MANAGEMENT ALGORITHM FOR THE COMPREHENSIVE SYSTEM OF TESTING SAMPLES OF ANTI-AIRCRAFT MISSILE SYSTEMS

Combat capability characterizes the ability of a military unit or unit to perform its assigned tasks. The combat capability of the modern army is based on the degree of staffing with modern types of weapons and military equipment, their technical level and combat capabilities. The main requirement for weapons samples is high efficiency in the performance of combat missions. Quality control of weapons samples requires the performance of the necessary number of comparative studies, including when conducting different levels of testing.

Testing is the main way of confirming the given tactical and technical characteristics of weapons samples and their constituent parts. The main way to assess the characteristics of the intended use of weapons is to conduct the necessary number of field experiments. It is not always possible to conduct live experiments due to various reasons of an objective nature in the conditions of hostilities, or large material costs or the impossibility of ensuring the safety of conducting experimental work.

An analysis of the introduction features of a complex system of testing samples of the anti-aircraft missile complex which involves replacing part of the live tests with its simulation using semi-live or mathematical modeling stands has been carried out.

A control algorithm is proposed that implements an integrated test system of samples of anti-aircraft missile systems and provides for the following procedures: collection and processing of the requirements of the tactical and technical (technical) task for the development of a weapons prototype, analysis of requirements for the tactical and technical characteristics of the sample; summarizing the tactical and technical characteristics of the prototype of the complex which are subject to verification and confirmation by conducting tests; determination of the tactical and technical characteristics of the intended purpose of the complex, the verification of which requires conducting full-scale experiments; determination of the tactical and technical characteristics of the intended purpose of the complex which can be verified by conducting semi-realistic, mathematical and computer simulation modeling; analysis of complete coverage of all significant tactical and technical characteristics of the complex; formation of a decision regarding the organization of tests of an anti-aircraft missile complex sample; analysis of the effectiveness of the tests and correction of the solution.

Keywords: integrated test system, sample of an anti-aircraft missile system, tactical and technical characteristics, experiment, modelling.

Introduction

Formulation of the problem. The Armed Forces of Ukraine are entrusted with the defense of Ukraine according to the Constitution of Ukraine, the protection of its sovereignty, territorial integrity and inviolability. The Armed Forces of Ukraine ensure deterrence of armed aggression against Ukraine and repulse it, protection of the state's airspace and underwater space within the territorial sea of Ukraine [1].

The state's defense capability characterizes its ability to defend itself in the event of armed aggression or armed conflict. The military power of the state is a set of forces and means allocated by the state in a certain period to protect its interests. The military power of the state is directly embodied in the Armed Forces, the state's ability to maintain and improve them, increase their fighting capacity, replenish them with trained personnel, provide them with modern weapons and military equipment and all types of supplies in peacetime and wartime.

Combat capability characterizes the ability of a military unit or unit to perform its assigned tasks. It is determined primarily by the degree of completion of modern weapons and military equipment, their technical level and combat capabilities [2-3].

The military doctrine of Ukraine [4] sets before the domestic military-industrial complex the task of "...adopting fundamentally new types of anti-aircraft weapons, developed on the basis of modern technologies." The main requirement for АМЕ samples is high efficiency when performing combat tasks. Quality control of AME samples requires the performance of the necessary number of comparative studies, including when conducting different levels of tests.

Testing is the main way of confirming the specified tactical and technical characteristics (TTC) of the samples and their constituent parts. The main method of assessing the characteristics of the intended purpose of AME samples is to conduct the required number of full-scale experiments. In the conditions of hostilities, it is not always possible to conduct live experiments due to various reasons of an objective nature, or large material
costs or the impossibility of ensuring the safety of conducting experimental work. One of the most appropriate approaches to solving problematic issues during testing is to replace part of the full-scale tests of the AME sample with semi-full-scale, mathematical and computer simulation modeling.

