objects characterized by multiple features (parameters, decision variables) of an identical or similar functional purpose. The main objective of a multi-criteria comparative analysis is a prioritization of objects and their sets in a multi-dimensional feature space from the point of view of some characteristic that cannot be directly measured.

The basis for making comparisons is always a certain value-criterion system, which is a function of the relevant features of the objects compared. There are distinctive stages in the multi-criteria comparative analysis procedure. It starts with identification of compared objects and their parameters (quality features). Then the parameters are standardized. The next step involves the aggregation of parameters of the objects compared into a comprehensive quality indicator using additional information on the preferences of the decision-maker (Górny, 2004).

Bellinger's method is part of a group of methods for a multi-criteria comparative analysis, uses a simple algorithm that does not require complicated calculations. As a result, Bellinger's method was adopted for the evaluation of the combat capabilities of surface to air missile systems. Due to its interdisciplinary nature, it can be analyzed in different areas of activity and science, thus supporting the decision-making process in the area chosen by a concerned organization or a person. The essence of the method relies on putting analyzed objects in an order on the basis of the total evaluation value, determined from a set of partial criteria, which should be previously reduced to the form of additive values (Górny, 1999). For each criterion of a given decision variant, the most and least desirable state and the direction of change of this state (i.e. stimulants and destimulants) are determined. The assessment of each criterion in this range for a given object is a fraction of the total distance, being the difference between the above states. The best decision-making option becomes the object which obtains the highest value in the total evaluation (after summing up the evaluations of all criteria of a given object). Each criterion to be evaluated is assigned a significance for further weighting. Its size depends on the relevance of a given criterion for the decision-maker and the impact of the criterion on the overall decision-making situation. It is important that all of the weights of the individual criteria be evaluated to be selected in such a way that their sum is equal to unity. However, the way in which the weights are recorded is arbitrary.

Figure. 2 shows the algorithm of stages in the adopted method of a multi-criteria analysis of the combat capabilities of surface to air missile systems.

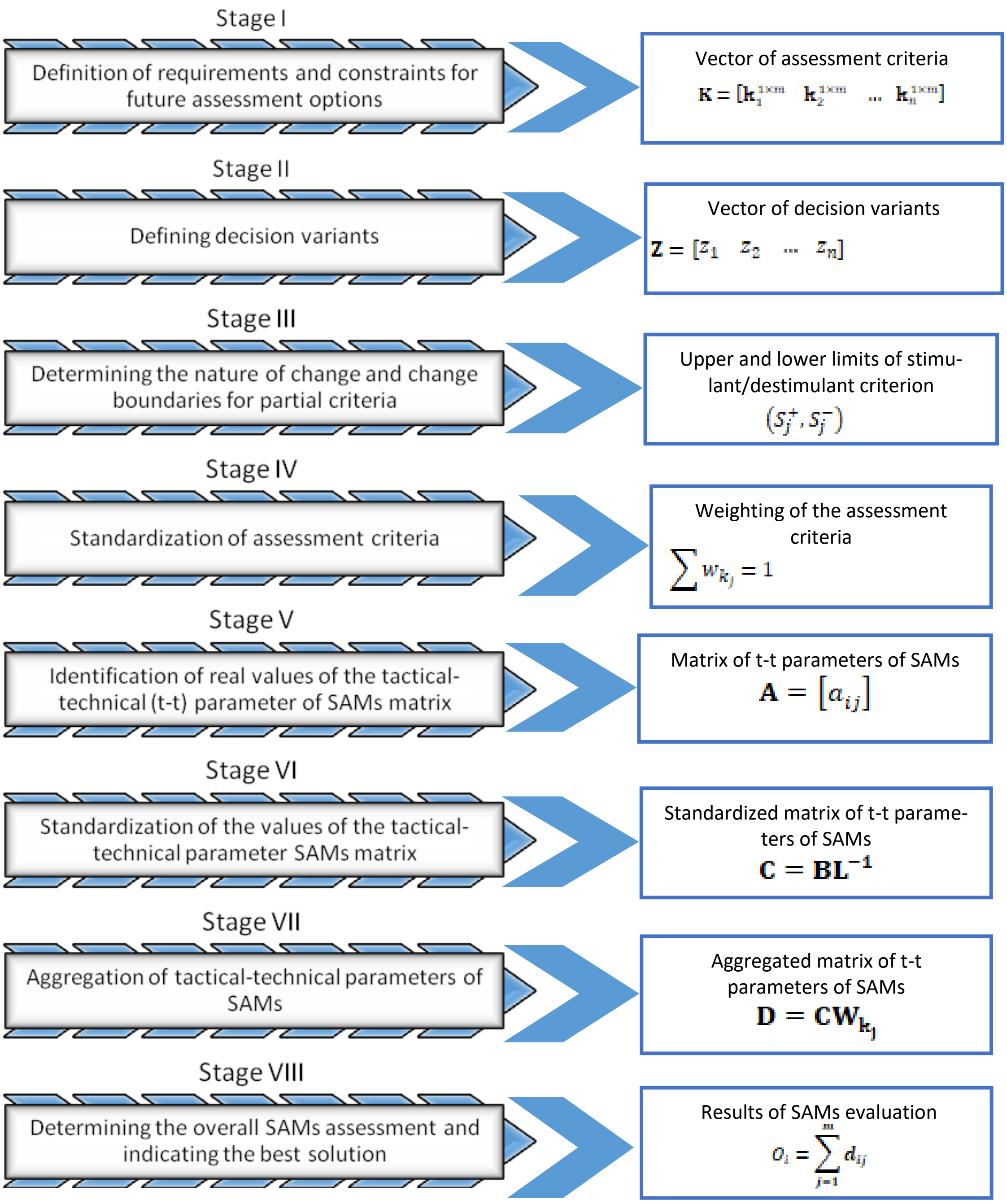


Figure 2. Algorithm of the multi-criteria analysis and evaluation of combat capabilities of surface to air missiles systems by means of Bellinger's method. Own work.

Stage one consists of identifying the requirements and constraints for future solution variants. In this phase, the criteria against which the analysis will be conducted, are defined. The evaluation criteria will be characterized by a vector as follows:

$$\mathbf{K} = [\mathbf{k}_1^{1\times m} \quad \mathbf{k}_2^{1\times m} \quad \dots \quad \mathbf{k}_n^{1\times m}] \tag{3.1}$$

Stage two consists of specifying decision alternatives, i.e. determining a set of surface to air missile systems to be analyzed, which will be characterized by a vector expressed as:

$$\mathbf{Z} = [z_1 \quad z_2 \quad \dots \quad z_n] \tag{3.2}$$

Stage three entails a detailed definition of the assessment criteria, the units of measurement, as well as the desired direction of change of the given criteria, i.e. stimulants indicating a preferable increase in values or destimulants indicating their decrease, together with boundary values of acceptable changes.

During this phase, the difference of the current value of the surface to air missiles systems parameter in relation to the most desirable value is also calculated. In order to determine it, it is necessary to calculate the arithmetic mean $X_j$of the values of particular variants in relation to particular sub-criteria:

$$X_j = \frac{1}{n}\sum_{i=1}^{n} a_{ij} \tag{3.3}$$

where: a_{ij}- the value of the *i-th* variant under *j-th* criterion.

This is followed by determining the boundary values of desirable S_j^+ and undesirable values S_j^-:

$$\text{If } z_j = \text{max} \text{then } S_j^+ = X_j \text{and } S_j^- = 0 \tag{3.4}$$

$$\text{If } z_j = \text{min} \text{then } S_j^+ = 0 \text{and } S_j^- = X_j \tag{3.5}$$

The obtained values allow the determination of the total distance L_j:

$$L_j = S_j^+ - S_j^- \tag{3.6}$$

Stage four is the stage in which the adopted evaluation criteria are prioritized by assigning them appropriate weights w_{k_j}in accordance with the following conditions:

$$w_{k_j} \geq 0 \tag{3.7}$$

$$\sum_{i=1}^{n} w_{k_j} = 1 \tag{3.8}$$

In stage five, the matrix **A**is created containing the actual values of the tested variants in relation to the individual criteria.

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1j} \\ a_{12} & a_{22} & \cdots & a_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ a_{i1} & a_{i2} & \cdots & a_{ij} \end{bmatrix} \tag{3.9}$$

where: *aij* - the value of the *i-th* variant under *j-th* criterion.

Stage six describes the elements of the matrix **A** as a percentage of the difference in the value of the actual state in relation to the most desirable one. For this purpose, matrix **B** is created, in which the calculated differences are placed. Next, matrix **C** is created, in which the elements of matrix **B** are presented as a percentage of the distance of the value of the actual state in relation to the most desired one.

$$\mathbf{B} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1j} \\ b_{21} & b_{22} & \cdots & b_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ b_{i1} & b_{i2} & \cdots & b_{ij} \end{bmatrix} = \begin{bmatrix} (a_{11} - S_1^-) & (a_{12} - S_2^-) & \cdots & (a_{1j} - S_j^-) \\ (a_{21} - S_1^-) & (a_{22} - S_2^-) & \cdots & (a_{2j} - S_j^-) \\ \cdots & \cdots & \cdots & \cdots \\ (a_{i1} - S_1^-) & (a_{i2} - S_2^-) & \cdots & (a_{ij} - S_j^-) \end{bmatrix} \tag{3.10}$$

$$\mathbf{C} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1j} \\ c_{21} & c_{22} & \cdots & c_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ c_{i1} & c_{i2} & \cdots & c_{ij} \end{bmatrix} = \begin{bmatrix} \frac{100b_{11}}{L_1} & \frac{100b_{12}}{L_2} & \cdots & \frac{100b_{1j}}{L_j} \\ \frac{100b_{21}}{L_1} & \frac{100b_{22}}{L_2} & \cdots & \frac{100b_{2j}}{L_j} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{100b_{i1}}{L_1} & \frac{100b_{i2}}{L_2} & \cdots & \frac{100b_{ij}}{L_j} \end{bmatrix} \quad (3.11)$$

In stage seven, matrix **D** is created, in which the products of matrix **C** elements with corresponding weights are described w_{kj}.

$$\mathbf{D} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1j} \\ d_{21} & d_{22} & \cdots & d_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ d_{i1} & d_{i2} & \cdots & d_{ij} \end{bmatrix} = \begin{bmatrix} c_{11}w_{k_1^1} & c_{12}w_{k_2^1} & \cdots & c_{1j}w_{k_j^i} \\ c_{12}w_{k_1^2} & c_{22}w_{k_2^2} & \cdots & c_{2j}w_{k_j^i} \\ \cdots & \cdots & \cdots & \cdots \\ c_{i1}w_{k_1^i} & c_{i2}w_{k_2^i} & \cdots & c_{ij}w_{k_j^i} \end{bmatrix} \quad (3.12)$$

In the last stage, stage eight, the overall assessment O_i for the analyzed development variants is determined, which is the sum of the partial assessments of the individual variants from the considered criteria.

$$O_i = \sum_{j=1}^{m} d_{ij} \quad (3.13)$$

On the basis of the value of the cumulative assessment, the armament variant with the best tactical and technical parameters is identified.

4. The multi-criteria analysis and evaluation of combat capabilities of surface to air missile systems

The analysis and evaluation of the combat capabilities of surface to missile systems, meeting the initial requirements of NAREW program, begins with the selection of their characteristic features in terms of reconnaissance, fire capabilities and mobility without considering the logistic capabilities.

The following designations for the vectors of the tactical and technical parameters of the surface to air missile systems' combat capability assessment have been adopted:

- **k1**- vector of tactical-technical parameters for the evaluation of reconnaissance capabilities;
- **k2**- vector of tactical-technical parameters of fire capabilities assessment;
- **k3**- vector of tactical-technical parameters for the assessment of mobility.

The set of evaluation criteria **K** will be characterized by a vector in the following form:

$$\mathbf{K} = [\mathbf{k}_1^{1\times 2} \quad \mathbf{k}_2^{1\times 4} \quad \ldots \quad \mathbf{k}_n^{1\times 2}] \quad (4.1)$$

for the assumed vector **K** , formula (4.1.), the criteria and the tactical-technical parameters characterizing them are summarized in Table 1.

Table 1.
Criteria and their characteristics adopted to assess the combat capabilities of surface to air missile systems.

Criterion of assessment				Features: tactical-technical parameters	Nature of criterion change*
Combat capabilities	Reconnaissance	$\mathbf{k_1}$	k_1^1	The maximum range of target detection [km]	S
			k_1^2	Number of simultaneously tracked targets	S
	Fire	$\mathbf{k_2}$	k_2^1	Spatial dimensions of engagement zone [km]	S
			k_2^2	Maximum engagement altitude [km]	S
			k_2^3	Missile velocity [m/s]	S
			k_2^4	Number of missiles in a launcher [missiles]	S
	Mobility	$\mathbf{k_3}$	k_3^1	Reaction time [s]	D
			k_3^2	Maximum mobility of SAM vehicles [km/h]	S

* S - stimulants; D - destimulants

For the purpose of the conducted analysis, it is assumed that the combat capabilities of the surface to air missile system will be expressed by three numerical tactical-technical parameters characterizing each of the features of the surface to air missile system.

Under the NAREW program, the Polish Armed Forces are to acquire several surface to air missile batteries of short-range SAM systems capable of engaging aerial threats at distances of up to 25 km. Israeli, British and Norwegian-American corporations have offered Poland the following products: Diehl Defense Holding (IRIS-T missile), MBDA Missile Systems (VL MICA and CAMM-ER missiles), Thales (VT-1 missile), Rafael Advanced Defense Systems (Derby and Python-5 missiles), Israel Aerospace Industries (Barak-8SR missile), Aselsan (AIHSF missile), Raytheon Company (AMRAAM and Stunner missiles) and Kongsberg Group (NASAMS II missiles). Each of the proposed systems features different combat capabilities.

A six-element vector was analyzed $\mathbf{Z} = [z_1 \quad z_2 \quad z_3 \quad z_4 \quad z_5 \quad z_p]$ in the configuration shown in Table 2, and the corresponding tactical and technical parameters have been summarized in Table 3. A vector $\mathbf{Z}$ is a set of five systems selected for the analysis of the systems. The SA-6 surface to air missile system (2K12 KUB),[3] which is in the inventory of the Polish Armed Forces, has been used for comparative purposes.

Table 2.
The hardware configuration of the analyzed SAM systems

	NASAMS	BARAK MX	VL MICA	IRIS-T SLM	EMADS	SA-6 KUB
Effector (missile)	AIM-120 C-8 AMRAAM-ER	BARAK MRAD	MICA FR/IR	IRIS-T	CAMM-ER	3M9M3E
Sensor	3D radar AN/MPQ64F1 Sentinel	M-2084 Multi Mission AESA 3D Radar	Radar TRML-3D/32	SAAB Giraffe AMB Radar	SAAB Giraffe 4A Radar	SURN 1S91 (SSWN)

[3] The 2K12 KUB system exploited in Poland has been used only for reference purposes.

Table 3.
A summary of parameter values of the evaluation criteria and their limits of change

Criterion of assessment			Parameter values						Auxiliary calculation values	
			NASAMS	BARAK MX	VL MICA	IRIS-T SLM	EMADS	KUB		
			Z1	*Z2*	*Z3*	*Z4*	*Z5*	Z_p	X_j	L_j
Combat capabilities	**k_1**	k_1^1	120	470	200	180	280	65	219	219
		k_1^2	60	1100	400	200	800	100[4]	443	443
	k_2	k_2^1	40	35	20	40	40	24	33	33
		k_2^2	14	20	9	20	10	7[5]	13	13
		k_2^3	1,350	680	1,360	1,100	1,020	950	1,077	1,077
		k_2^4	6	8	4	8[6]	8	3	6	6
	k_3	k_3^1	1,200	120	600	600	1,200	420	690	-690
		k_3^2	60	60	60	60	60	50	58	58

In the next stage of the analysis, the adopted evaluation criteria were prioritized by assigning appropriate weights to them. The weight values of the individual evaluation criteria were determined on the basis of the experts' preferences during a survey with a total of thirty respondents, who were academic teachers from military universities working on air defense issues as well as officers serving in air defense units. The standardized weighting values for the individual assessment criteria are shown in Table 4.

Table 4.
A summary of the weighting values of the individual evaluation criteria

Weighting of the assessment criterion	$w_{k_1^1}$	$w_{k_1^2}$	$w_{k_2^1}$	$w_{k_2^2}$	$w_{k_2^3}$	$w_{k_2^4}$	$w_{k_3^1}$	$w_{k_3^2}$
Weight value	0.165	0.118	0.147	0.154	0.132	0.088	0.150	0.046

The input data for the evaluation of the combat capabilities of surface to air missile systems is matrix **A**, whose form for the actual quantities listed in Table 3, are as follows:

$$\mathbf{A}=\begin{bmatrix} 120 & 470 & 200 & 180 & 280 & 65 \\ 60 & 1100 & 400 & 200 & 800 & 100 \\ 40 & 35 & 20 & 40 & 40 & 24 \\ 14 & 20 & 9 & 20 & 10 & 7 \\ 1350 & 680 & 1360 & 1100 & 1020 & 950 \\ 6 & 8 & 4 & 8 & 8 & 3 \\ 1200 & 120 & 600 & 600 & 1200 & 420 \\ 60 & 60 & 60 & 60 & 60 & 50 \end{bmatrix}$$

4 Value adopted on the basis of expert interviews.
5 With Rega-Łowcza system (without K1 cabin).
6 Initially the system was mounted on the Polish manufactured Jelcz undercarriage and displayed during the International Exhibition of Defense Industry held in Kielce in 2015.

The final form of matrix **C**, in which its individual elements constitute a percentage of the distance of the actual state values of the parameters in relation to the most desired value, equals:

$$\mathbf{C}=\begin{bmatrix} \frac{100b_{11}}{L_1} & \frac{100b_{12}}{L_2} & \cdots & \frac{100b_{1j}}{L_j} \\ \frac{100b_{21}}{L_1} & \frac{100b_{22}}{L_2} & \cdots & \frac{100b_{2j}}{L_j} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{100b_{i1}}{L_1} & \frac{100b_{i2}}{L_2} & \cdots & \frac{100b_{ij}}{L_j} \end{bmatrix}=\begin{bmatrix} 55 & 214 & 91 & 82 & 128 & 30 \\ 14 & 248 & 90 & 45 & 180 & 23 \\ 121 & 106 & 60 & 121 & 121 & 72 \\ 105 & 150 & 68 & 150 & 75 & 53 \\ 125 & 63 & 126 & 102 & 95 & 88 \\ 97 & 130 & 65 & 130 & 130 & 49 \\ -74 & 83 & 13 & 13 & -74 & 39 \\ 103 & 103 & 103 & 103 & 103 & 86 \end{bmatrix}$$

The final form of matrix **D**, which is the product of the elements of matrix **C** and the corresponding weights $w_{k_j^i}$ equals:

$$\mathbf{D}=\begin{bmatrix} c_{11}w_{k_1^1} & c_{12}w_{k_2^1} & \cdots & c_{1j}w_{k_j^i} \\ c_{12}w_{k_1^2} & c_{22}w_{k_2^2} & \cdots & c_{2j}w_{k_j^i} \\ \cdots & \cdots & \cdots & \cdots \\ c_{i1}w_{k_1^i} & c_{i2}w_{k_2^i} & \cdots & c_{ij}w_{k_j^i} \end{bmatrix}=\begin{bmatrix} 9 & 35 & 15 & 14 & 21 & 5 \\ 2 & 29 & 11 & 5 & 21 & 3 \\ 18 & 16 & 9 & 18 & 18 & 11 \\ 16 & 23 & 10 & 23 & 12 & 8 \\ 17 & 8 & 17 & 13 & 13 & 12 \\ 9 & 11 & 6 & 11 & 11 & 4 \\ -11 & 12 & 2 & 2 & -11 & 6 \\ 5 & 5 & 5 & 5 & 5 & 4 \end{bmatrix}$$

The total assessment O_i for the analyzed surface to air missile systems, which is a sum of partial assessments of particular systems out of the considered criteria, is presented in Table 5 and depicted in Figure 3.

Table 5.
The cumulative assessment values of the analyzed armament alternatives.

NASAMS	BARAK MX	VL MICA	IRIS-T SLM	EMADS	SA-6 KUB
63	140	74	91	89	52

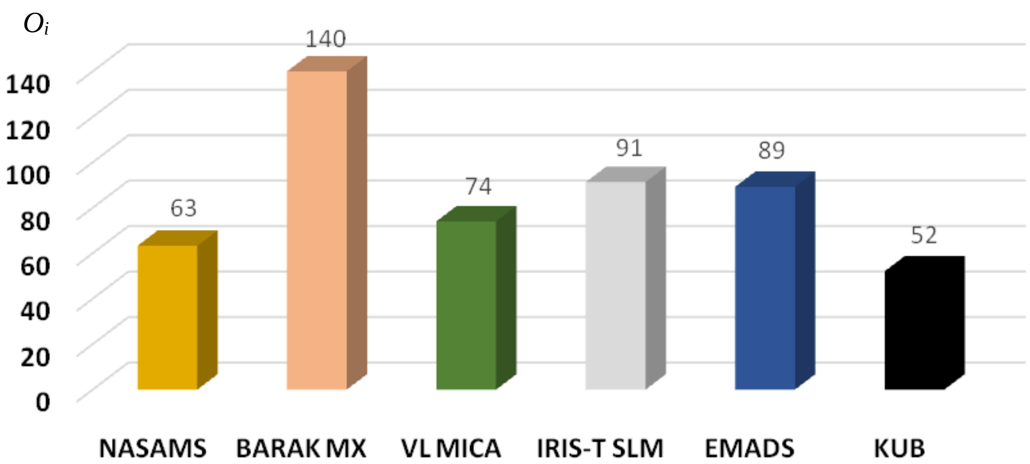


Figure 3. The overall evaluation of the combat capabilities of the examined armament variants. Author's own work.

