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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

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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.

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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.

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