Analysis of recent research and publications. The general provisions on conducting AME tests in Ukraine are specified in normative documents, in particular [5]. To date, there are many works dealing with the methodology of conducting experiments and tests of military equipment, improving the quality of the process and test results [6–8].

A whole series of works is intended to consider the issues of feasibility of created new samples of weapons and ensuring the conduct of range tests, as well as the shortcomings and advantages of the existing system of testing samples of AME. Thus, the article [9] summarizes the features, the most important stages and mechanisms of the functioning of the system of creating AME samples of the former USSR, which are expedient to obtain (use) when conducting tests of AME samples in Ukraine.

In work [10], issues related to the possibility of introducing in Ukraine the requirements for electromagnetic compatibility of samples during tests of typical types of AME for compliance with NATO standards are considered.

The authors of the work [11] reviewed the main principles and principles of using simulation tools, and also highlighted the history of creation, implementation, and the latest trends in the development of simulation tools in the leading countries of the world. The possibilities of implementation and further prospects for the development of means of simulation modeling of AME in the Armed Forces of Ukraine are analyzed.

In work [12] it is noted that the creation of modern integrated test system, in particular, radio-electronic means, is based on the integration of their multi-faceted computer modeling and significantly more complex and expensive experimental studies of the object - its tests. The significant improvement and spread of computer modeling to the object's ecosystem provides a fundamental opportunity to reduce the specific weight of experimental research, replacing them with powerful computer modeling – the so-called virtual tests.

In work [13], actual areas of improvement of the system of metrological support of AME samples (complexes) at the stage of their field tests are determined. The main requirements for the normative, organizational and technical foundations of metrological support for tests and directions for their implementation are systematized.

The authors of the work [14] point out that in the current conditions, the task of developing new approaches to conducting SAM tests, which take into account both resource and time limitations, as well as the need to improve the quality of the TTC assessment of the tested products, has become of urgent importance. The most promising approach to solving this problem is the use of a combined test system, the basis of which is the technology of a virtual training ground (or virtual reality). But the work does not consider the mechanism of implementation and implementation of a complex system of testing SAM samples.

Thus, the analysis of literary sources shows that insufficient attention is paid to the mechanisms and algorithms of the implementation of the integrated test system of air defense, in particular samples of air defense systems.

This indicates the need to analyze the features of the introduction of a complex system of testing SAM samples and develop a control algorithm for its implementation.

The purpose of the article is to develop a control algorithm for the implementation of an integrated test system of testing SAM samples. To achieve the goal, the following tasks must be solved:

– analyze the features of the introduction of an integrated test system of SAM samples;
– to propose a control algorithm for the implementation of a complex system of SAM testing samples.

Main material

Modern systems of anti-aircraft missile weapons are one of the varieties of integrated technical systems and are capable of fighting almost all types of air attack means.

The anti-aircraft missile system (SAMS) is a set of functionally related combat and technical means that ensure the autonomous execution of tasks to destroy aerial targets. The air defense system includes radar means for detecting and tracking air targets, anti-aircraft guided missiles (SAMS) and launch equipment.

The combat effectiveness of each type of weapon depends on the properties and their indicators embedded in it during the development. For air defense systems, indicators of such properties are: channelization of targets and missiles, target detection and tracking range, missile flight speed, measurement errors of target and missile movement parameters, limits of hit zones, probability of hitting air targets, speed of movement in different terrain conditions, and a number of others. Collectively, they determine the reconnaissance, fire, mobile (maneuverable) and operational capabilities of weapons [15].

Reconnaissance capabilities of air defense systems characterize the ability of radar equipment to detect targets (minimum and maximum target detection range, minimum and maximum target detection height, etc.).