The intermediate results of the discussed variants for the evaluation criteria under scrutiny have been illustrated in the bar diagrams in Figure 4.

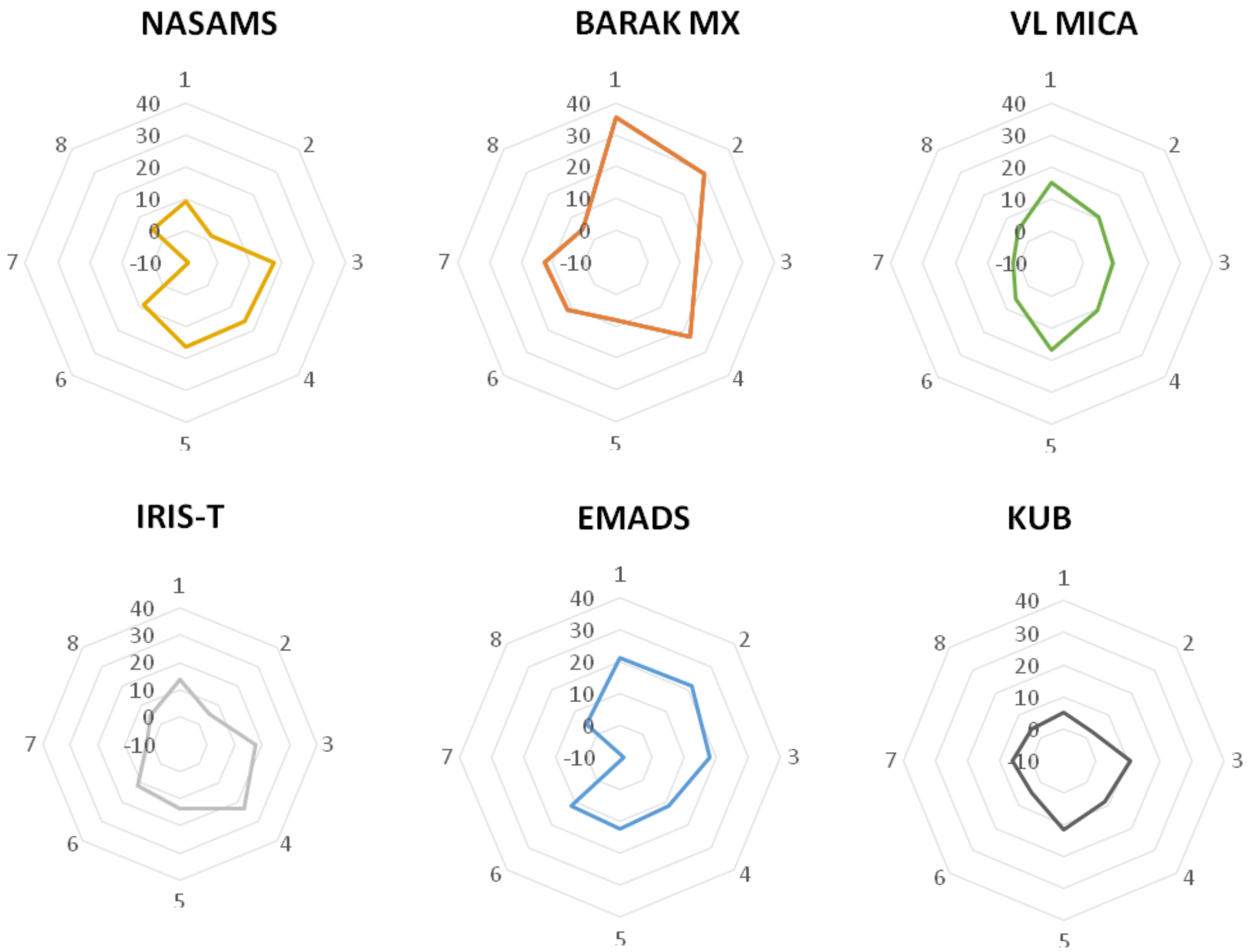


Figure 4. The detailed characteristics of combat capabilities of the analyzed SAMs variants (adopted axes labeling: 1 - k_1^1; 2 - k_1^2; 3 - k_2^1; 4 - k_2^2; 5 - k_2^3; 6 - k_2^4; 7 - k_3^1; 8 - k_3^2) (author's own development)

5. Conclusions

Based on the obtained findings, it can be observed that for each indicator of the combat capabilities features, the highest values were determined for the BARAK MX surface to air missile system. When analyzing the graph showing the comparison of values of the synthetic quality indicator of the systems, it can be concluded that the BARAK MX system is the most effective among the examined surface to air missile systems. In contrast, the lowest values for the adopted indicators of combat capabilities are featured by the SA-6 (KUB) system. However, it should be noted that the technical parameters of the surface to air missile systems used in the calculations are taken from generally available sources and do not necessarily reflect the systems' current technical characteristics. Consequently, the results obtained are representative since only a few parameters out of many others were compared in the conducted study. For the purpose of the conducted study,, certain criteria had been adopted. The author does not intend to select the best or the worst surface to air missile system for the NAREW program. His deliberations are to encourage discussion about making such choices. The adopted manner of reasoning and the presented method for evaluating the combat capabilities of surface to air missile systems are intended to indicate one of the possible directions in their selection. If more input data are used, and the criteria are expanded, the result of the combined combat capability assessment may give a more comprehensive picture of the analyzed surface to air systems, and their selection may prove easier.

Knowledge and practical consideration of the indicators of the combat capabilities of surface to air missile systems form the basis for making rational decisions on their combat employment. This, in turn, allows for a rational approach to planning for tactical employment, the formation of a combat task force, and coordination with other elements of the integrated air defense system. Due to less expensive missiles and a higher number of launchers than the PATRIOT system, the surface to air missile systems planned for the NAREW program will be better suited for providing effective air defense for critical zones and areas such as land forces troops 'groupings, air bases and logistic support assets or command posts. Taking into account the combat capabilities of such current surface to air missile systems, including SA-8 OSA, SA-6 KUB, and SA-3 NEWA, it is not difficult to notice that on today's battlefield, the ability to engage and destroy a one air threat at a time is not a solution. Therefore, there is a real need for surface to air missile systems that are capable of simultaneous engagement of multiple air threats, such as aircraft, helicopters, UAVs, cruise missiles, and loitering munitions. It is important that such surface to air missile systems are compatible with national and allied command and control systems, air reconnaissance assets and other weapon systems. Moreover, new surface to air missile systems planned for the NAREW program should be capable of acquiring and exchanging information on the air threats. In addition, they also have the ability to simultaneously engage several air targets with a high probability of kill. Hence, every effort should be made to ensure that the surface to air missile systems acquired within the framework of the NAREW program will, on one hand, possess appropriate combat capabilities and, on the other hand, become an integral element of the Polish air defense system, enabling its reliable and effective operations.

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

References

1. Lele, A. *(2019)*. Hypersonic weapon. *Disruptive Technologies for the Militaries and Security, 132*. 47-78. DOI: 10.1007/ 978- 981-13- 3384- 2/045002
2. Cieślak, E., (2020). The Development of Poland's Air Defense System: The Operational Context. *Safety and Defense Scientific and Technical Journal,6*(1). 1-10.https://doi.org/10.37105/sd.44
3. *Leksykon wiedzy wojskowej*. (1979). Ministerstwo Obrony Narodowej.
4. Andruszkiewicz M., Głowiński J. (2008). *Osłona przeciwlotnicza w działaniach taktycznych (dywizjony pułków)*. Wyższa Szkoła Oficerska Wojsk Lądowych.

5. Zdrodowski B., Groszek Z., Bobkowski A., Dubrawski Z., Miodek S., Koliński K., Kubow R., Marciniak M., & Skwarek Z. (1996). *Obrona powietrzna*, Akademia Obrony Narodowej.
6. Kuriata R. (2005). *Obrona przeciwlotnicza wojsk*. Akademia Obrony Narodowej.
7. Bużantowicz W., Pietrasieński J. (2018). Dual-control missile guidance: a simulation study, *Journal of Theoretical and Applied Mechanics, 56* (3). 727-739. https://doi.org/10.15632/jtam-pl.56.3.727
8. Mitkow S. (2013), *Analiza wielokryterialna w procesie wyboru dostawcy systemu uzbrojenia*, Gospodarka Materiałowa i Logistyka no 5, CD, 385. Polskie Wydawnictwo Ekonomiczne.
9. Miszalski W.,Mitkow, Sz.(2011). On certain methodologies of technology assessment for national security, *Studia Bezpieczeństwa Narodowego 1*(29), Wojskowa Akademia Techniczna. ISSN 2082- 2677, pp 27-50.
10. Górny P. (2004). *Elementy analizy decyzyjnej*, Akademia Obrony Narodowej.
11. Górny P. (1999). *Metody analityczno-ocenowe w analizie systemowej ugrupowań bojowych, systemów uzbrojenia i techniki bojowej*. Akademia Obrony Narodowej.
12. Rada Ministrów. 17.09.2013.*Uchwała Rady Ministrów nr 146 z dnia 17 września 2013 r. w sprawie ustanowienia wieloletniego programu obejmującego priorytetowe zadania modernizacji technicznej Sił Zbrojnych Rzeczypospolitej Polskiej*.Retrieved fromhttp://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WMP20130000796, 20.07.2021
13. Ministerstwo Obrony Narodowej.10.2013. *Program rozwoju Sił Zbrojnych RP w latach 2013–2022*.
14. Sejm. 25.05.2021.*Ustawa z dnia 25 maja 2001 r. o przebudowie i modernizacji technicznej oraz finansowaniu Sił Zbrojnych Rzeczypospolitej Polskiej (Dz. U. z 2009 r. Nr 67, poz. 570, z późn. zm.)*.Retrieved fromhttps://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20010760804, 20.07.2021 r.

SAFETY & DEFENSE ISSN 2450-551X

An Analysis of the Factors Affecting the Number of Safety Incidents in Civil Aviation

Patrycja GUZANEK[1*], Anna BORUCKA[2]

[1] Military University of Technology, Faculty of Safety, Logistics and Management, Warsaw; patrycja.guzanek@student.wat.edu.pl, ORCID: 0000-0001-6650-7187
[2] Military University of Technology, Faculty of Safety, Logistics and Management, Warsaw; anna.borucka@wat.edu.pl, ORCID: 0000-0002-7892-9640
* Corresponding author

DOI: https://doi.org/10.37105/sd.145

Abstract

Aviation is the youngest of the transport industries, yet despite its short history, it is considered one of the most important spheres of transport, both in terms of passenger and cargo transportation. Civil aviation is used by an increasing number of people, and the number of aircraft used by airlines around the world continues to grow. An inherent element that is a particularly important aspect of this mode of transportation is security. In civil aviation, there are numerous dangers associated with events occurring before the flight, during the flight, as well as those associated with the landing process. The events need to be controlled and their causes actively sought and ultimately prevented. The Polish Civil Aviation Authority, as part of the creation of the National Civil Aviation Safety Program, developed the National Safety Plan 2020-2023. The document covers threats identified in the Systemic, European, and National Areas. They are characterized and classified based on the materiality (significance) of the event. The aim of this article is to characterize and analyze selected factors (e.g. collisions with birds, helicopter events) that affect the number of safety incidents in civil aviation. The background of the study was the analysis and synthesis of the literature on the subject, while the main research method was the statistical analysis of historical data on aviation incidents. The data provided in Poland's National Security Plan 2020-2023 were used to distinguish the factors associated with the threats present and synthetically evaluate their impact. The analyses made it possible to identify areas of particular safety risks and form the basis for further detailed research.

Keywords

air transport, civil aviation, safety incidents, transport safety

Submitted: 19.07.2021 Accepted: 19.08.2021 Published: 20.10.2021

1. Introduction

Aviation has developed rapidly and is now one of the most important transportation industries. The number of flights performed each year is increasing (Menon, 2019). Air transport is used extensively for both passenger traffic and the movement of material goods. Air travel is generally considered to be very safe, however, as with any mode of transportation, there are incidents that threaten the safety of flying (Denney et al., 2019).

Therefore, the problem of aviation safety is frequently addressed in literature on the subject. In a general way, focusing on the assessment of risk and safety in civil aviation, the causes of aircraft accidents were described by Janic (2000). The article takes into account factors such as air, water, soil or noise pollution, waste management and congestion. A similar analysis was made by Janic together with Netjasov (2008). Their publication presented an overview of existing research on risk and safety modeling in civil aviation. Cui and Li (2015), on the other hand, focused on the issue of safety efficiency in civil aviation in their publication. This article proposed an efficiency model, taking into account labor, capital, funds, and technology.

Ni et al. (2019) focused on major accidents and incidents affecting aviation safety. Their publication proposes forecasting the number of hazardous events using deep learning methods based on Big Data resources. In contrast, Greenberg et al. (2005) proposed the use of a Bayesian Belief Network to study civil aviation accident rates. The model considered the influence of airline policies and social behavior patterns.

In his article, Zieliński (2010) focused on the airport as a place where security issues are addressed by both state and non-state actors. He described the services responsible for maintaining security and their duties. By contrast, Szafran (2018) highlighted the relationship between decision-making and safety in aviation in his publication. Publications on aviation safety also consider the area of cybersecurity (Cieślak, 2016). Cyber threats in aviation are a serious concern and are no less significant than threats directly related to the physical control of the aircraft.

The considerations contained in this article concern Polish civil aviation. The authors focused on the issue of air transport safety. The essence of the National Aviation Safety Program is described, and data from the National Safety Plan 2020-2023 are used to analyze factors affecting safety (only such data was made available to the authors). Information concerning the National Threat Area was also used. The aim of this article is to characterize and analyze selected factors that affect the number of safety incidents in civil aviation. The background of the study was the analysis and synthesis of the literature on the subject, while the main research method was the statistical analysis of historical data on aviation incidents.

As part of the analysis, information was obtained on the type of threats occurring most frequently in Polish civil aviation. The study provides a basis for further detailed analyses, allowing us to identify and foresee threats as time series models, based on more accurate data, from a wider time interval. Research can also be expanded to include threats from the Systemic and European Threat Areas. Similar analyses can also be conducted for other modes of transportation.

2. The issue of safety in civil aviation

The concept of safety can be defined depending on a specific area. Safety is usually defined as a condition in which the risk of harm to a person or property is reduced to an acceptable level or is below such a level. Moreover, it is maintained at that level (or lower) through continuous processes of hazard identification and risk management (Ilków, 2011). Therefore, it is undeniable that safety is closely related to dynamics -especially in the aspect of both building it and providing it. In view of this, safety manifests itself mainly in actions implemented against threats and those that mitigate risks (Bielski & Krawczyk, 2010).

In “Leksykon wiedzy wojskowej” [The Lexicon of Military Knowledge] (Auerbach, 1979), flight safety is defined as certain conditions that ensure that an aircraft performs its flight without endangering the safety of the crew, passengers, and the aircraft itself, as well as the population and facilities on the ground. Safety in air transport is also defined as a property of a system to operate under certain environmental conditions without the occurrence of accidents and adverse events (Żurek, 2009). Flight safety can be attributed to the following characteristics (Łuczak et al., 2016):

- loss avoidance;
- no accidents or incidents;
- ensuring that flight operations are conducted in such a way as to avoid unnecessary hazards;
- controlling and maintaining risk at an appropriate level;
- people's attitudes toward unsafe activities and conditions;
- error avoidance;
- compliance with regulations and institutions.

However, flight safety is primarily defined by the relevant international and state institutions. Appendix 19 of the Convention on International Civil Aviation, entitled “Safety Management”, provides the definitions of key terms related to civil aviation safety. In this document, safety is described as a state in which the risks associated with aviation activities have been reduced to an acceptable level and are kept under control. A hazard is defined as a condition or object that has the potential of causing or contributing to an incident or accident. An incident is defined as an event, other than an accident, associated with the operation of an aircraft that has (or could have) an impact on safety. An accident is an event in connection with the operation of an aircraft in which any person is killed or seriously injured, the aircraft is damaged or its structure destroyed, or the aircraft is lost or inaccessible.

There are five main elements in aviation that are sources of safety risk. These are represented in the 5M model. This model includes:

- human factor (Man);
- aircraft and related technology (Machine);
- operating space (Media);
- Mission;
- Management (Szymaniec, 2018).

Adequate control of and response to the elements listed above can have a positive effect on safety management in civil air traffic (Kasianov & Goncharenko, 2018).

In Poland, the authority responsible for civil aviation safety is the Civil Aviation Authority. It is a state institution, which is a government administration body responsible for civil aviation matters.

3. Hazards in Polish Civil Aviation – Safety Program and Plan

3.1. Poland's National Civil Aviation Safety Program

The Civil Aviation Authority defines its primary objective as ensuring a high level of safety in civil aviation. The institution wants to achieve it, among others, through the implementation and development of the National Civil Aviation Safety Program (NCASP). The purpose of the NCASP is to accomplish the integration of the state's safety management activities in the areas of both legislation and state policy and objectives and to promote safety and oversight of safety management systems.

The document provides information on safety oversight in civil aviation. The modern approach to safety is based on a safety management system and a national safety program. The system assumes that appropriate preventive actions are taken that can protect the aircraft from the threat.

The National Civil Aviation Safety Program incorporates regulations introduced by the International Civil Aviation Organization regarding the Safety Management System. It also complies with European regulations. The European Parliament, together with the Council of the European Union, has established rules related to safety management in civil aviation. National regulations are based, among others, on the Act of July 3, 2002, Aviation Law (Journal of Laws of 2020, item 1970) and on Article 30 of the Regulation of the Minister of Infrastructure of October 9, 2020, on the control of compliance with regulations and decisions in the field of civil aviation (Journal of Laws of 2020, item 1843).

The document describes the investigation of air accidents and the responsibilities and powers of state authorities. Importantly, it also describes a mandatory system for reporting aviation events.

3.2. Poland's National Safety Plan

The National Safety Plan 2020-2023, on which this study is based, is an appendix to Poland's National Civil Aviation Safety Program. It includes data on aviation accidents from 2011-2019 and such data were used in the presented study. The purpose of the document is to indicate the areas of risk that should be covered by the procedure of detailed analyses and supervision of the President of the Civil Aviation Authority. The Safety Plan draws information about the sources of hazards from sources operating at three levels. At the global level it is the Global Aviation Safety Plan. Meanwhile, at the European level, it is the Regional (European) Aviation Safety Plan. The third level is the national level, which is considered in this paper. National hazard areas include:

- collisions with birds;
- threats from animals;
- unmanned aerial vehicle operations;
- blinding the pilots with lights from the ground;
- aircraft events related to glider towing;
- performing operations with limited visibility;
- events involving the transportation of hazardous materials;
- helicopter events;
- Foreign Object Damage (FOD) events.

This paper analyzes the number of events that occurred in civil aviation between 2011 and 2019 that are listed on the National Hazard Register. The hazards noted can be described as:

— accident – an event in which any person is injured, an aircraft is damaged, an aircraft is lost;
— serious incident – a near-miss event;
— incident – an event, other than an accident, related to the operation of an aircraft that may affect safety;
— event – a situation occurring in air traffic, not assigned to any other group.

4. An analysis of the factors affecting flight safety

Aviation is steadily gaining popularity and, despite its short history, it is growing rapidly as a branch of transportation. Over the years 2011-2019, the number of flight operations has steadily increased (Figure 1).

Figure 1. The number of flight operations from 2011 to 2019. The author's own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

The data shown in the chart refer to domestic and international passenger traffic, charters and regular connections. Nearly 1/3 of the presented operations were performed by Polish carriers. There was a noticeable increase in the number of flight operations throughout 2011 and 2012. There was a decrease in 2013, but the chart shows a steady increase in subsequent years. The number of operations recorded in 2019 amounted to 398,073, the highest to date. The cumulative growth in the number of flight operations during the period under review was over 61%.

As the number of flight operations increases, so does the number of passengers using air transportation. The data presented also refer to domestic and international passenger traffic, charters as well as regular connections. About ¼ of passengers used Polish carriers (Fig. 2).

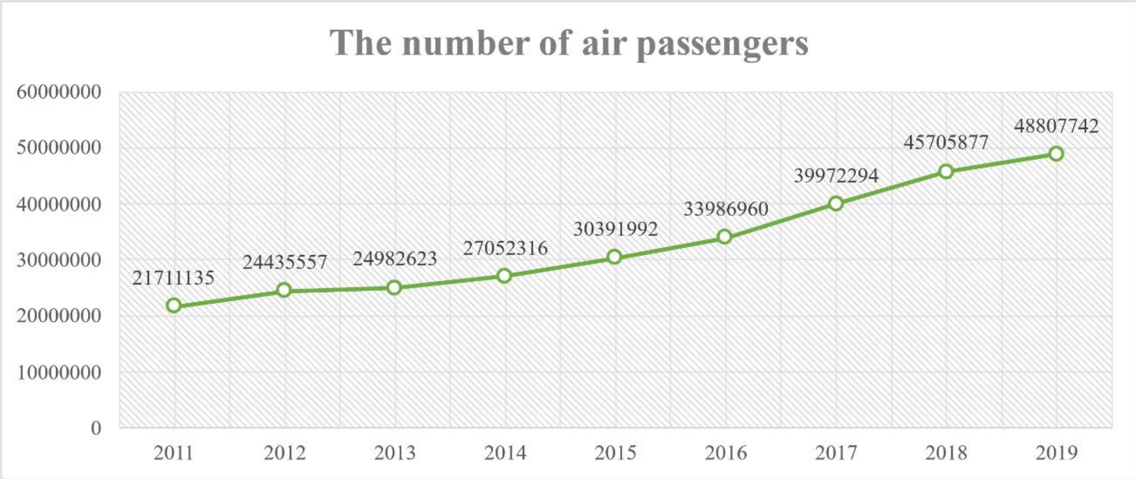


Figure 2. The number of air passengers from 2011 to 2019. The author's own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

The chart showing the number of passengers is strongly related to the chart showing the number of flight operations. The increase occurred in late 2011 and early 2012. There was a decrease in 2013, and a steady upward trend is evident in subsequent years. In 2019, 48,807,742 passengers used civil air transportation. It was determined that the cumulative passenger growth between 2011 and 2019 was nearly 125%. The number of aviation events increased steadily during the study period. In 2011, 1,601 cases were reported, and in 2019, as many as 5,838 aviation events were reported (Figure 3).

