

Evolution and Enlightenment of the U.S. Military Equipment T&E Theory

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Abstract—T&E plays an important role in the construction and development of weapons and equipment. After a century of exploration, the U.S. military has gradually established an equipment T&E system with scientific organizational mechanism, highly unified resources, and clear development plans. Based on the analysis of development process of the U.S. military's T&E reform, this paper explores the general laws and internal logic of its development and maturity from different perspectives such as national strategic trends, equipment technology development, and test theory improvement. On this basis, combined with the reality of our country's T&E work, some enlightenment are put forward from the three aspects of test resource management, the independence of combat tests, and the strategy of selective " Shift Left ". The research can provide a useful reference for the fast and healthy development of the T&E of our country.

Keywords- U.S. military, T&E, Evolution, enlightenment

1. Introduction

Test and evaluation (T&E) is the process of conducting tests on equipment systems or components, and analyzing and evaluating performance and effectiveness of them. It is a necessary step to ensure that weapons and equipment are usable, effective, and easy to use. The world's major military powers all attach great importance to the important role of T&E in the process of military technology development and weapon equipment construction. As one of the earliest countries in the world to carry out equipment T&E, the United States has a history of more than 100 years of T&E. The authoritative status of the T&E work has been established by the law, and a scientific and reasonable system has been established. As a result, a relatively complete T&E system has been formed in U.S. military. With the fast development of our country's equipment from the stage of tracking, testing and imitation to the stage of independent innovation, the significance of T&E work to the development of our country's equipment construction is also increasing. It is important to develop T&E technology vigorously, build T&E resources, and promote the comprehensive develop of T&E, as it is conducive to the construction of our country's national defense and the development of weapons and equipment. Based on the analysis of the development process of the US military's T&E, this paper attempts to dig out the internal logic of its construction and development, explore the general rules of the T&E system construction, and provide reference for the development and improvement of our country's T&E system.

2. Research Status of Foreign Military's T&E System

Due to the late start of the T&E work in our country, the results of the research on the T&E system of foreign military forces have only gradually appeared in recent years. Zhao Xun et al. gave an overview of the modernization evolution of equipment T&E in Russia, Britain, France and other countries, focusing on the new development of the T&E organization and management mechanism of various countries under the background of the times and analyzed its laws and characteristics [1]; Jiang Shengxin et al. analyzed the aerospace equipment COTS T&E work of the U.S. military from three dimensions of horizontal scope, vertical depth and existing problems, and put forward suggestions suitable for the T&E of aerospace shelf products in China [2,3]. Based on the background of joint operations, Zhang Bing et al. conducted an in-depth analysis of the U.S. military equipment interoperability T&E from the perspectives of development history, policy systems, organization management, and implementation processes, and summarized the main experience and practices of U.S. military equipment interoperability T&E technology which have certain enlightenment significance for the development of our country's construction of interoperability T&E [4]. Most of the studies above are aimed at a specific field of foreign military T&E, which is of positive significance to the development of T&E work in our country. But in general, the system and completeness of the existing research are still lacking, and the pertinence of the revelation and suggestions is not strong enough.

3. The main development history of US military's T&E

3.1 The embryonic stage

The U.S. military's T&E work began in the early 20th century. In 1902, the U.S. Army established the Field Artillery Commission to conduct research on artillery ammunition, caliber, and transportation, and undertook part of the test and inspection work. This is the germination of the idea of equipment T&E [5,6]. In 1917, the U.S. Army built the Aberdeen Proving Ground in Maryland, which marked the initial establishment of the U.S. military equipment T&E system [7]. The test range during this period mainly served equipment research and product acceptance, and had the ability to evaluate the equipment capabilities of hostile forces through experimental means.