The main indicators of the fire (combat)
capabilities of the air defense system are the firing zone and the defeat zone. The firing zone is a part of the space around the air defense system, within which it is possible to direct missiles at the target and destroy them with a probability different from zero. This zone determines the limit capabilities of the antiaircraft guided missile system. The zone of damage is a part of the firing zone, within which the air defense targets are hit with a probability not lower than the specified one. The zone of defeat is the most important generalized characteristic of the combat capabilities of air defense systems to destroy air targets in various conditions. Fire capabilities are characterized by the following main characteristics: types of targets to be hit, minimum and maximum range of targets to be hit, minimum and maximum height of hitting targets, maximum speed of hitting a target on the oncoming course and follow-up, probability of hitting different types of targets with one missile (oncoming/follow-up), etc.

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Mobility (maneuverability) characterizes the ability of air defense systems to move quickly before the start and start of hostilities, deployment in battle order, and removal from position. It is determined by the following basic characteristics: movement speed, power reserve, maximum power, cross-country ability, engine type, time of deployment and bringing to combat readiness, etc.

When developing new samples of air defense systems, they try to improve first of all the most important characteristics of the target purpose of air defense systems (probability and parameters of the damage zone of an air target of a given type by one antiaircraft missile; the number of targets that are simultaneously fired at and the number of anti-aircraft missiles directed at them).

A test sample of an air defense system is an AME product, manufactured according to the newly developed working design (repair) documentation and technology of experimental (repair) production for verification by tests of its compliance with the tactical and technical task (TTT) or technical task (TT) and the correctness of the adopted design and technical decisions for the purpose of making a decision on the intended use of the sample and its introduction into production (serial (repair) production) [5].

The test is an experimental determination of the quantitative and/or qualitative characteristics of the properties of the SAM sample, as a result of the action on it during its operation and during the simulation of the SAM sample and/or actions on it. The purpose of the tests is to assess the combat capabilities, check and confirm their tactical and technical characteristics (TTH) in accordance with the requirements of the TTT or the TT for the performance of research and development work (RDW) or the TT for carrying out work on the development of repair documentation in conditions that are as close as possible to regular operation in troops, as well as to determine the possibility of accepting the developed (modernized, repaired according to the newly developed repair documentation) sample of AME for service (supply, use as intended), making a decision to put it into production (for serial repair production).

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Sample testing is a type of experimental work carried out at various stages of their life cycle. It is the main way of confirming the given tactical and technical requirements (characteristics) for the samples (their constituent parts) and checking the correctness of the selected technical (design) solutions and substantiated new technical (design) solutions.

At the testing stage, the TTT of the AME sample is evaluated. The main principle of organizing and conducting tests of the AME sample is to fully cover all significant characteristics. The main method of
assessing the target characteristics of the air defense system is to conduct the necessary number of live experiments related to the flight of the test model by aircraft of various types and the launch of anti-aircraft missiles at targets of various types in conditions as close as possible to the predicted conditions of operation and combat use of the air defense system. As the experience of field studies [14] shows, difficulties in solving this problem at the test stage are due to the following factors:

– in order to evaluate the performance characteristics of the experimental air defense system at the test site, it is necessary to create such an air and obstacle environment that takes into account both modern and promising means of air attack of the enemy and means of radio-electronic warfare (MREW);

– carrying out field tests requires large material and time costs associated with the need to check a large number of parameters in different modes and operating conditions in order to make a decision on the compliance of the SAM prototype with the requirements of the TTT;

– currently there are no aircraft and targets that allow to simulate aerodynamic and ballistic targets of various types based on their spatio-temporal and speed characteristics, which does not allow to assess the combat capabilities of the experimental air defense system with the necessary reliability and in full;

– to evaluate the firing efficiency of a prototype air defense system by performing test firings (launches) of anti-aircraft guided missiles (AGMs) at the maximum range, the launch points of the targets must be located at a distance from the test sites of the training ground, which is significantly greater than the far limit of the air defense zone;

– field tests of the prototype air defense system, related to the execution of overflights of radar equipment by aircraft at low and extremely low altitudes, the execution of test launches (firing) of anti-aircraft missiles at targets of various types, the assessment of protection against high-precision and self-guided enemy weapons carry risks of abnormal and emergency situations;

– some of the requirements specified in TTT cannot be verified in a real environment due to the lack of real systems, for example, high-altitude and hypersonic targets, or the impossibility of ensuring safety, for example, flying at ultra-low altitudes.