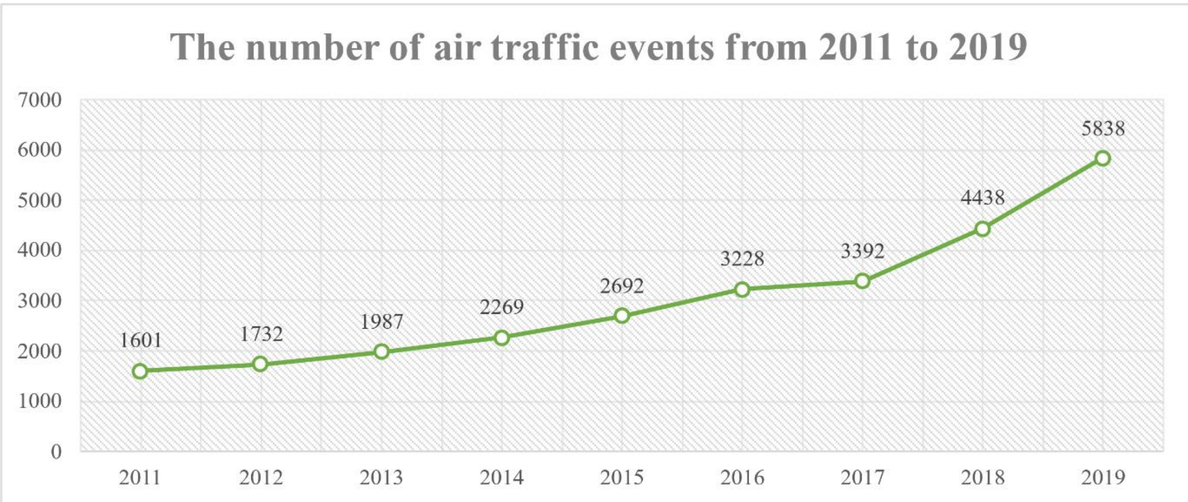


Figure 3. The number of air traffic events from 2011 to 2019. The author's own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

Civil aviation accidents and serious incidents were also reported from 2011 to 2019 (Fig. 4).

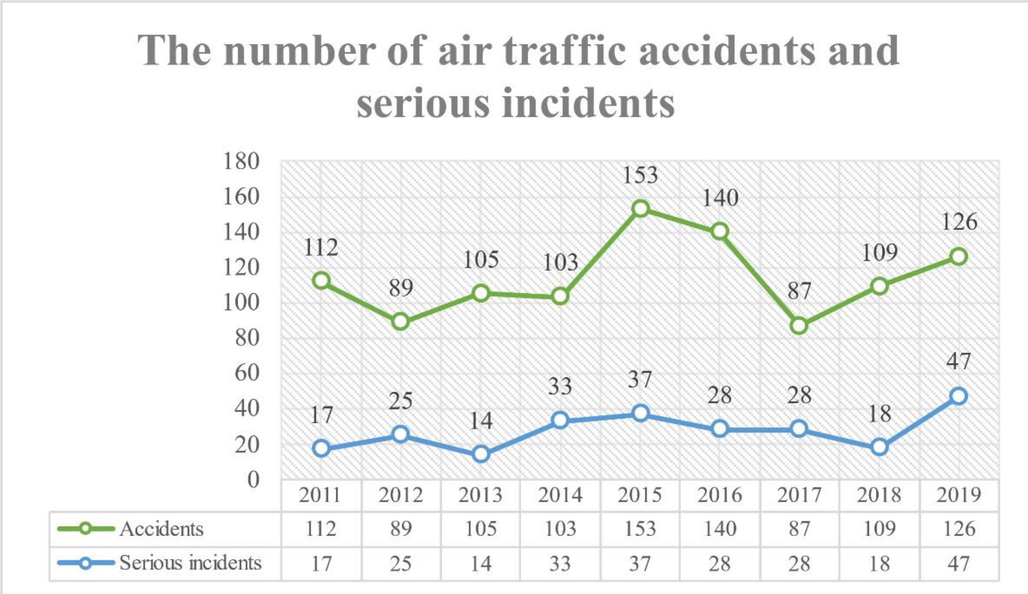


Figure 4. The number of air traffic accidents and serious incidents from 2011 to 2019. The author's own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

The average number of accidents is 114 per year, the average number of serious incidents is 27. In contrast, the average total number of accidents and serious incidents is 71 incidents per year. The highest number of such events occurred in 2015 and 2016.

The National Hazard Area identifies birdstrike events as the first of the threats. Events of this nature did not result in an aircraft accident during the study period; however, there was a nearly fivefold increase in birdstrike incidents between 2011 and 2019 (Figure 5).

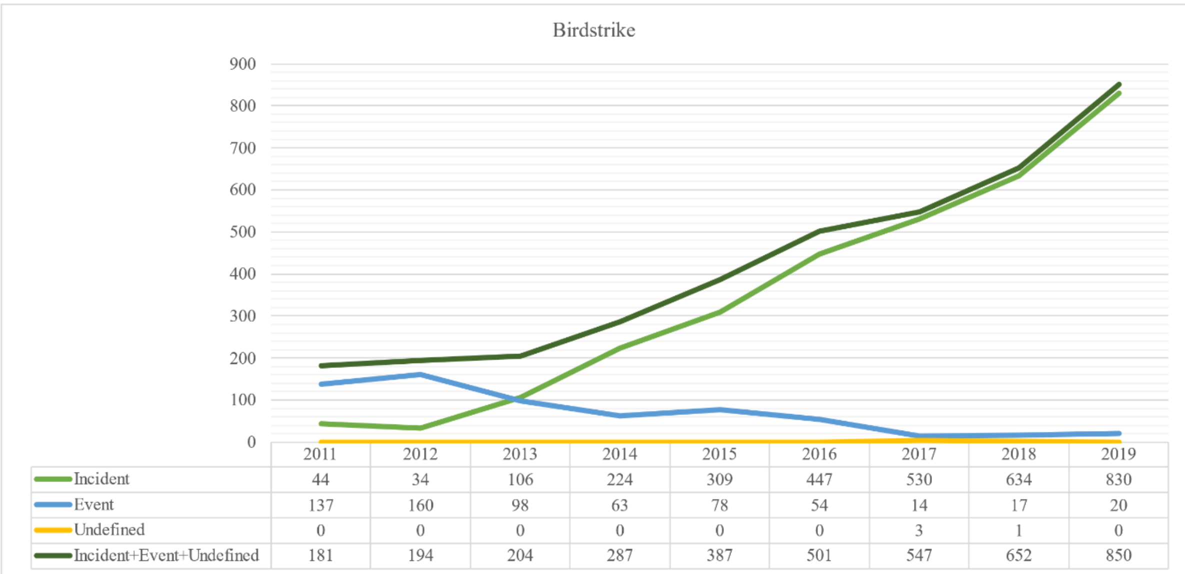


Figure 5. The number of birdstrike events in air traffic from 2011 to 2019. The author's own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

In 2011, there were only 181 events and incidents related to bird-aircraft collisions. However, the number steadily increased, and as many as 850 events of this nature were reported in 2019.

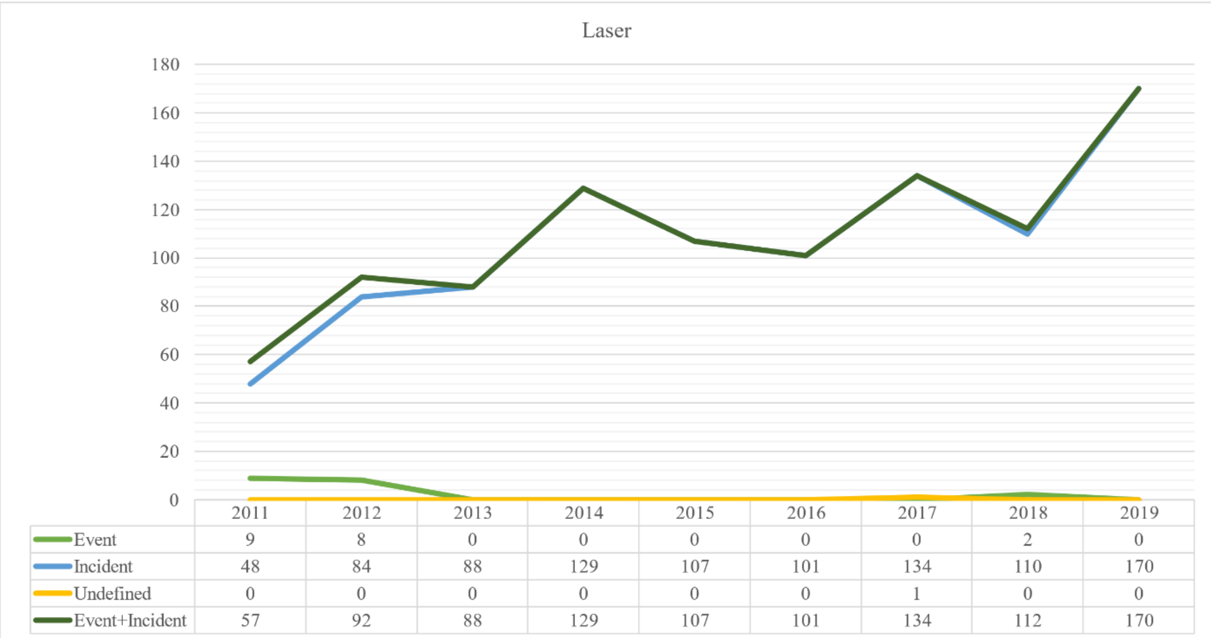
Another of the risks identified is wildlife hazards. These are closely related to the presence of wildlife on the airfield of airports. Collisions of this type also occur at major airports and can adversely affect the safety of passenger operations. During the study period, there were only two accidents correlated with the occurrence of wildlife on the airfield of airports.

Actions taken against risks associated with birds and wildlife include the development of a manual describing the methodology of risk management of aircraft collisions with birds and other animals at airports in FIR (Polish Flight Information Region) Warsaw. The goal of the effort is to maintain zero accidents that could be caused by the presence of animals.

Unmanned aerial vehicle (drone) operations are another hazard. They are one of the newest threats to civil aviation safety. UAVs appear in spaces above airports. Irresponsible behavior by drone owners stems from a lack of required licensing and adequate knowledge of airspace regulations. In 2019, the first accident involving the described hazard occurred, and the number has been increasing dramatically since then.

In 2011, there were six such events and incidents, and in 2015, there were already 18. In 2018, there were already 57 events and incidents, and as many as 75 events and inidents and one accident in 2019. Actions taken against this hazard include the continuation of the “Use your head when flying” information and education campaign aimed at the UAV industry and the planned introduction of a pilot program to deploy drone flight ban signs in specific zones. The objective of the actions taken was set to monitor UAV events to determine the actual threat level.

Blinding pilots with lights from the ground (lasers) was identified as another hazard. This hazard comes from deliberate violations of standards and regulations by third parties. The scale of the phenomenon is constantly growing, so it was decided to take preventive measures against it. There were numerous events and incidents caused by laser use during the study period (Figure 6).



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Event	9	8	0	0	0	0	0	2	0
Incident	48	84	88	129	107	101	134	110	170
Undefined	0	0	0	0	0	0	1	0	0
Event+Incident	57	92	88	129	107	101	134	112	170

Figure 6. The number of LASER events in air traffic from 2011 to 2019. The author’s own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

Actions against this threat include controlling the number of events based on the data collected and drafting a LASER information and education campaign that can be conducted in schools. The purpose of this effort is to continue to monitor events and verify the extent of the problem related to blinding pilots with lights from the ground. Adequately effective preventive measures (information campaign) should also be selected.

Aviation events involving glider towing also constitute a group of hazards. These are indicated as those that may be directly related to equipment that is not subject to aviation certification: winches and tow ropes. In contrast to others, this group is characterized by a high number of accidents (an average of about four accidents per year) and at the same time a low number of incidents and events (an average of about eight cases per year). This may indicate a lack of reporting on this group of hazards.

Actions taken against this threat include, for example, controlling the number of events and verifying whether additional measures are needed to address the quality of the equipment used to tow gliders. This is also expected to reduce the number of accidents in this event category.

The next hazard is the performance of flight operations below acceptable visibility. It is associated with landing operations below the Runway Visual Range (RVR) minima, which can result in very serious aviation accidents. There are regular attempts to continue such operations despite having knowledge about RVR below the minimum value. Thus, it is important to determine whether this is incidental or whether these actions are related to intentional unwarranted risk-taking. There were no accidents in the described hazard category, and the number of events and incidents did not reach more than 13 (in 2012) during the period under study, which is an average of six per year.

Risk mitigation activities associated with this hazard focus on, among others, controlling the number of events in this category, with the goal of determining the true magnitude of events associated with landing operations below the minimum RVR.

Events involving the transportation of hazardous materials also pose significant risks, as such transportation is only safe if specific regulatory restrictions are followed. Any failure to comply with the regulations and neglect of their requirements can contribute to an aviation accident. Hazardous materials incidents are defined as events, other than accidents, involving and relating to the transportation of hazardous materials that result in injury to persons or damage to property or the environment. The number of events related to the transportation of hazardous materials is increasing annually, but no accidents or serious incidents occurred during the study period. There was only an average of about 39 incidents and 170 events per year.

The largest increase in the number of events and incidents occurred between 2017 and 2018 – from 175 to 437 (of which there were as many as 391 events). For this threat, the actions taken include controlling the number of events, analyzing events involving the transportation of lithium batteries, or measuring the level of culture of reporting events of this type by the responsible parties. The objectives of the efforts are to continually observe and minimize events involving the transportation of hazardous materials.

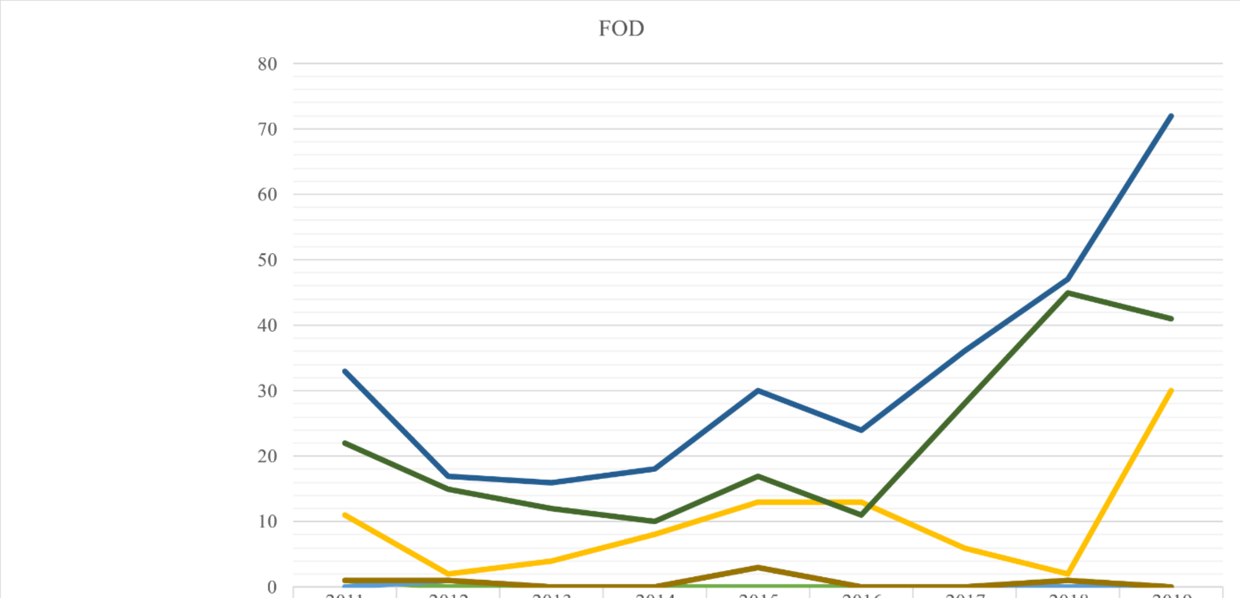
Helicopter events also pose a threat to air traffic. They are singled out due to the specificity of helicopter operations. This group was required to be monitored by the President of the Civil Aviation Authority.

Accidents related to helicopter events associated with SCF-NP (System/Component Failure or Malfunction (Non-Powerplant)) occurred in 2013 and 2019 (single cases). In contrast, the number of events and incidents increased from 13 in 2011 to 25 in 2015. In 2016, there was a significant increase in recorded events and incidents, amounting to 49 cases. A year later, that number had risen again to 68. In 2018, there was a decrease to 55 events and incidents, but in 2019, the number increased again to 61.

Accidents and serious incidents involving SCF-PP (System/Component Failure or Malfunction (Powerplant)) on helicopters occurred with high frequency. Twelve such situations occurred during the study period.

Helicopter event risk minimization measures focus on, among others, analyzing accidents and serious incidents, as well as controlling events. Their goal is to verify the number of events against all aviation events.

The last group of hazards are FOD (foreign object damage) events. These can have effects both on the ground and in the airspace. FOD is divided into those found on runways, taxiways, and aprons and those associated with aircraft maintenance (Maintenance FOD). FOD events are increasingly being reported in civil aviation, as it is clearly shown in Figure 7.



	2011	2012	2013	2014	2015	2016	2017	2018	2019
Accident	1	0	0	0	0	0	0	1	0
Serious incident	0	1	0	0	3	0	0	0	0
Incident	11	2	4	8	13	13	6	2	30
Event	22	15	12	10	17	11	28	45	41
Incident+Event+Undefined	33	17	16	18	30	24	36	47	72
Accident+Serious incident	1	1	0	0	3	0	0	1	0

Figure 7. The number of FOD events in air traffic from 2011 to 2019. The author's own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

Preventive actions against this type of hazard include, but are not limited to, analyzing accidents and serious incidents to verify the number of events involving foreign objects at airports and during the maintenance process.

5. Discussion of the study results

The conducted analysis shows that the highest average value of accidents and serious incidents is characterized by the category of events related to glider towing (Fig. 8). In 2015, there were 12 such cases (maximum). Many accidents and serious incidents are also associated with SCF-PP and foreign object damage (FOD). Hazards such as RVR, hazardous materials events, birdstrike, and laser blinding of pilots did not result in accidents or serious incidents over the study period. All of the average numbers of accidents and serious incidents in the assigned hazard categories are shown in the bar graph (Fig. 8).

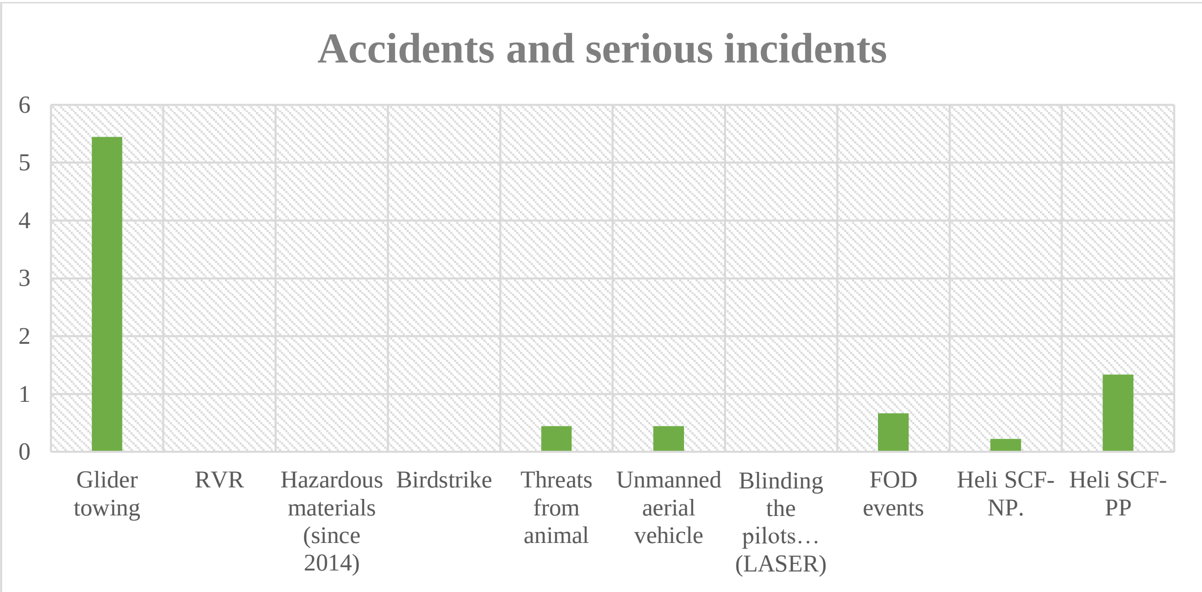


Figure 8. The average number of accidents and serious incidents in the provided air traffic hazard categories from 2011 to 2019. The author's own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

Similarly, the average number of incidents and events related to the types of hazards for Polish civil aviation was analyzed (Fig. 9).

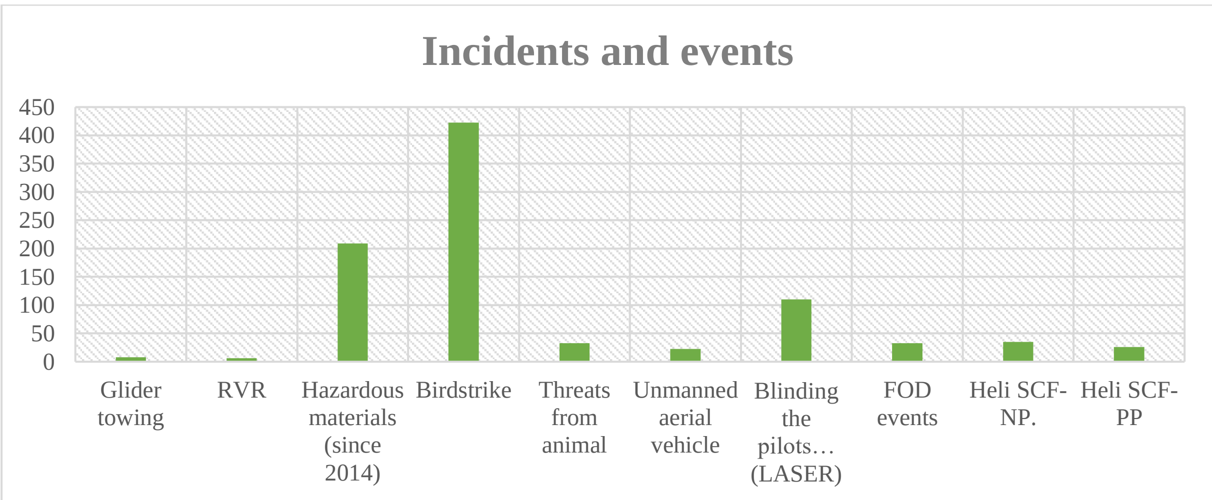


Figure 9. The average number of incidents and events in the provided air traffic hazard categories from 2011 to 2019. The author's own elaboration based on: Civil Aviation Authority (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.

The "Birdstrike" hazard group definitely stands out. Incidents and hazards in this category were recorded, on average, 426 times per year. Situations, where hazards may have been caused by improper transportation of hazardous materials, were also common, with an average of 209 times per year (data spanning from 2014 through 2019). The number of events and incidents is also high for the use of lasers to blind pilots; such an attempt to disrupt flight safety has been made on average 110 times per year. Interestingly, each of these hazard categories simultaneously has zero accidents and serious incidents over the 2011-2019 period. The least number of events and incidents are characterized by events related to glider towing and attempted landings in limited visibility. No accidents occurred as a result of attempting to land when the RVR minimum was not met; however, hazards associated with the glider towing process caused an average of 5 accidents and serious incidents per year in civil aviation over the study period.

6. Summary

Safety is inherent in all modes of transportation, not just aviation (Borucka & Pyza, 2021; Kamiński et al., 2016; Świderski, 2009). The article was created in order to identify the hazards in Polish civil aviation and the scale of the danger they are associated with. Moreover, the hazards that are characterized by the highest frequency were indicated. This allowed for the identification of incidents that should be subject to the procedure of special analyzes and supervision. Moreover, such a survey provides information on the level of security on a national scale. It enables the planning of precise preventive actions. It allows for more effective use of available funds and resources, both on the part of aviation entities and the state budget. It is also part of the risk management strategy. The analysis was based on data collected in the National Safety Plan 2020-2023. This study uses figures for accidents, serious incidents, incidents and events for the period 2011-2019 (only such data was made available to the authors).

Extremely dangerous events are linked to the actions of third parties. The increasing number of events related to the mishandling of UAVs is a major concern for air traffic safety. This may have to do, for example, with the uncomplicated process of purchasing an unmanned aerial vehicle and its growing popularity. The steps taken against this threat are primarily preventive in nature (education and information campaign, decision to place information signs). In addition, laser blinding of pilots is also a hazard with tragic consequences. In this case, it was also decided to conduct an awareness campaign about the harmfulness of this type of activity.

The study shows that over the period under review, the number of safety incidents and events in civil aviation has been steadily increasing. This implies the need to undertake scientific research in this area as well as to develop tools and methods to prevent such events (Boyd, 2017). This study is an introduction to such analyses and may be expanded by conducting further research covering a broader time horizon. Conducting an analysis of hazards that occurred in 2020 (COVID-19 virus pandemic outbreak) would certainly identify areas that threatened flight safety even with air transport restrictions. In addition, mathematical modeling methods may be used to identify and forecast in this area. It is also possible to extend the analysis to other areas of aviation.

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.

7. References

1. Auerbach, W. (1979). Leksykon wiedzy wojskowej. Wydaw. Min. Obrony Narodowej.
2. Bielski, M. & Krawczyk, A. (2010). Bezpieczeństwo ruchu lotniczego. Bezpieczeństwo Pracy: nauka i praktyka, 10-13. Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy.
3. Borucka A. & Pyza D. (2021). Influence of meteorological conditions on road accidents. A model for observations with excess zeros. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2021; 23 (3): 586–592, http://doi.org/10.17531/ein.2021.3.20. Polish Maintenance Society
4. Boyd, D. D. (2017). A review of general aviation safety (1984–2017). Aerospace medicine and human performance, 88(7), 657-664.
5. Cieślak, E. (2016). Bezpieczeństwo cybernetyczne w lotnictwie cywilnym. SECRETUM. Służby specjalne, bezpieczeństwo, informacja, 5(2), 71-82.
6. Cui, Q., & Li, Y. (2015). The change trend and influencing factors of civil aviation safety efficiency: the case of Chinese airline companies. Safety science, 75, 56-63, https://doi.org/10.1016/j.ssci.2015.01.015.
7. Denney, E., Pai, G., & Whiteside, I. (2019). The role of safety architectures in aviation safety cases. Reliability Engineering & System Safety, 191, 106502. https://doi.org/10.1016/j.ress.2019.106502.
8. Greenberg, R., Cook, S. C., & Harris, D. (2005). A civil aviation safety assessment model using a Bayesian belief network (BBN). The Aeronautical Journal, 109(1101), 557-568, https://doi.org/10.1017/S0001924000000907.
9. Ilków, A. (2011). Czynnik ludzki w systemie bezpieczeństwa ruchu lotniczego. Prace Instytutu Lotnictwa, 99-119. Wydawnictwa Naukowe Instytutu Lotnictwa.
10. Janic, M. (2000). An assessment of risk and safety in civil aviation. Journal of Air Transport Management, 6(1), 43-50, https://doi.org/10.1016/S0969-6997(99)00021-6.
11. Kamiński, T., Niezgoda, M., Siergiejczyk, M., Oskarbski, J., Świderski, A., & Filipek, P. (2016). Wpływ stosowania usług inteligentnych systemów transportowych na poziom bezpieczeństwa ruchu drogowego. Prace Naukowe Politechniki Warszawskiej. Transport, (113), 201-208. Oficyna Wydawnicza Politechniki Warszawskiej.
12. Kasianov, V. A., & Goncharenko, A. V. (2018). Entropy methods of human factor analysis applied to the problem of safety of aviation. National Aviation University.
13. Łuczak, K. (2016). Zarządzanie bezpieczeństwem w lotnictwie cywilnym. Śląska Biblioteka Cyfrowa, Katowice.
14. Menon, P. K., Dutta, P., Chen, O., Iyer, H., & Yang, B. J. (2019). A modeling environment for assessing aviation safety. In AIAA Aviation 2019 Forum (p. 2937), https://doi.org/10.2514/6.2019-2937.
15. Netjasov, F., & Janic, M. (2008). A review of research on risk and safety modelling in civil aviation. Journal of Air Transport Management, 14(4), 213-220, https://doi.org/10.1016/j.jairtraman.2008.04.008.
16. Ni, X., Wang, H., Che, C., Hong, J., & Sun, Z. (2019). Civil aviation safety evaluation based on deep belief network and principal component analysis. Safety science, 112, 90-95, https://doi.org./10.1016/j.ssci.2018.10.012.

17. Organizacja Międzynarodowego Lotnictwa (2016). "Załącznik 19 do Konwencji o międzynarodowym lotnictwie cywilnym".
18. Rozporządzenie Ministra Infrastruktury z dnia 9 października 2020 r. w sprawie kontroli przestrzegania przepisów oraz decyzji z zakresu lotnictwa cywilnego (Dz. of Laws of 2020, item 1843).
19. Szafran, K. (2018). Bezpieczeństwo w lotnictwie: sytuacje krytyczne w aspekcie teorii analizy subiektywnej. Autobusy: technika, eksploatacja, systemy transportowe, 19, https://doi.org/10.24136/atest.2018.391.
20. Szymaniec, K. M. (2018). Systemowe zarządzanie ryzykiem zagrożeń w lotnictwie transportowym.
21. Świderski, A. (2009). Studies and quality assurance neural modeling of the technical transport means. Archives of Transport, 21(3-4), 177-188.
22. Urząd Lotnictwa Cywilnego (2016). Krajowy Program Bezpieczeństwa w Lotnictwie Cywilnym. Ministerstwo Infrastruktury i Budownictwa.
23. Urząd Lotnictwa Cywilnego (2020). National Safety Plan 2020-2023. Appendix to the National Civil Aviation Safety Program.
24. Ustawa z dnia 3 lipca 2002 r. Prawo lotnicze (Dz. U. z 2020 poz. 1970).
25. Zieliński, M. (2010). Bezpieczeństwo w porcie lotniczym. Zeszyty Naukowe Akademii Marynarki Wojennej, 51, 157-180. Akademia Marynarki Wojennej.
26. Żurek, J. (2009). Wybrane metody oceny bezpieczeństwa w lotnictwie. Problemy eksploatacji, 61-70. Instytut Techniczny Wojsk Lotniczych.

SAFETY & DEFENSE
ISSN 2450-551X

Flight Screening of Military Pilots in Poland

Dariusz BOGUSZ

Military University of Aviation, Dęblin, Poland;
d.bogusz@law.mil.pl, ORCID: 0000-0001-7755-0949

DOI: https://doi.org/10.37105/sd.120

Abstract

This article diagnoses and evaluates the process of selecting and preparing candidates for military pilots in Poland. The presented changes in the screening training system are to help with understanding the principles of organizing an effective system of recruitment and selection of military pilots at present. It also indicates directions for improvement. The organization of initial flight screening contributes to improving the efficiency of flight training and can serve as a model for use by flight training systems in other countries. The purpose of the article is to diagnose and evaluate recruitment and selection of candidates for military pilots in Polish Armed Forces. The problem that the author addresses is expressed in the following question: in what directions should the current solutions in the selection and training of candidates for military pilots, be improved in order to reduce the attrition rate at subsequent stages of flight training in the future? The research has been conducted at the Military University of Aviation using case study methods. The theoretical research methods, such as analysis and synthesis of information contained in literature and source materials, conclusions and comparison were used to develop the article. In order to confirm the conclusions drawn with the use of theoretical methods, an empirical method was used, which consisted in examining the opinions with the use of expert interviews. Experts were selected from the group of commanders of training units and military pilots involved in selection training, who had an impact on the applicable aviation training and recruitment system in Polish Armed Forces. The results shows main directions of military pilots initial flight screening improvement.

Keywords

air force, aviation training safety, flight screening, military pilots, safety

Submited: 29.04.2021 Accepted: 04.08.2021 Published: 20.10.2021

1. Introduction

The system of aviation training for military pilots in Poland is constantly evolving. A good example to support this statement is the training that checks flight predispositions before admission to the Military University of Aviation (MUA). Since 2017 significant changes have been made in the system of candidates' selection for military pilots. The ordinance of the Ministry of National Defense of December 28, 2016 changed the way of training organization. The Rector-Commandant of the MUA became responsible for the implementation of such training and he/she is the one to determine the conditions and procedure for admitting candidates in pilot specialties. The method of financing the flight screening has also changed. Currently, the funds for the implementation of the training come from the budget of the Ministry of National Defense, and not as before, from subsidies which were awarded after winning the tender offer competition. The transformations were so important that the name of the training has also been changed – from selective training to flight screening (Regulation, 2017).

Changes made in the system of selecting candidates for military pilots resulted in a decrease in the number of hours spent in the air during training which aimed to test flight predispositions. At this stage, the changes contribute to making savings and enable more candidates to be trained. During the selection training which was carried out until 2016, the candidates had 20 hours of practical training on airplanes, currently, during the check-up training they fly from six to ten hours. The ability to train more than twice the number of candidates compared to the previous selection training is a huge advantage. As a result, we can speak of a positive selection, i.e. the selection of the right candidates from among the many willing to practice the profession of a military pilot.

This article aims to diagnose and evaluate the recruitment and selection of candidates for military pilots in the Polish Armed Forces. The flight screening implemented since the 2017/2018 academic year consists of three stages: theoretical, simulator and practical training. Reducing the number of hours for training in the air and increasing the importance of training on simulators is intended to train more candidates for military pilots and increase the effectiveness of this training.

The problem which the author wanted to draw attention to is expressed by the following question - in what directions should the current solutions in the selection and training of candidates for military pilots be improved in order to reduce the attrition rate at subsequent stages of flight training in the future?

The research was conducted at the Military University of Aviation using case study methods. The theoretical research methods, such as analysis and synthesis of information contained in literature and source materials, conclusions and comparison were used to develop the article.

In order to confirm the conclusions drawn with the use of theoretical methods, an empirical method was used, which consisted in examining the opinions with the use of expert interviews. The implementation of research with the participation of experts seems appropriate in relation to those areas of social life that are currently undergoing the process of advanced professionalization.

2. Selection, recruitment and assessment of aviation predispositions

The system of candidate selection in the military pilot profession is a very important element of the flight education and training process as it directly affects flight safety. The first stage of flight training is flight screening carried out before admission to the MUA. The proper preparation of pilots for the subsequent stages of training and the performance of tasks in combat units depend on well-conducted flight screening. However, a poorly functioning recruitment system contributes to an increased attrition rate[1] and often results in belated decision to drop out of the training. Poland has long and proven traditions in preparing candidates for military aviation. Checking the air predispositions of future military pilots has a long tradition of more than 80 years. The preparation of flight personnel before joining the school, earlier and now is referred to by pilots as Initial Flight Screening.

In Poland, this type of undertaking has been organized since the 1930s. The aviation training system was then based on the extensive cooperation of military aviation with civilian entities such as aeroclubs and the Airborne and Antigas Defense League. At the time, American for Polish Aviation Military Adaptation was being introduced to later become Initial Flight Screening. Completing the pilot course was one of the conditions for admission to the Officers' Aviation School. If the candidate did not have the required training, he was directed to a qualifying course at the Military Gliding Centre in Ustianowa, also called the elimination gliding course (see: Celek, 1979). Currently, Polish Aero Club, High School of Aviation and Military University of Aviation's Academic Aviation Training Centre (AATC) are responsible for preparing candidates for military aviation (Figure 1).

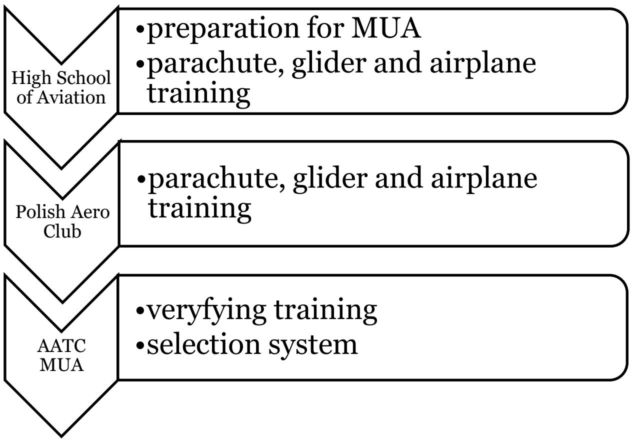


Figure 1. The tasks of institutions responsible for candidate preparation and air selection for military aviation. Author's own work.

In accordance with the demands made by the management of the MUA, the training assessing aviation predispositions of candidates for military pilots has been fulfilled by the entity responsible for further aviation education and training since 2017 . The flight screening will bring the expected results if it is implemented by a specialized training centre, which has specific aviation equipment, technical facilities and instructor staff with useful experience in training candidates for military pilots (most reputable aviation schools in the world have this type of academic aviation training centres). Earlier, verifying (selection) training was carried out in Regional Aero Clubs which represented a level that did not always meet

[1] An attrition rate is the percentage of cadets who, for various reasons, did not graduate from an aviation university.

the requirements of the aviation school. Currently, the MUA Academic Aviation Training Centre is responsible for this training. The organisation and functioning of AATC in the current structure, together with experienced instructors, airplanes equipped with the MUA AATC and the "Selector" simulator, on which the training is carried out, ensure a high level of checking the flight predispositions of pilots.

Before recruits are selected for flight screening during recruitment to the MUA, a candidate for military pilot must successfully undergo MIAM (Military Institute of Aviation Medicine) aero-medical examination. The first stage of selection is an examination in the District Military Medical Commission. After obtaining a positive test result and sending the medical examination documents by Army Recruiting Command to the MUA, the school directs the candidate for examination to the MIAM in Warsaw. As a result of these tests, candidates receive health groups assigning them to a given volatile group, after which they are qualified for selection flights (Fig. 2).

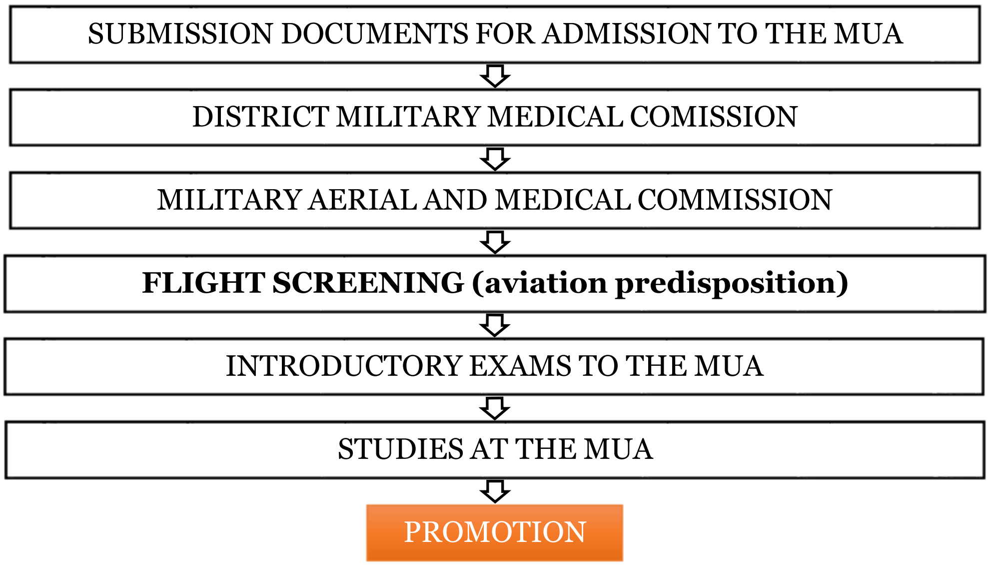


Figure 2. The *stages of recruiting candidates for the Military University of Aviation*. Author's own work

Flight screening is the first stage inextricably linked to the subsequent stages of aviation training and is intended for the initial verification of candidates for the military pilot profession. Technical progress has forced changes in the way aviation works and has created ample opportunities for the development of pilot flight training systems around the world. The use of simulators from the very beginning of flight training, already at the recruitment stage is an example. The training system in Poland is based on Polish experience, but it also uses solutions used in most countries that make up the North Atlantic Treaty Organisation. In recent years, the training system has changed many times, but its characteristic feature, its phased nature, has stayed the same. Currently, many countries use a unified flight training system, consisting of four stages: flight screening, basic flight training, advanced and tactical (combat) flight training (Fig. 3).

I - FLIGHT SCREENING	II - BASIC TRAINING	III-ADVANCED TRAINING	IV- COMBAT TRAINING
•AATC MUA •DA-20, Cessna 150	•AATC MUA •DA-20, DA-42,CABRI,...	•4th Air Training Wing (4 ATW) •TC-130, M-346, SW-4, Mi-2, Bryza,...	•combat units of Polish Armed Forces •F-16, Mig-19, Sokół , Bryza,...

Figure 3. The *stages of flight training in Poland***.** Author's own work.

In order for the flight training system to function efficiently, first and foremost, it is necessary to ensure the proper recruitment and selection of candidates. It has a decisive impact on the implementation and effectiveness of such training. As part of the selection, in addition to a number of medical and psychomotor tests, it is necessary to carry out flight screening. This training aims to determine the elementary flight predispositions of the candidates for pilots and in addition:

- familiarize the candidates with the capabilities of the aircraft;
- check manual and psychophysical skills before starting basic flight training;
- test one's skills to properly distribute attention during the flight;
- assess the proper operation of the aircraft;
- determine the suitability of the student-pilot, as a candidate for pilot of military aircraft (pilot of transport aircraft, pilot of jet aircraft, helicopter pilot) (Grenda, 2012).

A well conducted check-up training should ensure the best possible check of aviation skills and selection of appropriate candidates for aircraft pilots.

The level of pilot's knowledge and skills depends on the quality of ground preparation. Furthermore, the number of practical flights can be decreased, and thus the time and costs of training in the air can be reduced (Bartnik, et all, 2012). The development of information technology has created new opportunities not only in the construction of aircraft, but also in devices supporting the science of piloting them. Therefore, it is currently difficult to imagine pilot training without the use of simulators - this also applies to flight training (fig. 4). Talleur, Taylor, Emanuel, Rantanen and Bradshow have shown in their paper that the simulator training is effective for all aspects of aviation training e.g. maintaining instrument currency, and their findings suggest that it is also effective in enhancing instrument proficiency (2003).