Thus, all this forces the development of new approaches to conducting SAM tests, which take into account both resource and time limitations, as well as the need to improve the quality of the TTC assessment of the tested products.

Obviously, in these conditions, at the testing stage, it is necessary to replace part of the field tests of the SAM sample with simulations using semi-real or mathematical modeling stands. Modeling [16] is a process of building, studying and applying models that, during research, replace the original object (a SAM sample) so that their direct study provides new information about the original object (a SAM sample).

A mathematical model of a physical object (SAM) is a set of mathematical relations (equations, formulas, graphical relations, inequalities) that connect the initial characteristics of the state of a physical object (SAR) with input information, initial data, geometric (spatial and other) restrictions imposed on the operation of the object. The mathematical model is in a certain correspondence with the physical object and can replace it for the purpose of studying and researching new information about the behavior of the object (mechanism of processes, dynamics, behavior of the object both in the past and in the future, etc.).

Imitation (computer) modeling, in which the logical-mathematical model of the studied air defense system (or its component part) is the algorithm of the functioning of the complex (its component part), is implemented in the form of a computer software product (complex of programs). In simulation modeling, the algorithm model of the process of the anti-aircraft missile system functioning in time is implemented. The elementary phenomena that make up the process are simulated, while preserving their logical structure and sequence of flow in time. Simulation models differ in the ability to simply take into account numerical factors and relationships of the process that are difficult to form, and in the absence of a real modeling object, they can serve as its analogues when checking the correctness of models of other classes.

Computer simulation models should be the basis of virtual reality technology, adequately simulate the processes that take place in the experimental air defense system and its components (combat assets) in different modes of their functioning (operation). Computer simulation models that allow conducting virtual tests should be developed for a specific type of air defense system, taking into account the composition and characteristics of its combat equipment (component parts). At the stage of field tests, these models must provide solutions to the following tasks:

– analysis of the effectiveness of the anti-aircraft reconnaissance means in a difficult obstacle environment;

– analysis of the effectiveness of SAM firing when using intensive target maneuvers;

– study of the main characteristics of air defense systems (detection zone, damage zone, tracking accuracy, etc.).

In semi-realistic modeling, the model and the modeled object (SAR) are real objects or processes of the same or different physical nature, and between the processes in the original object and in the model, some
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The replacement of part of the field tests of the air defense system sample will be effective if it provides the necessary volume of evaluated performance characteristics of the experimental weapon sample with the necessary accuracy and reliability indicators under the given limitations on the duration and cost of the tests. Such a system of tests of the SAM sample is of a combined nature, when at the test stage part of the full-scale tests of the air defense sample is replaced by modeling using semi-full-scale and mathematical modeling stands. The basis of such a system is the technology of a virtual training ground (or virtual reality).

The complex test system represents a hierarchical set of methods and techniques of full-scale (semi-full-scale) tests and mathematical models, agreed on the purpose, used indicators and criteria, input and output parameters, system of restrictions and assumptions. It can be implemented in the form of a set of technologies that allow you to take into account how the possibilities of real training ground equipment, as well as the possibilities of virtual reality (virtual training ground) to ensure the conditions and safety of tests of the prototype SAM. This will make it possible to significantly reduce the time and cost of conducting SAM tests, increase the accuracy of TTC estimates, and also expand the range of test conditions.

The control algorithm for the implementation of a complex system of tests of the SAM sample is presented in Fig. 1.

The first level consists of:
- a unit for collecting and processing TΤ requirements for the development of a prototype SAM;
- a unit for collecting and processing TT requirements for the development of a prototype air defense system.