Figure 4. Candidates for military pilots during the screening training on „Selector" symulator with F-16 module at Military University of Aviation in Dęblin. Author's own work.

3. Flight screening

In the years 2006 – 2016, flight screening (then called selection training) was conducted in aeroclubs throughout the country. In those years, most of the competitions for the implementation of selection training on airplanes for candidates for cadets at the MUA were won by the Academic Aviation Training Center of the MUA's Aero Club in Dęblin.[2] Due to the high intensity of flight training provided by the 4th Wing of School Aviation on military aircraft and limited access to the airport in Dęblin, practical training was also carried out at the airport in Radom.

Currently, flight screening is carried out at the MUA Academic Aviation Training Center on light piston planes and is to ensure the preparation of pilot candidates for further training. Verification training occupies an important place in the recruitment process of which it is part. It is a modification of the selection training implemented in the years 2006 - 2016, when the candidates carried out theoretical training in the amount of 130 hours and flew 20 hours in the air.

For candidates who have successfully passed the Military Aerial and Medical Commission in Warsaw and obtained a certificate of the ability to perform the duties of pilots, the next stage related to the qualification to become a military pilot is a training to check flight predispositions. While at the stage of submitting documents it is difficult to assess the applicant's aviation predispositions effectively, the flight screening carried out during the recruitment to the Military University of Aviation gives such an opportunity and should ensure initial selection.

[2] The advantage of the Dęblin Aero Club is having the right number of aircraft and instructors with military aviation experience. Most of the instructors were former military pilots with considerable air raids, who served at the Military University of Aviation in Dęblin as instructors and in their careers trained hosts of military pilots.

Pursuant to the Ordinance of the Minister of National Defense of December 28, 2016 amending the ordinance on the military service of candidates for professional soldiers, the condition for writing the entrance examination to the Military University of Aviation (formerly: Polish Air Force Academy) is graduating with a positive result, and training verifying predispositions to perform service in pilot positions (Regulation, 2016).

The verification training at the Military University of Aviation is carried out in three stages (Fig. 5) and includes simulation training, theoretical and practical training in the air, implemented in accordance with the applicable flight training program approved by the Civil Aviation Office. An additional criterion in flight screening is the division of candidates into those with and without experience.

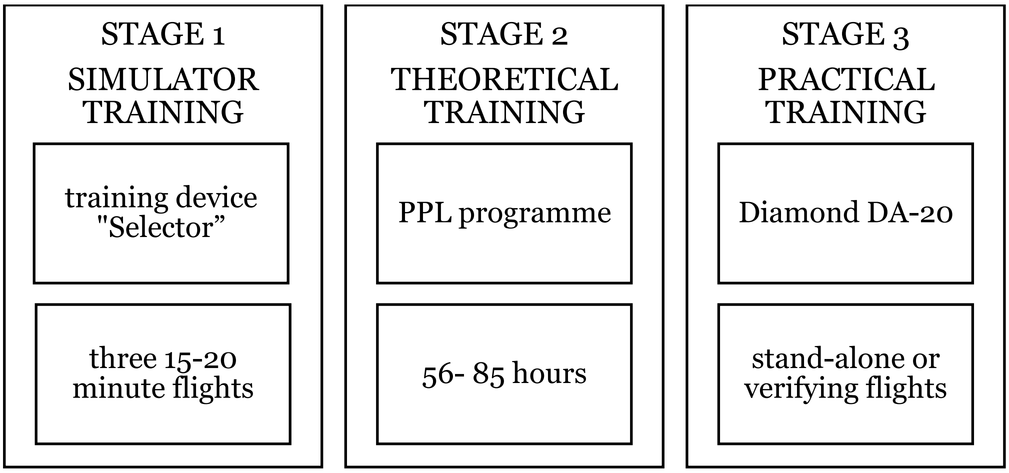


Figure 5. The stages and main objectives of the flight screening. Author’s own work.

Stage 1, is a verifying training on the flight simulator "Selector", in which the candidate performs three flights in approximately 20 minutes each (Fig. 6.). The first flight, which precedes check flights, is a non-evaluable familiarization flight that aims to familiarize the candidate with the simulator and its piloting capabilities. The flight components performed there depend on the candidates themselves. The next two flights are verification flights and are performed according to scenarios previously known to the candidate. The training includes two exercises. The first exercise is designed to test the skills of piloting technique, i.e. the implementation of basic pilotage figures, such as straight flight, turns, ascent, descent. The second exercise is to check the piloting technique combined with psychological examination, which involves performing simple arithmetic operations, remembering symbols and recognizing shapes. During this exercise, commands are displayed on the monitor screen in the simulator's cockpit and are spoken by a speech synthesizer (Annex to the Resolution of the Senate of the Polish Air Force Academy, 2017).

STAGE 1
•first flight - getting to know the trainee and his/her piloting capabilities
STAGE 2
•second flight - checking the ability to perform basic pilot figures (straight flight, turns, ascents, descents) combined with psychological examination (divisibility of attention, perceptiveness, short-term memory)
STAGE 3
•third flight - verifying the ability to perform basic pilot figures (straight flight, turns, climbs, descents) combined with psychological examination (divisibility of attention, perceptiveness, short-term memory)

Figure 6. The *stages and main objectives of simulator flight screening*. Author's own work.

The simulator automatically counts errors made by the candidate, and after the flight is completed, a graph is created showing the rate of errors made. Then, as a result of the analysis of the flight performed and based on the assessment scale introduced to the system for maintaining the prescribed flight parameters, the system generates a numerical rating, and the final result of individual tests is generated in the form of an overall rating. In the case of a negative result, after consulting the Military Aviation and Medical Commission at Military Institute of Aviation Medicine, the candidate may be considered a person with no predisposition to the profession of a pilot. Obtaining a positive grade is necessary for the candidate to enter the second stage of the training.

Stage 2 of the flight screening includes theoretical training that is carried out in accordance with the applicable flight training program approved by the Civil Aviation Authority (CAA) (Table 1). The second stage ends with an exam. However, this stage of the training does not apply to candidates with aviation experience, i.e. with PPL(A) tourist pilot license, or the ones who completed selection training in previous years (Annex to the Resolution of the Senate of the Polish Air Force Academy, 2017).

Table 1.
The subjects and hours of the theoretical training.

Role name	number of hours
Human - possibilities and limitations	7
General knowledge about the aircraft	20
Flight performance and planning	4
Flight rules	10
Aviation law	10
Connection	7
TOTAL	**58**

Source: Author's own work

Obtaining a positive result from the first and second stages is a prerequisite for admitting the candidate to the third stage, i.e. practical training on airplanes.

Stage 3 is conducted differently depending on the applicant's aviation experience. A person with aviation experience implements this training according to an individual program. In this case, the training includes resumption flights and verifying flights. In turn, for people without aviation experience, practical air training is conducted in accordance with the applicable flight training program approved by the Civil Aviation Authority and the flight lasts six hours at the most. During practical training, elements such as piloting technique, radio communication, spatial orientation, behavior in special (emergency) situations, situational awareness are assessed (Annex to the Resolution of the Senate of the Polish Air Force Academy, 2017).

The training is carried out on Diamond DA20 aircraft and Cessna 150. After completing the training process, the aviation predisposition with a positive result, the Rector-Commandant issues an appropriate certificate confirming the qualification of a given person for the recruitment procedure. The training is carried out on a Diamond DA20 aircraft and Cessna 150 . After completing the training the aviation predisposition with a positive result, the Rector-Commandant issues an appropriate certificate confirming the qualification of a given person for the recruitment procedure.

During practical training, elements such as piloting technique, radio communication, spatial orientation, behavior in special (emergency) situations, situational awareness are assessed (Table 2).

Table 2.
The subjects and hours of the theoretical training.

Task/exercise	**Number of flights - duration**	**Performed elements**
Task 1 exercise 1	1 flight in 40 seconds	Familiarization flight
Task 1 exercise 2	3 flights in 1:30	Learning the basic elements of flight – zone
Task 1 exercise 3	20 flights in 2:00	Learning flights in circle
Task 1 exercise 4	10 flights in 1:00	Correcting errors at take-off and landing
Task 1 exercise 5	5 flights in 0:50	Verifying flight (with an instructor other than the learner)

Source: Author's own work

The program of practical training in the air on these types of aircraft provided for 38 daily flights in normal atmospheric conditions, for a total of six hours. In the years 2017-2018, practical training was carried out at the airport (airstrip) in Nowe Miasto.

Flight screening in 2019 only included flights on the "Selector" simulator - practical training in the air of MUA candidates was abandoned. Predispositions to the profession of pilot were assessed on the basis of points obtained after training on the "Selector" simulator (Table 3). During the flight screening on the simulator, the candidate was evaluated on a scale of 0 to 100 points, which were then converted into recruitment points. The trainee's reaction during psychological tests and the maintenance of prescribed flight conditions were included in the process of automatic assessment of the candidate. Based on the grading scale entered into the system, the final result was generated in the form of an overall grade. A prerequisite for taking the entrance exams is obtaining at least a satisfactory overall grade from the training. After completing the training process testing the aviation predisposition with a positive result, the Rector-Commandant of the Military University of Aviation issues an appropriate certificate confirming the qualification of the given person for the recruitment procedure.

Table 3. *Candidates' scoring after simulation training*

Lack of predisposition to serve as a pilot	
From **0** to **49** points SELECTOR	0 recruitment points
Basic predisposition to perform service as a pilot	
From **50** to **62** points SELECTOR	10 recruitment points
Medium predisposition to perform service as a pilot	
From **63** to **75** points SELECTOR	20 recruitment points
High predisposition to serve in as a pilot	
From **76** to **88** points SELECTOR	30 recruitment points
Very high predisposition to perform service as a pilot	
From **89** to **100** points SELECTOR	40 recruitment points

Source: Author's own work

In the years 2017-2019, 422 candidates were referred for flight screening (then still known as selection training) in the new formula. The training with positive assessment was completed by 377 candidates. There were 45 trainees who did not complete the training with a positive grade, and so were not able to apply for pilot specialization (Fig. 7). The effectiveness of this form of checking the air predispositions of candidates for military pilots can be analyzed only after the number of candidates promoted to the first officer rank and directed to air units with military pilot title has been determined.

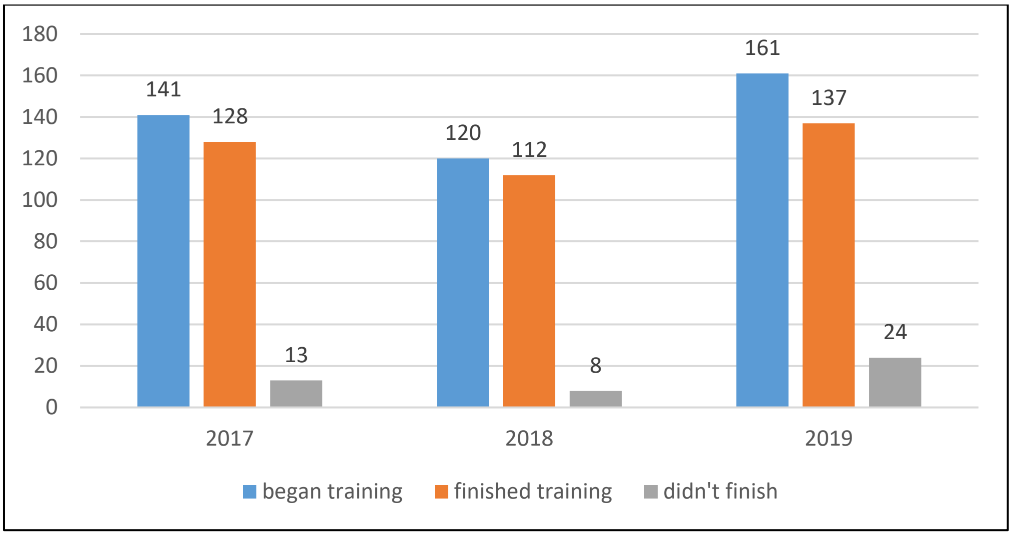


Figure 7. The results of verification training (flight screening) in 2017-2019. Author's own work.

The advantage of flight screening is the use of simulators that allow the trainees to safely check their flight skills, analyze their concentration and perceptiveness. The purpose of this training is to check basic aviation skills, select the best and stop training non-predisposing candidates. Campbell, Castaneda and Pulos made an important finding that different personality constructs possess different relationships with military aviation training success (2009). The Selector simulator allows carrying out tests to assess aviation predisposition of candidates at the recruitment stage. It seems that currently conducted training saves money on aviation training, which is the most expensive type of training in the world. However, the question arises whether six hours is sufficient training in the air to check flight predispositions and how effective it is to perform only simulator training to check flight predispositions.

At this stage, effectiveness can only be assessed on the basis of a comparison of how many trainees started the training and how many completed it with a positive result - which is associated with a high risk of error. Ultimately, it will be possible to make conclusions on the impact of the checking training on the effectiveness of aviation training based on the results of how many cadets will be promoted as a military pilot. It will be possible to evaluate when the first group graduates from the air force academy. As experts note, the results of the training may also interfere with the adaptation of young people to function in the digitized world. Young people do well in a virtual environment, and after getting off the ground, most people cannot cope with stress. Taking up in the air ultimately verifies the suitability for aviation (fear of heights and other barriers disrupting the rational functioning of the human body).

In addition, the implementation of continuous training, approved by the Minister of National Defense on December 13, 2011, allows for obtaining a higher level of pilot training by achieving a greater raid on a single pilot (Fig. 8). This is possible due to the raid obtained in AATC, including during training to check flight predispositions. As a result of this and training on military aircraft in the 4th Air Training Wing (4th ATW), cadets of pilot specialties before reaching the combat units are to achieve number of flying hours ensuring better preparation for service in positions in the Polish Armed Forces.

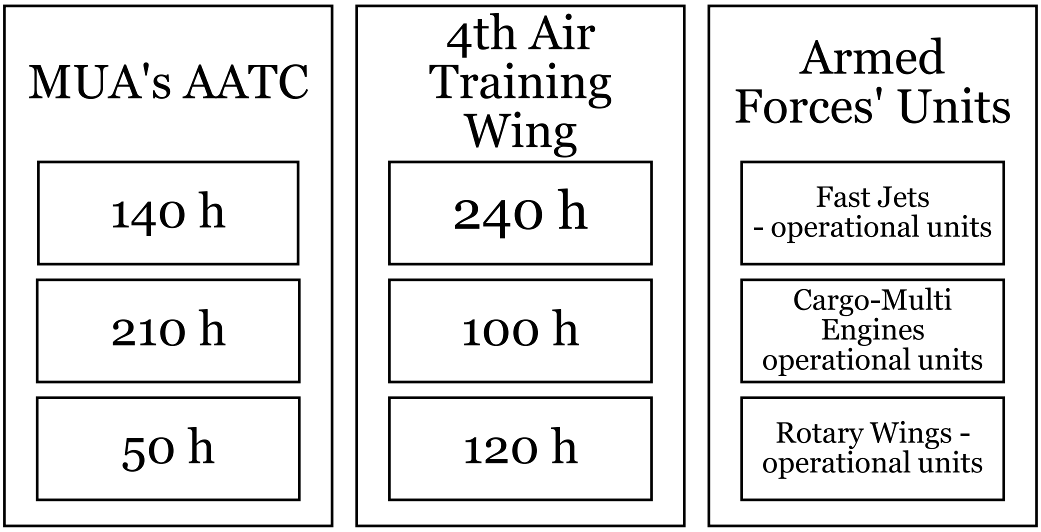


Figure 8. Raid on a single pilot by specialty Adopted from: "Training of aviation personnel for the needs of the air force and the related future challenges" by P. Krawczyk Copyright 2018, War Studies University, Scientific Quarterly.

4. Conclusions

The modifications in the system of selection and selection of candidates for military pilots resulted in a decrease in the number of hours spent in the air during training testing aviation predispositions. At this stage, it brings savings and the opportunity to train more candidates. During the selection training implemented until 2016, the candidates had practical training on airplanes composed of 20 hours. Currently, during the flight screening, they fly from six to ten hours. This has the advantage of training more than twice the number of candidates compared to the previous selection training. Through this, it is possible to talk about positive selection, i.e., selecting the right candidates from among many willing to practice the profession of a military pilot. However, the question arises whether this is enough hours to check the flight predisposition. With such a minimum flight time, verifying air-worthiness is virtually impossible. The idea of flight screening is to select candidates with predispositions for particular types of aviation and to eliminate at the initial stage people who do not have such predispositions. The recruitment and selection system ensures the selection of candidates at a good level. A decision to abandon practical training is a contradiction to the idea of this training. Moreover, in the future, it will have negative effects in the training of military pilots. Therefore, it is necessary to return to practical training at the recruitment stage.

Experts appointed for the study from the MUA and Aeroclubs are responsible for conducting the selection training of candidates for military pilots. Meanwhile, experts from the training aviation bases who train cadets in subsequent stages of aviation training and have the opportunity to assess the level and quality of selection training directly, indicate a small number of hours to assess candidates.

However, experts consider it justified to introduce simulator training to check future pilots' aviation predispositions.

The effectiveness of this form of checking the air predispositions of candidates for military pilots can be analyzed only after it can be counted how many of them are promoted to the first officer rank and directed to air units with military pilot title. After introducing changes to flight screening, the training cycle was not closed. Good results at this stage can be verified in further stages of practical training at the air force academy and units of the 4th School Aviation Wing, accomplished until the officer promotion is obtained. This will be the reason for the continuation of the research.

Taking into account the research results and, in particular, the opinions of aviation training experts, a proposal has been made to improve the training process in two areas:

- carrying out simulator training along with conducting psychological research thanks to the possibilities offered by the Selector simulator developed in MUA.
- increasing the number of hours of flight training and the completion of a solo flight by the applicant in order to clearly determine the aviation suitability.

Improving the system of selection and flight screening of candidates for military pilots should be aimed at a greater selection number of flying hours at the recruitment stage. In the future, in order to reduce extensibility at subsequent stages of aviation training, the optimal solution would be to return to acquiring future candidates in cooperation with non-governmental organizations that have an agreement with the Ministry of National Defense. Such solutions operated in the interwar and post-war years until the 1990s. In addition to popularizing aviation in society, it provided hundreds of pre-trained pilots for the armed forces and the national economy. A return to these best practices would contribute to a reduction in attrition rate at later stages of the career of military pilots.

Declaration of interest The author/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.

References

1. Regulation of the Minister of National Defense of December 28, 2016 amending the regulation on the military service of candidates for professional soldiers §1 (Dz. U. 2017, Poz. 71).
2. Annex to the Resolution of the Senate of the Polish Air Force Academy No. 67/2017 of October 16, 2017. *Conditions and procedure for admission to the Polish Air Force Academy for studies for candidates for professional soldiers for the academic year 2018/2019*.
3. Bartnik R., Grenda B., Galej P. (2013) *Symulatory lotu oraz symulatory ruchu lotniczego w szkoleniu lotniczym*, AON, Warsaw, p. 9.
4. Campbell, Castaneda, Pulos, (2009), *Meta-Analysis of Personality Assessments as Predictors of Military Aviation Training Success*, The International Journal of Aviation Psychology, 20(1), 92–109, Northeastern University, London, pp. 106-107. DOI: https://doi.org/10.1080/10508410903415872.
5. Celek J. (1979) *Wyższa Oficerska Szkoła Lotnicza im. Jana Krasickiego. Dzieje dęblińskiej Szkoły Lotniczej*, Wojskowy Instytut Historyczny, Warszawa, p. 52.
6. Grenda B. (2012) *Szkolenie personelu latającego na potrzeby Sił Zbrojnych Rzeczypospolitej Polskiej*, AON, Warsaw, p. 44.
7. Krawczyk P. (2018) *Training of aviation personnel for the needs of the air force and the related future challenges*, War Studies University, Scientific Quarterly no. 4(113) 2018, Warsaw, p. 8.
8. Talleur, Taylor, Emanuel, Rantanen, Bradshow, (2003), *Personal Computer Aviation Training Devices: Their Effectiveness for Maintaining Instrument Currency*, The International Journal of Aviation Psychology, Northeastern University, London, p. 397. DOI: https://doi.org/10.1207/S15327108IJAP1304_04.

SAFETY&DEFENSE
ISSN 2450-551X

Cooperation Between Poland and the USA in the Protection of Classified Information

Mirosław TOKARSKI

Academic Military University of Aviation, Dęblin, Poland;
m.tokarski.mil.pl, ORCID: 0000-0003-1882-668X

DOI: https://doi.org/10.37105/sd.134

Abstract

The military cooperation between Poland and the USA so far has undoubtedly influenced the shape of the external security. The tangible expression of this cooperation is, among others, the signing of an agreement between Poland and the USA for the purchase of the Patriot system in July 2017. As a result, Poland joined the elite group of countries possessing weapons capable of countering enemy ballistic and maneuvering missiles. It also adjusts the domestic armed forces to the NATO standards and the requirements of the modern battlefield. An additional aspect of the existing cooperation between Poland and the USA is the agreement on the protection of classified information in the military sphere. In this context, the aim of this article is to identify the scope of cooperation between Poland and the USA in the area of security measures, which should guarantee the protection of classified information considering the interests of both countries. During the considerations, two basic research methods were used: analysis and synthesis. The former method was used in relation to the content of the concluded contract and the opinions presented in the literature on the subject. The latter method was used to formulate conclusions resulting from the conducted analysis. The considerations undertaken proved that there is an area of mutual cooperation in the field of protection of classified information between Poland and the USA. They also made it possible to obtain an answer to the question of what security measures determine the effectiveness of the protection of classified information in the military sphere between the contracting states.

Keywords

international agreement, military sphere, safety, security measures, protection of classified information

Submitted: 22.06.2021 Accepted: 06.08.2021 Published: 20.10.2021

1. Introduction

The present study is the result of an analysis of the provisions of the Agreement of March 8, 2007, between the Government of the Republic of Poland and the Government of the United States of America concerning security measures for the protection of classified information in the military sphere. Upon the commencement of the analysis of the Agreement, the current state of knowledge in the field covered by the Agreement was diagnosed. It turned out to be extremely scarce. Meanwhile, the cooperation between Poland and the USA is developing, and everything implies that it will continue developing in the near future. This is evidenced by various types of contracts and agreements of strategic importance for the defense of the state, among others, regarding the country's air defense in connection with the implementation of the “Wisła” program, under which an agreement was concluded between Poland and the USA for the purchase of the Patriot system. As a result, Poland will acquire weapons capable of countering ballistic and maneuvering missiles that threaten state air security. An additional aspect of the existing cooperation between Poland and the USA is the agreement on the protection of classified information in the military sphere. It is extremely important because detailed information on air defense, land forces equipment, air force, logistic security was and still is the object of desire of other countries. On the other hand, the intelligence services wage a continuous and undeclared war over them (Goryński 2013). For this reason, the aim of the research project was to identify the scope of cooperation between Poland and the USA in the area of the security measures, which should guarantee the protection of classified information considering the interests of both countries. Moreover, the article aims to solve the research problem presented in the form of the following question: can the security measures specified in the Agreement ensure effective protection of classified information in the military sphere between the contracting states? Using the methodological approach, the adopted hypothesis was that the provisions of the concluded agreement constitute an optimal model of security measures for the protection of classified information in the military sphere.

It should be emphasized that the significance of the aforementioned security measures for the protection of classified information for both countries should not raise any doubts. As it was raised in domestic and foreign literature, the disclosure of classified information relating to the military sphere could have negative consequences for the organization and functioning of the state and its defense capabilities (Johnson 1989, p. 89). Consequently, the disclosure of information may be legally withheld for national security reasons if there is no reasonable measure by which to limit the harm arising from such disclosure (Földes 2014).

On the other hand, it should be noted that the concluded Agreement does not exhaustively regulate all the issues related to the protection of classified information. It is related to the specificity of the mentioned protection. In practice, depending on the territorial location, classified information will remain under the jurisdiction of the Polish or American regulations. If it remains outside the territory of these countries, the protection of classified information will be determined by the provisions of the Agreement. This triplicity of regulations has an impact on the scope of measures for the protection of classified information by the Parties to the Agreement.

It is necessary to highlight the fact that at the stage of drafting the Agreement, the Parties resolved a fundamental problem related to the types of clauses that should be applied to classified information relating to the military sphere. This issue was resolved as follows: it was agreed to use the same security classifications i.e. "top secret", "secret", "confidential".

On the other hand, classified information marked by Poland as "restricted", which does not have an American equivalent, should be treated as "confidential". Apart from the arrangements concerning the use of the security classification, the Parties did not define them. In view of the above, the granting of clauses concerning classified information in the military sphere in Poland is carried out according to the following criteria (Agreement, 2010, Article 5):

- the "top secret" clause shall be used if the unauthorized disclosure of information causes extremely serious damage to the Republic of Poland;
- the "secret" clause shall be used if the unauthorized disclosure of information causes serious damage to the Republic of Poland;
- the "confidential" clause shall be used if the unauthorized disclosure of information causes damage to the Republic of Poland (Topolewski 2020, p. 59).

Ultimately, the verification of the adopted hypothesis laid out the perspective of the research procedure aimed at determining the legal nature of the concluded Agreement, the conditions for its conclusion, the scope of the subject, the competence of the national authorities to comply with the contractual provisions and the contractual reservations in disputes.

2. The conclusion of a contract in relation to treaty provisions

Moving on to specific issues, it should be noted that the Agreement of March 8, 2007 between the Government of the Republic of Poland and the Government of the United States of America on security measures for the protection of classified information in the military sphere, concluded between Poland and the USA, can be classified as an international agreement. It is in line with Article 2(1)(a) of the Vienna Convention on the Law of Treaties of May 23, 1969, which states that "a treaty means an international agreement between states, concluded in writing and governed by international law, whether or not it is included in one document, or in two or more documents, and regardless of its particular name" (Convention, 1969). In the legal doctrine, it is emphasized that international agreements are the main mechanism for creating legally binding standards between states (Fritzmaurice, 2010), and are an instrument for ensuring stability, reliability and order in international relations (Dörr & Schmalenbach 2012). It is also regulated by the law of treaties, which specifies the procedure for concluding contracts, the rules of validity, termination or withdrawal (Convention, 1969). For this reason, Poland and the USA, being subjects of international law, are obliged to fulfil the concluded Agreement on the terms on which they agreed (Villiger, 2009). Of key importance for the discussed issue is the fact that the subjective and objective scope of the concluded Agreement has been met: the parties have clearly indicated who is to be a participant in the concluded agreement and what it should refer to.

3. Prerequisites for the conclusion of the Agreement

The preamble to the Agreement on security measures for the protection of classified information in the military sphere concluded by the Government of the Republic of Poland and the Government of the United States of America shows that its conclusion was inspired by the need to strengthen mutual cooperation in the military sphere. It is appropriate to agree with the idea of the concluded Agreement, taking into account the fact that the cooperation declared in the Agreement was determined by factors that had an impact on the security of Poland at that time. In the related literature, there are convergent positions on this issue. These factors include geopolitical location, the lack of political stability in Ukraine (Timothy, 2015), the unpredictability of the Belarusian government (Hansbury, 2020), the direct adjacency of Poland and the Kaliningrad Oblast and Russia's effort to maintain its influence in this area (Douhan, 2012).

Along with the agreement with the views presented, it can be concluded that Poland's external security should be perceived as a set of external elements influencing the state and related to its functioning. The perception of external security as a system of mutually connected elements of the environment has become a key argument for the thesis that in the face of mutual military relations, normative solutions are necessary at the level of the contracting states, which should serve, inter alia, the protection of classified information in the military sphere. The above thesis seems to be correct if we take into account that the lack of security measures in the field of classified information protection in the military sphere may disrupt or seriously disturb the functioning of the state organization or harm its security (Johnson 1989). Hypothetically, such a situation may occur in the reality of Poland's functioning, especially since the military cooperation with the United States concerns many issues related to the functioning of the Polish Armed Forces, such as the purchase of weapons, modernization of military equipment, and participation in joint military missions.

4. The subject matter of the contract

Before the detailed considerations on the regulations of the concluded Agreement are presented, the importance of the issue under consideration should be emphasized. Taking a stance on its subject is important not only for the assessment of the correctness of the Agreement, but also for the description of the individual contractual solutions. Even a cursory analysis of the content of the Agreement indicates that it includes the following issues: transmitting and marking classified information; limited access to classified information; physical security; personal security; destroying, duplicating and translating classified information: sharing classified information with contractors; records and control of classified information. The Agreement also includes the procedure in the case of loss or unauthorized disclosure of classified information in the military sphere. In addition, the issue of the competence of national authorities in the field of classified information security in the military sphere between Poland and the USA was resolved. These issues will be analyzed in detail below.

The issue of transmitting and marking classified information between Poland and the USA has been regulated in Article 2 of the Agreement. According to the adopted solution, information may be transmitted directly to the Contracting Party or through an officer or other authorized representative. It is worth noting that the phrase "other authorized representative" used in Article 2 shows that an intermediary in the transfer of classified information may be a person who is not an officer or a soldier. It should be added that classified information may be transmitted in oral, visual or written form, including the form of equipment or technology. The Agreement also allows for classified information to be transmitted via ICT systems and networks; however, classified information provided by electronic means must be encrypted.

The procedure adopted in the Agreement requires that the security classification of the transmitting Party's classified information should correspond to the classification of classified information of the receiving Party. Documents and electronic media containing classified information are required to be provided in double and sealed envelopes containing the business address of the recipient. The receipt of attached documents or other media must be confirmed by the last recipient, and the sender must be provided with the confirmation.

The Agreement also regulates the issue of protecting the transport of classified equipment. According to the adopted standard, classified equipment should be transported in sealed and covered vehicles and secured against its identification. In addition, it is required to secure classified equipment in order to prevent unauthorized access to it with the use of security devices and security personnel holding a security clearance. In the case of transporting classified equipment by changing persons, it is required to confirm that the transport has been taken over by subsequent persons up to and including the last recipient. The presented regulations lead to the conclusion that in the field of security measures, an important place belongs to undertakings related to the transfer, transport and protection of classified information in the military sphere. In this case, the Parties to the Agreement did not refer only to the national regulations, but introduced their own legislative clarifications.

Limited access to classified information in the military sphere is reflected in Article 6 of the Agreement. According to the aforementioned provision, in light of the legal status in question, limited access to classified information in the military sphere is based on the following principles. Firstly, it is allowed to disclose classified information only to persons whose official tasks require familiarization with it. Secondly, these persons must hold a security clearance issued by the Parties. Thirdly, the indicated persons have been trained to protect classified information in accordance with the domestic law of each Party. Importantly, the mere possession of a military rank, official position or possession of a security clearance, in light of the concluded Agreement, does not constitute sufficient grounds for gaining access to classified information.

In the context of compliance with the order of limited access to classified information, attention is drawn to the additional rigors of Article 6 of the Agreement. According to these: 1) The Parties may not provide classified information to a third party without the written consent of the sending Party; 2) the Party receiving the classified information is obliged to ensure the level of protection corresponding to the security classification specified by the sender; 3) the Party receiving the classified information is obliged to use it only for the purpose for which it was disclosed; 4) the Party receiving the classified information will respect the protection of personal rights, such as patents, copyrights or other rights that form part of the information being transmitted; 5) units using classified information will keep a register of persons who hold a security clearance and who are authorized to access such information in the units concerned.

The presented normative solutions lead to the conclusion that the Agreement contains "autonomous" regulations increasing the guarantees of limited access to classified information in the military sphere.

The issue of physical security of classified information has been regulated in Articles 10-12 of the Agreement. In light of the presented regulations, each Party to the Agreement is responsible for the protection of classified information received from the other Party during its transfer or storage on its territory. Each Party is also responsible for the security in all facilities where the received classified information is stored. It is necessary for each Party to assign a qualified person to each facility with authority to control and protect this information. At the same time, under the concluded Agreement, the Parties undertook to store the classified information in a way that restricts access to it only to persons who have a security clearance and have been trained in the protection of classified information, in accordance with the national regulations. A similar regime applies to persons whose official tasks require familiarization with the discussed information.

The presented regulations lead to the conclusion that the regulations established by the Agreement are effective in the field of physical protection of the classified information in the military sphere.

The next issue, personal security in the area of classified information, is regulated by the provisions of Articles 7-8 of the Agreement. Under the first provision, Article 7, the decision to issue a security clearance to a natural person should be consistent with the national security interests of the Parties to the Agreement. Most of all, it can be issued only after conducting the verification procedure. At the same time, pursuant to the concluded Agreement, an obligation to carry out a screening procedure was introduced in relation to persons having access to classified information in terms of the proper use of the information. In light of the latter provision, Article 8, before admitting to access classified information, the officer or authorized person should be checked for security clearance and the confirmation that access to information is necessary for them due to the performance of official tasks.

The presented contractual regulation of the Parties shows that the purpose of the screening procedure is to obtain knowledge about the ability of the natural person to use classified information without risking disclosure. The arguments of the parties are reflected in professional literature. Namely, it was emphasized that personal security is one of the key elements of the classified information protection system. For this reason, it is desirable that a person who has access to this type of information on account of the performed professional duties gave the pledge of secrecy (Krzykwa 2018).

By the way, it should be mentioned that the provisions of the Agreement do not regulate the validity period of a natural persons' access to classified information marked with a specific type of secrecy classification (i.e.: "top secret", "secret", "confidential"). In this situation, it must be assumed that the Polish side to the Agreement is bound by the criteria of validity of access to classified information in the military sphere indicated in Article 29 sec. 3 of the Act on the protection of classified information: 10 years – in the case of access to classified information marked as "confidential"; seven years – for access to classified information marked as "secret"; five years – for access to classified information marked as "top secret".

Another issue of destroying, duplicating and translating classified information in the military sphere found its normative expression in Articles 14-18 of the Agreement. Pursuant to the presented regulation, the documents and other media containing classified information are destroyed in a way that prevents the reconstruction of classified information contained therein. Whereas classified equipment should be destroyed in a way that excludes partial or complete reconstruction of classified information. In the case of duplicating classified documents or other media, all the original classification clauses contained therein should be placed on each copy and be subject to the same control rules as the originals.

In addition, any translations of classified information may be made only by persons holding a security clearance. The number of copies produced is limited to the necessary minimum and controlled. The translations made in this way should be marked with security classification and in the language into which the translation was made with information that the document contains classified information from the sending Party.

In conclusion, the presented regulations impose an obligation on users of classified information to be particularly careful with regard to their destruction, duplication and translation.

The issue of disclosing classified information in the military sphere to contractors is regulated in Article 19 paragraph 1-6 of the Agreement. At the beginning, the meaning of the term "contractor" requires clarification, as it is difficult to deny that it is ambiguous. In light of Article 1(5) of the Agreement, a contractor is an entity that has been awarded a contract by the contract agency of one of the Parties. In relation to the defined "contractor", the Parties to the Agreement have introduced a legal requirement to comply with certain rules for familiarization with the classified information received from the other Party. Namely, in light of the rigors resulting from the provisions of Article 19, the Party receiving classified information relating to the military sphere should ensure that: 1) the contractor and their enterprise meet the conditions for ensuring protection of classified information; 2) the contractor will have an industrial security certificate; 3) security clearance will be held by all natural persons whose duties require access to classified information; 4) all natural persons who have access to classified information will be instructed on the responsibility for violating the principles of classified information protection; 5) periodic inspections of establishments that have an industrial security certificate will be carried out in order to control the level of protection of classified information, 6) access to classified information will be limited only to persons whose official tasks require familiarizing with it.

The presented regulation leads to the conclusion that the Agreement contains effective normative solutions concerning the organization of the protection of classified information in the military sphere in relation to entities, de facto from outside the military sphere. This is evidenced by the introduced additional restrictions in the area of industrial security.

In turn, recording and controlling classified information in the military sphere has been regulated by the provision of Article 9 of the Agreement. Pursuant to the said provision, the Parties established a requirement to record and control classified information in the military sphere, both on the basis of the Agreement and the national regulations. It should be noted that on the basis of the contractual regulations it is not possible to define the terms "recording" and "controlling" classified information.

In the doctrine of administrative law, "recording" is perceived in the context of material and technical activities in the external sphere. This is manifested in making entries in registers, records and other official lists and compliance with information obligations imposed on natural persons (Mierzejewski, 2013). However, in light of Regulation No. 58/MON of the Minister of National Defense of December 11, 2017 on the special method of organization and operation of secret offices and other organizational units responsible for the processing of classified information, the method and procedure of processing classified information, the term "recording" deliberate actions is aimed at ensuring the record of classified materials in an organizational units and determining who has read the classified documents (Regulation 2017, §15 point 1, §16).

On the other hand, the term "controlling" is perceived in the legal doctrine as a process of monitoring activities in accordance with the given orders, instructions or rules. The formal controls consist in measuring, comparing and correcting on the basis of the above-mentioned standards on the basis of which these activities can be performed (Marume, et al., 2016). Whereas, under the national regulations of the Ministry of Defense, the term "controlling" refers to the deliberate and organized activity of a team (committee, group, controller, inspector, etc.) carried out in the controlled unit, based on a plan and authorization to carry it out (Decision 2015, point 3, item 8).

The cited definitions of the terms "recording" and "controlling" lead to the conclusion that the indicated actions constitute an important element in terms of increasing the effectiveness of the protection of classified information in the military sphere.

The loss or unauthorized disclosure of classified information in the military sphere is referred to in Article 21 of the Agreement. Pursuant to the aforementioned provision, the Party sending classified information is obliged to inform immediately about the loss, unauthorized disclosure, or the alleged loss or unauthorized disclosure of the information in the Party's possession. In each case of the occurrence of the issues listed in Article 21 of the Agreement, proceedings should be initiated to clarify the circumstances of the loss or disclosure of classified information. The results of the investigation, together with information on measures taken to avoid similar situations in the future, should be provided to the producing Party by the Party that conducted the investigation.

The presented regulation shows that both Parties to the Agreement are entitled to conduct an independent investigation aimed at clarifying the circumstances of the loss or unauthorized disclosure of classified information based on national procedures. For this reason, neither Party needs the consent of the other Party to take steps to initiate the investigation.

5. The competence of national security authorities to comply with the contractual provisions

The important solutions in the concluded Agreement include the specification of national authorities competent in the field of protection of classified information in the military sphere. Pursuant to Article 5(1) of the Agreement, the powers of the national security authorities in the area in question in the Republic of Poland fell under: the Head of the Internal Security Agency (Polish: Agencja Bezpieczeństwa Wewnętrznego; hereinafter: ABW) and the Head of the Military Counterintelligence Service (Polish: Służba Kontrwywiadu Wojskowego; hereinafter: SKW), and in the United States of America to the Department of Defense. The indicated competences in the scope of the contractual provisions do not constitute a closed catalog, because according to the provisions of Article 5(2) of the Agreement, the national security authorities may conclude additional implementing agreements to this Agreement between Poland and the USA in the military sphere. Without going into detailed considerations about the term "competence" in reference to the indicated bodies, it can be mentioned that it is a set of normatively defined rights, perceived as power and responsibility in the performance of specific activities (Skorková, 2016).

Conferring the powers to ABW and SKW on the national level does not raise any doubts. Nevertheless, the doctrine argued that the role of the ABW and SKW in the system of classified information protection may be fully effective only when the provisions of law adequately precisely define the competence of both authorities in the scope of activities performed by both services (Antosiak & Pałka 2017). One should agree with the presented view, but it should be clarified that the Regulation of the Prime Minister of October 4, 2011 on the cooperation of the Head of the ABW and the Head of SKW in the performance of the functions of the national security authority gave the appropriate rank to ABW and SKW in the field of protecting classified information (Regulation 2011). The empowerment of the national authorities with regard to the protection of classified information in the military sphere also results from Article 5(3) of the Agreement, which obliges each of the Parties to inform each time about any changes in their national security authorities or the scope of their liability resulting from the provisions of the concluded Agreement.

In addition, the importance of the authorities responsible for the protection of classified information (ABW and SKW) was emphasized in Article 22(1-3) of the Agreement, which gave the services in question the competence to consult and review security systems. Within the framework of their powers, the national security authorities of the Parties have been authorized to exchange information on any changes in national law relating to the protection of this information. In order to ensure close cooperation, consultations at the request of one of them are to be carried out. In addition, the implementation of security requirements may be supported by mutual visits of representatives of national security authorities to review the implementation of the protection procedures under the Agreement and to compare the existing security systems.

The presented ABW and SKW competences in the field of protection of classified information in the military sphere are valid. One needs to be aware of the specificity of the tasks performed by these bodies. Pursuant to Article 10 of the Act of August 5, 2010 on the protection of classified information, they include, among other things: supervising the functioning of the classified information protection system in organizational units remaining in their jurisdiction; controlling the protection of classified information and compliance with the provisions in force in this regard; the implementation of tasks in the field of security of ICT systems; carrying out verification procedures, control checks and industrial safety procedures; ensuring the protection of classified information exchanged between the Republic of Poland and other countries or international organizations.

In addition, it should be noted that SKW performs tasks in relation to 1) the Ministry of National Defense and units organizationally subordinate to the Minister of National Defense or supervised by it; 2) defense attache's offices in foreign missions; 3) soldiers in active service appointed to service positions in other organizational units. ABW performs tasks in relation to organizational units and persons subject to the act, which do not fall within the competence of SKW (Article 10 sec. 2).

To sum up, the above-mentioned provisions grant national security authorities the power to protect classified information. In this way, any disputes over powers between state authorities regarding the responsibility and supervision over compliance with the regulations set out in the Agreement were eliminated.

6. Contractual stipulations in disputes

Referring to the final provisions of the contract, it is worth paying attention to two issues: the issue of settling disputes arising from compliance with the Agreement and the duration of the Agreement. Referring to the first issue, it should be cited that each agreement, regardless of its form, is binding both for the USA and for Poland, because it is the result of a clear expression of the will of the contracting parties (Lesaffer, 2000). And the symptom of the will of the contracting Parties as to the implementation of the provisions concluded is clear and unequivocal. Moreover, the Parties are bound by the Agreement on the basis of the pacta sun servanda principle, which is a formal guarantee of the effectiveness of international law, due to the necessity to fulfill obligations resulting from the concluded agreements (Lukashu, 1989). However, it is difficult to assume that in practice the rules contained in the Agreement will never be violated by any of the Parties, and disputes will be eliminated.

In the legal doctrine, it has been pointed out that there can always be a conflict between international agreements and national regulations as a result of the interpenetration of the two legal systems (Klafkowski, 1965). The question then arises, how can a hypothetical conflict be resolved? The analysis of the text of the Agreement leads to the conclusion that a unilateral settlement of the dispute is not allowed. The provision of Article 24 of the Agreement provides for the possibility of settling disputes in the scope covered by the Agreement in two ways. Firstly, any disputes relating to this Agreement may be settled through direct negotiations between the national security authorities. Secondly, when it is not possible to resolve a dispute through direct negotiation, the issues should be resolved through diplomatic channels. Thus, in essence, the concluded Agreement rejects the possibility of submitting the disputable issues for decision to any other entity including a national court, an international tribunal or any other person.