On the second level are placed:
- block of analysis of requirements for the TTC of the air defense system sample;
- a block of analysis of the requirements for the TT sample of the air defense system.

On the third level, there is a block summarizing the performance characteristics of the experimental air defense system, which are subject to verification and confirmation by conducting tests.

The following blocks are located on the fourth level:
- a unit for determining the performance characteristics of the target purpose of air defense systems, the verification of which requires full-scale experiments;
- a unit for determining the performance characteristics of the target purpose of the air defense system, the verification of which can be carried out by carrying out semi-realistic modeling;
- a unit for determining the performance characteristics of the target purpose of the air defense system, which can be checked by computer simulation modeling.

At the fifth level, there is a block of analysis of the completeness of coverage of all significant TTC of the air defense system sample.

The sixth level consists of a block of decision-making regarding the organization of air defense tests, a block of analysis of the effectiveness of tests of an air defense sample, and a block of decision correction.

Thus, the control algorithm for the implementation of the complex system of tests of the SAM sample consists of 13 blocks, which are placed on 6 hierarchical levels and are connected by forward and reverse logical connections.

**Conclusions**

1. The main method of assessing the characteristics of the target purpose of SAM samples is to conduct the necessary number of full-scale experiments. In the conditions of hostilities, it is not always possible to carry out live experiments due to various reasons of an objective nature, or large material costs or the impossibility of ensuring the safety of conducting experimental work. One of the most appropriate approaches to solving problematic issues during testing is to replace part of the full-scale tests of the AME sample with semi-full-scale, mathematical and computer simulation modeling.

2. The features of the introduction of a complex system of testing SAM samples were analyzed. The complex test system represents a hierarchical set of methods and techniques of full-scale (semi-full-scale) tests and mathematical models, agreed on the purpose, used indicators and criteria, input and output parameters, system of restrictions and assumptions. It can be implemented in the form of a set of technologies that allow you to take into account both the capabilities of real test equipment and the capabilities of virtual reality (virtual test site) to ensure the conditions and safety of tests of the SAM prototype.

3. A control algorithm is proposed that implements a complex system of testing SAM samples and provides for the following procedures: collection and processing of the requirements of the tactical and technical (technical) task for the development of a prototype weapon, analysis of requirements for its tactical and technical characteristics; summarizing the tactical and technical characteristics of the prototype of the complex, which are subject to verification and confirmation by conducting tests; determination of the
tactical and technical characteristics of the intended purpose of the complex, the verification of which requires conducting full-scale experiments; determination of the tactical and technical characteristics of the intended purpose of the complex, the verification of which can be carried out by conducting semi-realistic, mathematical and computer simulation modeling; analysis of complete coverage of all significant tactical and technical characteristics of the complex; formation of a decision regarding the organization of tests of a sample of an anti-aircraft missile complex; analysis of the effectiveness of the tests and correction of the solution.

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КЕРУЮЧИЙ АЛГОРИТМ РЕАЛІЗАЦІЇ КОМПЛЕКСНОЇ СИСТЕМИ ВИПРОБУВАНЬ ЗРАЗКІВ ЗЕНІТИХ РАКЕТНИХ КОМПЛЕКСІВ
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Боєздатність характеризує спроможність військової частини чи підрозділу виконувати завдання за порядком, який відповідає боєздатності. В основі боєздатності сучасної армії лежить ступінь укомплектованості сучасними зразками озброєння та військової техніки, їх технічний рівень та бойові можливості. Основна вимога до зразків озброєння – це висока ефективність при виконанні бойових завдань. Контроль якості зразків озброєння вимагає виконання необхідної кількості порівняльних досліджень, в тому числі при проведенні натурних експериментів. Контроль якості озброєння та військової техніки, їх технічний рівень та бойові можливості. Основна вимога до зразків озброєння – це висока ефективність при виконанні бойових завдань. Контроль якості зразків озбо