As a comment, the opinion that the adopted solution is correct should be voiced, because if the parties were involved in the dispute before courts or tribunals and other entities, this would inevitably lead to the disclosure of the subject of the dispute, and at the same classified information, during the investigation. Consequently, such actions would harm the interests of both Parties to the Agreement.

The last issue that needs to be raised is the duration of the concluded Agreement. It is characteristic that due to the duration of the Agreement, it is of a time-limited nature. In light of Article 26(3), the Agreement was concluded for a five-year period, automatically extended for subsequent one-year periods. Nevertheless, the parties allow the Agreement to be terminated in writing and through diplomatic channels 90 days in advance. The introduced clause is justified. As emphasized in the doctrine of law, the states conclude international agreements as a way of exchanging promises regarding future proceedings, and agreements have value only if the promises made serve to bind the parties (Guzman 2005, p. 80). Thus, in a situation where one Party fails to fulfill its contractual obligations, the other Party may also evade compliance with them (Kwiecień, 2000).

In addition, it should be noted that the final provisions contain one more regulation important from the point of view of the security of classified information protection in the military sphere. In particular, Article 26(4) states that notwithstanding the termination of the commented Agreement, all classified information provided under it should continue to be protected in accordance with its provisions. The presented provision has the following legal effect: in the event of formal termination of the agreement, classified information in the military sphere concerning both Parties should still be protected by national security measures.

7. Conclusions

The findings obtained on the basis of the considerations made allow us to conclude that the agreement concluded between the Government of the Republic of Poland and the Government of the United States of America on security measures for the protection of classified information in the military sphere is valid. Conclusions resulting from the identification of the scope of cooperation between Poland and the USA in the area of security measures, which should guarantee the protection of classified information due to the interests of both countries, are as follows. The in-depth analysis of the provisions of the Agreement has contributed to showing the actual state of cooperation between Poland and the USA, which remains within the boundaries of rational bilateral regulation. Due to the specific nature of the subject, the concluded Agreement can be categorized as military and meets the expectations of the Parties. Moreover, it is the result of the explicit expression of the will of the contracting Parties. The manifestation of the will as to the implementation of the provisions concluded is clear and beyond doubt. A visible result of the cooperation in the discussed scope is the established procedure for the protection of classified information in the military sphere, aimed at counteracting unfavorable or illegal activities aimed at obtaining protected information by unauthorized entities. On this basis, it can be finally concluded that the hypothesis assuming that the concluded Agreement contains an optimal model of the security measures, which effectively contribute to the protection of classified information in the military sphere between Poland and the USA, has been confirmed.

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

References

1. Antosiak, P., Pałka, J. (2017). *Wybrane aspekty ustawy z 5 sierpnia 2010 r. o ochronie informacji niejawnych. Problemy, interpretacje oraz propozycje ewentualnych rozwiązań legislacyjnych, w: Uprawnienia służb specjalnych z perspektywy współczesnych zagrożeń bezpieczeństwa narodowego. Wybrane zagadnienia*. ABW.
2. Convention (1990). Vienna Convention on the Law of Treaties of May 23 1969, Journal of Laws 74(439)
3. Decision. Decision No. 345/MON of the Minister of National Defense of August 27 2015 on the supervision over the protection of classified information in organizational units subordinate to or supervised by the Minister of National Defense and in organizational units of the (Journal Ministry of National Defense of Laws of Ministry of National Defense of 2015, item 252).
4. Dörr, O., Schmalenbach, K. (2011). Introduction: On the Role of Treaties in the Development of International Law. In: *Vienna Convention on the Law of Treaties*, pp. 1–6. DOI:10.1007/978-3-642-19291-3_1
5. Douhan, A. (2012). CIS, CSTO and the United Nations: Could an Active Regional System of Collective Security Be Established? *Baltic Yearbook of International Law Online*, 12 (1), pp. 131–155. DOI: https://doi.org/10.1163/22115897-90000090.
6. Fitzmaurice, M. (2010). *Max Planck Encyclopedias of International Law*, https://opil.ouplaw.com/view/10.1093/law:epil/9780199231690/law-9780199231690-e1481#
7. Földes, A. (2014). *Classified Information. A review of current legislation across 15 countries & the EU*. Corruption risks series. Defence and Security Programme Transparency International UK. Editor: Saad Mustafa
8. Goryński, G. (2013). Prawne podstawy ochrony informacji niejawnych w Polsce. *Colloquium Wydziału Nauk Humanistycznych i Społecznych. Kwartalnik*. 1, pp. 999-128.
9. Guzman A. T. (2005), The Design of International Agreements, *The European Journal of International Law*, 16 (4), pp. 579–612. DOI: https://doi.org/10.1093/ejil/chi134.
10. Hansbury, P. (2021). Friends in Need: Belarusian Alliance Commitments to Russia and the Ukraine War, *The Journal of Slavic Military Studies*, 33 (4), pp. 542-555. DOI: https://doi.org/10.1080/13518046.2020.1845093
11. Johnson Loch, K. (1989). Covert Action and Accountability: Decision-Making for America's Secret Foreign Policy, *International Studies Quarterly*, 33 (1), pp. 81–109, DOI: https://doi.org/10.2307/2600495
12. Klafkowski, A. (1965). *Umowa międzynarodowa a ustawa*. https://repozytorium.amu.edu.pl/bitstream/10593/18311/1/002%20ALFONS%20KLAFKOWSKI
13. Krzykwa, K. Bezpieczeństwo osobowe i ochrona fizyczna informacji niejawnych w Unii Europejskiej, *Obronność - Zeszyty Naukowe*, 4 (28), pp. 127-128.
14. Kwiecień, R. (2000). Miejsce umów międzynarodowych w porządku prawnym państwa polskiego, Warszawa. Wydawnictwo Sejmowe

15. Law. Act of August 5 2010 on the protection of classified information (Journal of Laws of 2019, item 742).
16. Lesaffer, R. C. H. (2000). Medieval canon law and early modern treaty law. *Journal of the History of International Law*, 2(2), pp. 178-198.
17. Lukashuk, I. I. (1989). The Principle Pacta Sunt Servanda and the Nature of Obligation Under International Law. *The American Journal of International Law*, 83 (3), pp. 513-518. DOI: https://doi.org/10.2307/2203309
18. Marume S. B. M., Jubenkanda R. R., Namusi C. W. (2016). Administrative Control and Evaluation International Journal of Science and Research, 5 (1), pp. 1074-1082
19. Mierzejewski P.(2013) *Problematyka ewidencji ludności. Zagadnienia wprowadzające* (in:) K. Biernat, M. Dobek-Rak, P. Mierzejewski, D. Trzcińska, Ustawa o ewidencji ludności. Komentarz. Lex.
20. Regulation. Regulation No. 58/MON of the Minister of National Defense of December 11 2017 on the special method of organization and operation of secret offices and other organizational units responsible for the processing of classified information, the method and procedure of processing classified information (Journal of Laws of Ministry of National Defense of 2017, item 226, as amended).
21. Regulation. Regulation of the Prime Minister of October 4 2011 on cooperation between the Head of the Internal Security Agency and the Head of the Military Counterintelligence Service in the performance of the functions of the national security authority (Journal of Laws of 2011, No. 220, item 1302).
22. Skorková, Z. (2016). *Competency models in public sector*. Procedia - Social and Behavioral Sciences, Volume 230, pp. 226 – 234. Available online at www.sciencedirect.com
23. Timothy T. (2015). Russia's, Military Strategy and Ukraine: Indirect, Asymmetric—and Putin-Leds. *Journal of Slavic Military Studies*, pp. 445-461. DOI: https://doi.org/10.1080/13518046.2015.1061819.
24. Topolewski, S. (2020) Classified Information Protection in Poland: Traditions and the Present Day, *Safety & Defense*, 6(1), pp. 48-62 DOI:https://doi.org/10.37105/sd.61
25. Villiger M. E. (2009). *Article 9: Adoption Of The Text*, In: Commentary on the 1969 Vienna Convention on the Law of Treaties, pp. 154–164. DOI: https://doi.org/10.1163/ej.9789004168046.i-1058.78.

SAFETY & DEFENSE
ISSN 2450-551X

Landmarks in Romanian History of Anti-Aircraft Artillery: The Anti-Aircraft Gun Director Computer, "Ion Bungescu"

Laurian GHERMAN[1*], Cosmina ROMAN[2], Małgorzata ŻMIGRODZKA[3]

1. Henri Coandă Air Force Academy, Brasov, Romania; lauriang@gmail.com
ORCID: 0000-0003-0315-629X
2. Henri Coandă Air Force Academy, Brasov, Romania; roman.cosmina@afahc.ro,
ORCID: 0000-0002-5784-973X
3. Military University of Aviation, Dęblin, Poland; m.zmigrodzka@law.mil.pl,
ORCID: 0000-0003-3896-0819
*Corresponding author

DOI: https://doi.org/10.37105/sd.101

Abstract

The main purpose of this article is to present the decisive contribution that Brigadier General Ion Bungescu had to the development of anti-aircraft artillery in Romania. To achieve this objective we describe in the paper the evolution of the anti-aircraft gun director computer he invented, as well as its modus operandi. The adopted methods include quantitative and qualitative analyses of documents, manuals and albums published during the considered period, and some published by Brigadier General Ion Bungescu. The results of the article are presented in the context of the accelerated development of military aviation between the two world wars. This development put terrible pressure on the development of anti-aircraft artillery that started with land guns adapted for anti-aircraft firing in 1916 and reached anti-aircraft guns controlled by Gun Director Computer in 1945. We can compare the development of military aviation during that time with the development of information technology over the last 30 years, from connecting computers in the network to the use of artificial intelligence.

Keywords

air defense, anti-aircraft artillery, Gun Director Computer , defense

Submitted: 20.02.2021 Accepted: 21.04.2021 Published: 18.09.2021

1. Introduction

Anti-aircraft artillery includes actions such as active combat actions against an enemy from the air, as well as mitigating actions against its impact on other containment elements, such as chemical defenses, cloaking, and engineering vehicles. All commanders of any type of combat are responsible for auxiliaries in the joint anti-aircraft defense. Romanian air defense appeared around the same period as in more advanced countries at the time and remained at the same level until 1945. This was possible thanks to well-trained world-class officers. Romania is also a country with a great tradition in the field of aircraft construction. It should be noted that the rise of aviation and its entry into the industrial era took place along with the preparations and course of the First World War. The subject of the article concerns the decisive contribution of Brigadier General Ion Bungescu to the development of anti-aircraft artillery in Romania. In order to get an idea of the actions of the Romanian army, it is necessary to look at the methods of combat, including types of anti-aircraft programs during the First World War. The conducted research on the use of quantitative and qualitative analysis on the basis of the collected materials show as well as development of military aviation in the interwar period as well. The purpose of qualitative research is to describe and interpret issues or phenomena systematically from the point of view of the problem being studied, and to generate new concepts and theories. The new era of technologies is very progressive, but knowledge of the research data of already tested equipment is always a necessary foundation in the process of new systems. The article examines the emergence and development of anti-aircraft artillery in Romania from 1915 until the end of the Second World War in 1945. This analysis is not only important from a historical point of view, but also in order to understand how the people of that time managed to find quick solutions to keep up with the extremely rapid development of aviation. Although the officers who established the new specialty in the Romanian Army came mainly from ground artillery, due to good training they were able to adapt easily to the new challenges offered by the development of aviation. Although this study highlights the major contribution that Brigadier General Ion Bungescu made in the emergence and development of anti-aircraft artillery in Romania, the study also highlights the contribution of other officers who have dedicated themselves to this specialization.

In the work *Air defense*, published in 1922, Lieutenant-Colonel Gheorghe Popescu classified the planes in a similar way to the current classifications proving a good understanding of aviation. Lieutenant-Colonel Gabriel Negrei and Lieutenant-Colonel Stefan Burileanu develop anti-aircraft artillery systems from land artillery. At the beginning of his career Brigadier General Ion Bungescu demonstrates the advantage of the transition from decentralized direct firings to centralized indirect firings. At the same time, it developed in successive stages an apparat for the centralized calculation of the firing elements and had an important contribution to the emergence and development of the school of anti-aircraft artillery officers.

To highlight the good training of these officers we have used quotes from the books published during the period analyzed as many times as possible. From the study of the sources published in the analyzed period of time, it emerged that the good training of these officers was due both the national schools and to the close collaboration with people sharing the same concerns in all the countries of Europe.

The first part of the article presents the extraordinarily fast evolution of aviation since the appearance up to the end of the Second World War in a simplified form. This evolution is somewhat similar to the evolution of IT systems today. In the next chapter the efforts to establish and develop anti-aircraft artillery in Romania in the period 1915-1925 are high-lighted. A special chapter is dedicated to the contribution of Brigadier General Ion Bungescu to the development of anti-aircraft artillery in Romania. In the last chapter the operation of the last type of anti-aircraft gun director computer model Bungescu as shown by the original documentation of the manufacturer is presented.

2. The emergence of the air threat and its development until the end of World War II (1900-1945)

Although flying has been mankind's dream since ancient times, it was only at the be-ginning of the twentieth century the first successes in flying with a heavier-than-air air-craft are recorded. Thus, on December 17th, 1903, the Wilbur brothers and Orville Wrights man-aged to fly 36.5 m in 12 seconds. Later, as they learned to control the glider, they managed to fly 260 m in 59 seconds. Although recorded as the first controlled flight of a heavier-than-air aircraft, the Wrights 'brothers' plane took off with the help of a rail on the ground and landed on the 'glider's wooden frame.

Figure 1 The Wright 'brothers' glider 1909 Wright Military Flyer, National Air and Space Museum Collection in Washington, (pinrerest.com.).

On March 18, 1906, the history of aviation records the first flight of an aircraft heavier than air, which took off, flew and was landing with the means on board. Thus, on the Mon-tesson plain near Paris, Traian Vuia manages to fly "Vuia I" aircraft over 12 m at a height of 1 m after accelerating with his own means over 50 m. Later, on August 9, 1906, after making some improvements, he managed to fly over 24 m at a height of 2.5m.

After this beginning, aviation experienced an accelerated pace of development, managing to add the vertical dimension to the war in the years of the First World War (1914-1918) (Gheorghiu, 1996).

Some of the authors of this publication are also working on these related projects:

Cfp EAA 2017 - Present identities from the past: providing meaning to modern communities to have an image of aviation from the end of the First World War. For this to occur, it is important to know the classification made by Lieutenant-Colonel Gheorghe Popescu in the work *Air Defense*, published in 1922 at the Military Artillery School from Timișoara Printing House. He classified military aircraft for three types to accomplish in the mission:

- observation aircraft;
- fighters;
- bombers (Popescu, 1922).

Observation aircraft. They are two-seat aircraft (two-seater for the pilot and an observer) with a wide range, and good visibility for observation. They have defensive weapons (machine gun), camera, radio station, missiles, and powerful binoculars. General data:

- the aircrafts have a speed of 35-45 m / s;
- rise in 45 minutes at approximately 1000 m altitude;
- fly at an average speed of 40 m / s;
- and at altitudes of 1000-4000 m.

Fighters have one place (monoplane), high horizontal speed, high ascent speed, high dive speed, maneuverability, powerful weapons. High ceiling (i.e. they can rise at high altitudes). Lifting speed 10-12 minutes at 3000 m altitude. They have a speed of 40-60 m / s. Fighters usually fly at high altitudes, in enemy lines 5-6 km altitude and drop at low altitudes when attacking captive balloons or planes. Ceiling 6000-6500 m. (Popescu, 1922).

Bombers have two to three seats (three-place aircraft), with a long range, large capacity for payload, defensive armament. General data:

- elevation speed of about 20 minutes at 3000 m altitude;
- speed of about 35-40 m / s and they can carry: pilot, observer, possibly another person, about 300 kg bombs, gasoline, oil.

They fly at altitudes of about 2500-3000 m, and when dropping bombs, they can descend to lower altitudes(Popescu, 1922).

Throughout the interwar period and also during the Second World War, military aviation experienced a period of significant development. To better understand the development of aviation, it will keep the same classification with the specification that the role of “observation” aircraft was taken over by the bombers.

Technical performances of a bomber of Boeing B17 Flying Fortress type used in World War II are (Fig. 4):

- heavy bomber with a crew of 10 people, maximum speed of 128 m / s, cruising speed of 81 m / s, range 3219 km with 2700 kg of bombs, maximum flight altitude 10850 m, speed ascending 4.6 m / s.;
- the aircraft had the following types of weapons: 13 Browning M-2 machine guns of 12.7 mm, up to 7800 kg of bombs.

Figure 2 Bomber from World War II, Ike-battered Lone Star Flight Museum moving inland by H. Alexander, H. Chronicle, 2014, (pinrerest.com.).

The end of World War II marks the appearance of the first jet aircraft Messerschmitt Me 262 Schwalbe fighter-bombing aircraft (Swallow)(Fig.5).

This fighter had the following technical performances:

- monoplane fighter, maximum speed of 250 m / s, range of 1050 km, maximum flight altitude 11450 m, ascending speed 20 m / s.;
- the fighter had the following types of weapons: 4 30 mm MK 108 guns, up to 500 kg of bombs and 24 55 mm missiles.

Figure 3 Fighter-bombing aircraft from World War II., Payerne, Switzerland – September 8, 2014: Messerschmitt Me 262 Luftwaffe World War II jet fighter aircraft, (dreamsteam.com).

In conclusion, it is in less than 30 years that the air means have evolved from a speed of 50 m / s to a speed of 250 m / s and from an altitude of 5000 m to a flight altitude of over 12000 m. This almost explosive development of air means has put a lot of pressure on the development of anti-aircraft means. The problem of meeting the projectile with the target, although it was known from the mathematical model perspective, was extremely difficult to put into practice with the means existing in the same period. In the next chapter, Romania's efforts to develop air defense systems capable of effectively fighting the air force means will be presented.

3. The emergence and development of air defense in Romania between 1915-1925

In Romania, the first actions in terms of creating means of combating aviation took place in 1914. Thus, on December 22, 1914, a contract was signed with the Italian company ""Vick-ersterni Spezia"" for the import of four 75 mm anti-aircraft guns of the ""Deport"" type, which were received by the Romanian army at the beginning of August 1916. At the same time, measures were taken to use land cannons for anti-aircraft missions without constructive changes and to transform and adapt cannons for anti-aircraft fire. The modification of the 75 mm Md. 1880 guns is part of the second category of measures, made by the Army Arsenal, which was mounted on the platform and intended for fixed firing positions and the modification of 57 mm cannons by lieutenant-colonel Ștefan Burileanu and Gabriel Negrei (Cutoiu, 1984). Lieutenant-Colonel Gabriel Negrei mounted the 57 mm gun on a shielded cannon carriage, without a firing brake. Modified in such a way, the cannon could accompany the maneuvering troops and execute fire vertically up to 90^{o} but with limited possibilities of changing firing direction. Lieutenant-Colonel Ștefan Burileanu mounted the 57 mm gun on a metal pivot and equipped them with a firing brake. In this configuration the cannon had the ability to fire in the direction of 360^{o} and in a vertical position from 0^{o} to 80^{o}. The firing rate of these cannon was of 25 shots/minute. On April 15, 1916, the General Staff decided to establish a "Shooting School for the 75 mm anti-aircraft cannon" and on June 23, 1916 for the 57 mm cannons Burileanu and Negrei system.

On August 9, 1916, immediately after signing the "Military Convention between Romania and the Entente" of August 4, 1916, the General Staff, analyzing the situation of providing anti-aircraft weapons and training of personnel, found that the conditions to establish a new branch in Romanian army were met (Collective, 1996).

Thus, on August 15, 1916, the Anti-Aircraft Defense Corps was established, which in the following period was equipped with cannons, machine guns, projectors, and observation posts for the accomplishment of the assigned missions. The first combat actions took place on the night of August 15-16, 1916, when fire was opened on a Zeppelin airship used on the eastern front (Steven, 2013) that bombed the capital without causing significant damage. These actions repeated almost daily until the night of September 13-14, 1916 when the Z-181 Zeppelin was hit, and it managed to reach Bulgaria. This was also the last attack executed with a Zepelin airship on Bucharest. Subsequently, the attacks were carried out by aircraft. On September 19, a German aircraft was shot down in the Flamanda region by the "Deport" cannon battery under the command of Lieutenant Constantin Constantin (Collective, 1996).

In the work *Air Defense* published in 1922 at the Military Artillery School Printing House from Timișoara, the author Lieutenant-Colonel Gheorghe Popescu mentioned in the introduction that:

"In anti-aircraft firing, the principle must be rigorously followed: On an aircraft, firing is not regulated but is continuously prepared".

The problem of anti-aircraft firing is quite complex, the commander is in front of an extremely small and mobile target in space, which involves many variables for shooting, all entering as parameters in the geometric relationships, linking the elements in a moment" (Popescu, 1922, p. 22).

Despite all the difficulties and problems posed by anti-aircraft firing, it was nevertheless solved, initially by calculation tricks and the application of the theory of probability (Michalski & Radomyski, 2020).

It was assumed that during the time required to transmit the coordinates of the target (direction, height, speed, warhead length) and the duration of the trajectory, the aircraft goes in the same direction with constant speed, at the same height, all of which can be called the fundamental hypothesis. Thus, in 1917, the first calculators appeared and a little later, devices were created to measure the height, speed of the target aircraft and central control stations were set up.

Because anti-aircraft cannons came from the adaptation of land ones, only one way of firing was known: decentralized direct firing. In this procedure, each cannon aimed the plane and made the main corrections resulting from the movement of the target through its own devices; a group of devices ensured for the whole platoon or the whole battery the determination of height, speed, and direction. The height was measured with the wired and optical altimeter (Busson); speed was measured rudimentarily with the tachiscope; the cannon-plane distance was measured with the control telemeter and the direction with the Bricard compass.

The actual firing was performed by a combat team that, in the case of the 75 mm caliber cannon, was composed of 9 soldiers: cannon leader, direction marksman, elevation marksman, corrector in the direction, corrector in the elevation, warhead regulator, projectiles supplier, loader and shooter. Initially, firings were performed only during the daytime. Later, cannons could fire at night, but in the light of the projectors, it was not possible to speak in these conditions of firing methods and devices.

The operation of the devices is extensively presented by Lieutenant-Colonel Gheorghe Popescu in the work *Air Defense*. In the same paper he lists some firing principles:

- any observation applies to the past. It is valid for the future only as a document which must be interpreted;
- any correction made to the next fire produces its effect, only after a time equal to at least the duration of the trajectory, of the projectile;
- distribution of work;
- judgment in orders;
- continuous measurement of aircraft elements" (Popescu, 1922, p.43).

To have the best possible image of how the anti-aircraft firings were carried out at that time, I will give a detailed overview of the 3rd principle of the distribution of labor as presented in the paper:

" One man 'can't do everything, especially in this complicated shooting. For this, the functions were distributed to each device for: tracking the target, recording the device with the necessary calculations, reading, and transmitting the command to another device. Thus, all the elements of the aircraft are measured and recorded, all the firing elements related to those of the target are calculated and recorded, thus making everyone work and compete to complete the work: the departure of the projectile from the barrel, in the best conditions. The situation of the explosion towards the target is the result of 'everyone's cooperation, obviously if the target has maintained the same elements from the current position

to the next one. The commander, when the smoke rises from the plane, reaps the fruit of his work in training the personnel" (Popescu, 1922, s. 85).

4. The anti-aircraft gun director computer Bungescu

It is obvious that although the problem of meeting the projectile with the target was solved at a theoretical level, the development of some anti-aircraft cannons, but also of the measuring devices used to determine the target parameters and atmospheric conditions, requires a special attention

Due to the increase in the flight speed of the aircraft, the main direction of improvement of the anti-aircraft systems was the improvement of the cannons and the increase of the projectile muzzle velocities to reduce the time in which the aircraft had to fly in the fundamental hypothesis.

Due to the need to combat air targets at different altitudes, the emphasis was on the diversification of calibers. The classification of artillery in small, medium, and large caliber appears in the specialized literature.

Improvements to measuring devices have experienced a slower improvement, perhaps due to the complexity of the knowledge required.

Under these conditions, the young field artillery officer, Lieutenant Ioan Bungescu, passionate about calculating probabilities, began to study the causes why number of enemy planes shot down by the first anti-aircraft artillery units was quite small during the war. Following the mathematical analyzes made, the officer concluded that this is explained by the lack of synchronization of the shots fired, a lack determined by the large scattering of projectiles fired and their explosions at different times.

To remedy these shortcomings, Lieutenant Ion Bungescu had the brilliant idea of a device that would centrally calculate the firing elements and send them simultaneously to several cannons. This seemingly simple approach brings about a major change in the structure of anti-aircraft artillery subunits. Firings were no longer performed by each individual cannon but were conducted centrally from a single place. The transition was made from decentralized direct firing to centralized indirect firing. This approach is not only an improvement to the existing systems but also a new approach to the organization and execution of anti-aircraft fire with artillery.

For the practical demonstration of the viability of the new approach, Captain Ion Bungescu, promoted in 1926 as commander of the anti-aircraft battery "Skoda" with 76.2 mm caliber cannons, built the first version of the anti-aircraft gun director computer Md. 1925. Later, he used this apparatus in the battery. With the restructured battery, he participated in firings in the firing range from Mamaia, Constanța County, where he destroyed the air target even after the execution of the first salvo.

His years of work has been rewarded by the leadership of the Ministry of National Defense with the "Great Trophy of Precise Shots".

The second perfected model came into operation in 1928. In 1935, the third model known as the "simplified central apparatus" Md. 1935 was created. It was also accompanied by the paper "Memorandum on the central apparatus for preparing and conducting anti-aircraft fire", a paper that met with the favorable appreciation of the members of the specialized technical commission of the Romanian Academy. For this reason, in 1935, the paper was nominated and awarded by the highest scientific forum in our country - the Romanian Academy. For the same achievement, the Government of our country, under Decree no. 7301935, granted Major Ion Bungescu the scientific order "Cultural merit for science" 2nd Class (Collective, 1996).

It must be said that the 'officer's invention aroused great interest among specialists abroad. The proof of this is the Order "Crown of Yugoslavia" 5th class by Decree no.4235/1935 granted by the Government of Yugoslavia to Major Ion Bungescu. In the fall of 1938, a prototype of anti-aircraft gun director computer "Maior Bungescu Md.1938" was presented. It was approved in 1939. The invention was appreciated and recognized by the specialized commission operating under the Romanian Ministry of Industry and Constructions. The device obtained patent no. 3199/1939. Considered an important event, "Romanian invention for air defense", military commentators and analysts in Romania, France, Germany, and other countries have made extensive comments in the press and periodicals, highlighting both the importance of the invention and the beneficial results in conducting anti-aircraft artillery fire. The officer refused an offer from abroad and handed over the project and all its documentation to the military and civilian specialists from "Resita" factories. They later went on to mass-produce the system, so necessary for the dozens of anti-aircraft artillery batteries in 1939, in the organizational structure of the Romanian Army in the anti-aircraft defense device around Bucharest and in the Prahova Valley.

The original prototype was a world premiere. Since 1931, it was appreciated as a simple, robust, accurate and cheap device compared to other similar foreign devices of very complicated and extremely expensive construction. In Western countries, indirect, centralized firing was not even carried out, while in Romania, the anti-aircraft artillery was fired between 1926 and1928 with the new device based on the geometric method. All measurements and calculations were performed with the central firing device which, by tele-indication, continuously transmitted the firing elements - elevation, azimuth, and warhead length to the cannons – the sight thus becoming indirect. The device solved the problem of meeting the projectile with the target in the fundamental hypothesis. For Romanian anti-aircraft cannons, caliber 75 mm English Vickers model were also produced.

They worked together with the central fire control device "Predictor Vickers" which used the tachymetric firing method, or with the central fire control device "Bungescu Md. 1938" which used the geometric method. In both devices, the centralized organization of firing was common (Regulations, 1936).

Simultaneously with the technical preoccupations, Major Ion Bungescu also carried out prodigious didactic activities. Concerned with the training of specially trained personnel in the field of defense against aircraft, he pressured the law enforcement agencies and managed, on April 1, 1938, to obtain approval for the establishment of the Training Center for Air Defense, and on December 10, 1939, for the School of Officers for Anti-Aircraft Artillery.

The main objective of the educational center was specified by the commandant of the School of Officers for Anti-Aircraft Artillery, Major Ion Bungescu, when taking the military oath of faith by the first class of students:

"You have started to have a role, a mission to fulfill in the defense of the Romanian borders and sky... Preparing to become active and reserve officers in the anti-aircraft artillery, working every day and learn continuously to handle the anti-aircraft cannon, you must have in mind only one thought, that of serving the country, that of being able to fulfill a high mission: in peacetime training yourself and training others in your turn, in times of war sacrificing yourself while on active duty".

5. Operation of the central apparatus for conducting anti-aircraft artillery fire, Major Bungescu Md. 1938 system

The general characteristics of the anti-aircraft gun director computer Major Bungescu Md. 1938 system, as presented by the manufacturer solves the problem of anti-aircraft fire by a rigorously accurate method.
1. It allows the following firing methods:
a) Indirect firing calculated and transmitted to the guns, continuously: the future azimuth, the total inclination, the future warhead distance.
b) Direct firing in direction, indirect in ascent, transmits to the guns: the total inclination, direction correction (in the horizontal plane of elevation), the future warhead distance.
2. The elements transmitted to the cannons are calculated, where horizontal distance and altitude at which the position of the target is measured in the vertical plan, the speed of the target and the angle of the target's path direction in space are used as variables.
3. It continuously and automatically determines wind and parallax corrections and allows the recording of ballistic and atmospheric corrections.
4. It can shoot unseen aircraft in connection, by remote indication, with aircraft tracking devices.
5. It traces the paths of various planes flying over the AAA batteries, with the double purpose of obtaining graphic data required for reports and the elements necessary for the group commander to lead the shooting of a set of batteries.
6. It allows shooting against aircraft that are defended by using the tail gunner.
7. It can act against the fastest aircraft up to 200 m / s or 720 km / h.
8. The device can be alternatively equipped with the O.P.L. stereoscopic rangefinder, with a removable 5 m base, mounted on the device and forming a system, or with a ""Resita"" aiming tube mounted on the device and an altimeter of any type installed separately near the device.
9. The device is transported on a two-wheeled trailer that ensures great tactical and strategic mobility. The wheels are foldable to be able to place the platform - the chassis/carriage on the ground. The horizontality of the platform is obtained with the help of four adjustable jacks. The actual platform has folding sides for placing the servants. The turret is provided with a series of circular contacts that ensure tele-indication and telephone transmission with the battery, the rangefinder (in the case of the separate rangefinder), the tracking devices and the battery commander. Thanks to the transmission system and the parallax corrector, the central device can be installed up to 2 km away from the battery, in the current situation of the electric remote indication up to 250 m. The device (including the rangefinder) is used by nine servants. The maneuver is easy, requiring quite simple operations from the servants. During the action, the servants are placed on chairs mounted on the platform and are trained in the movement of the device by means of the turret.
10. The device can be used on any cannon, being sufficient to provide it with the abacus set corresponding to the respective material. For this purpose, ballistic abacuses in focal length, inclination and travel time are easily removable (Regulations, 1941).

By reading these technical-tactical characteristics, we can appreciate the fact that the device offered a top solution worldwide, perfectly adapted to the specific level of development until 1945. Obviously, with the advent of jets with speeds over 200 m / s, this system becomes morally obsolete. We must not forget, however, that between 1926 and 1945, the hard work of the future Brigadier General Ion Bungescu held Romania among the elite of countries capable of producing and being equipped with the most advanced anti-aircraft artillery systems.

The ~~central apparatus~~ anti-aircraft gun director computer Major Bungescu Md. 1938 system consists of the following large parts: an O.P.L stereoscopic altimeter, mechanism box., turret with circular platform, and a two-wheeled car trailer.

The personnel necessary for the maneuvering of the Central Apparatus Major Bungescu Md. 1938 System, consists of a chief of staff and nine servants appointed as follows (Fig 4):

- No. 1 telemetry height operator;
- No. 2 azimuth marksman;
- No. 3 elevation marksman;
- No. 4 horizontal distance recorder;
- No. 5 speed and road angle measurer;
- No. 6 speed recorder, road angle, wind and altitude reader;
- No. 7 trip length and altitude recorder;
- No. 8 tilt recorder;
- No. 9 focal length recorder.

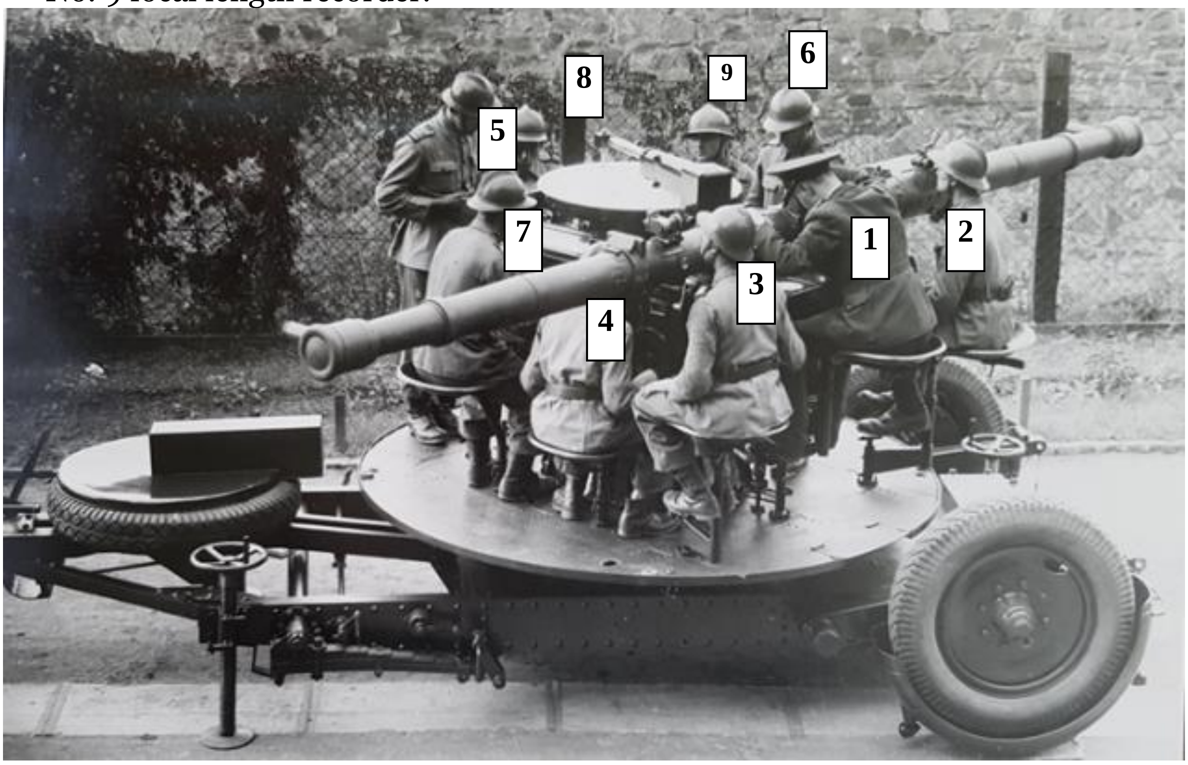


Figure 4. The place of servants on the Central Apparatus for preparing and conduct of anti- aircraft firing equipped with a stereoscopic altimeter with a base of 5 m. (Regulations, 1944).

The main duties of the telemetry height operator no. 1:

- executing height and distance adjustments;
- handling the steering wheel of the search movement. When a target appears from a different direction from those of the device, he uses the search movement with the help of the search wheel;
- controling the approximate sight, and giving instructions to servants 2 and 3 for maneuvering the aiming mechanisms.

The main duties of the servant no. 2 direction marksman and recorder:

- when aiming at a visible aircraft, performing the approximate and precise shooting in azimuth;
- when aiming at a heard aircraft, recording the alignment division on the azimuth receiver or records the azimuth transmitted from the sound tracking section.

The main duties of servant no. 3 elevation marksman and recorder:

- when shooting a visible aircraft, executing the approximate and precise aiming in elevation;
- when the aircraft is heard, recording the alignment division on the lift receiver or records the lift angle transmitted from the sound tracking section.

The main duties of servant no. 4, horizontal distance recorder:

- recording the horizontal distance as follows: either by extending the indices of the angle dial by rotating the steering wheel of the horizontal distance, or by keeping the reticle of the rear-view mirror of the horizontal distance device on the target by rotating the steering wheel of the horizontal distance.

The main duties of servant no. 5, speed, and road angle measurer:

- putting the pencil in the drawing position;
- orienting the road and measures the speed of the target.

The main duties of servant no. 6, speed, and road angle recorder:

- recording the altitude ballistic correction;
- reading the altitude;
- recording the wind direction and speed;
- recording the target speed;
- recording the road angle;
- stalling the azimuth;
- recording the percentage speed correction;
- handling the crank for clutching the recording movement;
- orienting the crown offset by the direction of the wind;
- handling the steering wheel to orient the parallax.

The main duties of servant no. 7 altitude and time recorder:

- recording the altitude on the altitude dial;
- recording the trajectory time;
- recording the parallax;
- turning the lights on and off at night.

The main duties of servant no. 8 tilt recorder is the total tilt.

The main duties of servant no. 9 warhead length recorder:

- recording the warhead length;
- recording the ballistic correction of warheads (Regulations, 1944, p. 26).

With the evolution of anti-aircraft artillery systems, it is the turn of aviation to adapt to the new conditions of the battlefield. Thus, to reduce losses, aviation plans missions especially at night when the accuracy of anti-aircraft artillery systems is the lowest. Referring to the attacks of aviation during the night, Lieutenant-Colonel Ion Bungescu mentioned, in the book Anti-Aircraft Artillery Firings Vol Iv edited by the Anti-Aircraft Artillery Training Center, Officers School in 1942, the following:

The problem of locating aircraft during the night is very up to date and of great importance. The attack of bombers during the night takes a widespread form in the current air war, especially in the case of distant and well-defended targets. The great advances made in the field of air navigation, give the bombing aviation, a great freedom of action and a great precision in the attack of the objectives during the night.

In the current state of the means, the sound reconnaissance is the basis of the action of the anti-aircraft artillery during the night, both in firing on the "illuminated plane" with the help of projectors, and in firing on the "heard plane" (Bungescu, 1942).

The action of anti-aircraft artillery during the night, being much more complicated than during the day, involves a special organization with sound tracking devices and a complex instruction.

Based on the experience of the current war, it is often the case that the action of the anti-aircraft artillery combined with that of the projectors (firing on an illuminated plane) is difficult or inapplicable. Therefore, the other form of action, shooting on an “unseen plane” is indispensable. Therefore, it is essential to practice and apply the sound measuring technology to the maximum of its capacity, both in terms of maneuvering with the projectors and shooting with the use of the sound target localization before new devices for target localization are introduced (Bungescu, 1942).

Also, in the same work, the author recognizes the limits of determining the position of airplanes with the help of sound waves. At the same time, however, he is aware of the research that was done in different countries to find more efficient solutions for locating airplanes.

It is interesting from a historical perspective how an anti-aircraft specialist looked at the development directions of aircraft location systems.

The first category of devices originally used the aircraft sound source as well, but the ear as a receiving organ was replaced by special instruments.

Another category of locating devices uses a different energy source than the acoustic one. In America, a method has been developed that has led to the construction of an instrument that allows perceiving the heat radiated by aircraft engines. It is believed that the results obtained are exceptionally good, but the tool/instrument seems impractical due to the narrowness of the field.

In France and England, there was talk before the war of devices using rays or radiation spreading at the speed of light. In Germany, a lot of work is being done in the same direction and we can speak of some especially important achievements. The devices using the electromagnetic waves emitted by the plane are being generalized (Bungescu, 1942).

6. Conclusions

In conclusion, Romanian air defense appeared in the same period as in the more advanced states of the time and remained until 1945 at the same level as them. This was possible due to the existence of well-trained officers able to understand the complexity of anti-aircraft artillery firing. The quality of officers’ education was also high because they benefited from courses and training periods abroad and thus were up to date with the latest advances in the field. This quality could be maintained owing to the establishment and development of weapons education in Romania. The quality of training of anti-aircraft artillery officers allowed Captain Ion Bungescu to radically change the firing, from decentralized direct fire to centralized indirect fire, which was much more effective. It also allowed him to make the first mechanical firing computer for anti-aircraft artillery in our country and among the first in the world. The domestic industry was able to produce both the central firing apparatus and the anti-aircraft artillery pieces. After 100 years of anti-aircraft defense in Romania (G. Visan, 2017), the history of anti-aircraft artillery can strengthen *l`esprit de corps* of elite officers. They were able, at different times in history, to succeed with the means at their disposal to maintain the air defense at the level of those existing in the most advanced states. This analysis highlights the importance of education in preparing those who will have to find solutions to future problems. Thorough education and cooperation are the prerequisites for future development.

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.

References

1. Bungescu, I.(1942), *Tragerile Artileriei Antiaeriene Vol. IV*, Centrul de Instrucție al Artileriei Antiaeriene, Școala de Ofițeri, București, Romania.
2. Comandamentul Artileriei Antiaeriene (1944), *Instrucțiuni referitoare la Variația elementelor determinate de Aparatul Central de Tragere sistem*.
3. Colectiv (1996) *Istoria Artileriei şi Rachetelor Antiaeriene Române Vol. I* – Editura Modelism, București, Romania.
4. Cutoiu, V., (1984), *Istoria apărării antiaeriene a teritoriului României*, Editura militară, București, Romania.
5. Deheleanu, A.(2011), *The beginnings of Romanian aviation*, Incas bulletin, Romania.
6. Michalski, D., Radomyski, A. (2020). *Counting the Uncountable. Safety & Defense*, *6*(2),100-112. https://doi.org/10.37105/sd.91.
7. Popescu, I. (1977) *Colectiv - Istoria artileriei române*, Editura Militarã, Bucureoti, Romania.
8. Rudeanu, I. V. (1931) *Tragerile de noapte ale Artileriei Antiaeriene* – Tipografia ”Dorneanu”, București, Romania.
9. Regulament provizoriu asupra nomenclaturii, descrierii, funcţionării, manevrei şi întreținerii tunului a.a. cal. 75 mm sistem Vickers Md. 1936.
10. Regulament asupra descrierii, funcţionării şi manevrei aparatului central de tragere simplificat sistem Maior Bungescu I. Md. 1941.
11. Steven, J. M., (2013*) Major-General G. V. Burman and the Creation and Development of ’Russia's Air Defense System in World War I*, The Journal of Slavic Military Studies,26:3,439-461, DOI: 10.1080/13518046.2013.812486.
12. Leitz, Ch.(1997), *Arms as Levers: Materiel and Raw Materials in Germany's Trade with Romania in the 1930.*, The International History Review, XIX, https://doi.org/10.1080/07075332.1997.9640786.
13. Visan, G. (2017) *Romania on Course to Revamp Its Air Defenses*, Eurasia Daily Monitor, 14(1).


PGZ
WISŁA
PILICA
POPRAD
PROVEN SOLUTIONS
FOR MODERN ARMED FORCES
GRUPAPGZ.PL
PITRADWAR
PCO
Zakłady Mechaniczne Tarnów
MESKO
HSW
WZU