3.2 Rapid development stage, "chimney" development of the test range

In the 1940s, due to the traction of war preparation needs and the support of modern scientific and technological progress, the construction of weapons and equipment and the military industry of major military countries developed rapidly. Various complex constraints lead to the redesignation of professions and functions, and the two departments of weaponry and equipment development and testing began to separate. Various arms of the United States have established equipment research and development departments one after another and are responsible for the research and development and testing of their equipment respectively. Since the 1950s, a large number of highly specialized weapons testing grounds have emerged, the scale and means of testing have become more comprehensive and complex, and T&E has rapidly evolved into a relatively independent scientific field [8]. At this stage, the number of test ranges increased to more than 80 rapidly, and the equipment test system was gradually established. The theory of

equipment T&E was initially formed. Since the equipment system and technology are relatively simple, the types of T&E at this time are mainly equipment development T&E which mainly considering the achievement of equipment's technical indicators. At the same time, due to the lack of unified supervision of equipment testing, each military branch organizes and implements equipment testing activities independently, resulting in duplication of construction and overlapping functions of some shooting ranges. And there is a great waste of testing resources and facilities.

3.3 The stage of deepening understanding

In the early 1970s, the United States learned the painful lessons of the Vietnam War and began a comprehensive reform of its equipment procurement management system. The development and use of weapon systems are divided into two relatively independent construction phases, and the evaluation of combat effectiveness and combat applicability is proposed and listed as key appraisal contents.

In this period, the lanchester equation, SEA method and ADC method, etc. have been proposed and widely used to carry out the evaluation of the combat effectiveness. Here is a brief introduction to ADC method.

ADC method is a representative model used for effectiveness evaluation of weapons and equipment and the expression of the combat effectiveness with ADC method is as shown in formula 1.

$$E = A \times D \times C = [a_1, a_2, \dots, a_n] \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nm} \end{bmatrix} \quad (1)$$

$$\times \begin{bmatrix} c_{11} & c_{12} & \dots & c_{1m} \\ c_{21} & c_{22} & \dots & c_{2m} \\ \dots & \dots & \dots & \dots \\ c_{n1} & c_{n2} & \dots & c_{nm} \end{bmatrix}$$

In which, A represents availability, usually expressed by availability vector $A = \{a_1, a_2, \dots, a_n\}$, where a_1, a_2, \dots, a_n represents the probability that the weapon system is in the state 1, 2, ..., n at

the beginning, and the sum of the probabilities of each state should be 1, that is $\sum_{i=1}^n a_i = 1$; D

represents the dependability of the weapon system, usually with an matrix of $n \times n$ represents the probability d_{ij} that the weapon system transfers from one state i to another state j in the

process of operation, and should meet the requirements $\sum_{j=1}^n d_{ij} = 1$; C represents the inherent

capability matrix of the system, usually with an $n \times m$ matrix represents the measurement of equipment's ability to complete the specified task m under the conditions of a_1, a_2, \dots, a_n .

In 1971, the U.S. military formally proposed the concept of operational testing, and divided equipment T&E into two stages: development testing and operational testing. In 1985, the U.S. Department of Defense carried out major reforms, and the Operational Test and Evaluation Bureau was formally established as an independent decision-making body for combat test and evaluation, which is directly under the leadership of the Department of Defense. The development T&E Office is under the direct leadership of the Assistant Department of Defense Deputy. The supervision of research and development tests and combat tests is completely separated from the Ministry of National Defense, presenting a dual-track parallel and independent of each other [6].

3.4 The mature stage

In the 1990s, with the disintegration of the Soviet Union and the end of the Cold War, the U.S. military began to reduce the number of troops and reduce the defense budget. The pace of equipment construction began to slow down, and equipment T&E funds and personnel were also greatly reduced, which leads to the testing capabilities lagging behind the development of weaponry and equipment technology. Therefore, the U.S. military began to plan the T&E system structure from the top level of the strategy, and set up two T&E authorities, namely, the Research and Development T&E Bureau and the Operational T&E Bureau. DTEG is headed by the Under Secretary of Defense for Acquisition and Technology; OTEG reports directly to the Secretary of Defense. In 2001, the U.S. National Defense Acquisition Instruction 5000.1 pointed out: "encourage the comprehensive development of research and development tests and operational tests to save time and costs." Accordingly, the U.S. military began to try the "integrated T&E strategy" and implemented this strategy in 2003 [9].

In 2003, the U.S. military also established a test resource management center to coordinate the construction and use of military T&E resources. It retained 24 key shooting ranges, made special investment in key test capabilities, and realized unified construction of the various test resources which improved the utilization efficiency of test resource and avoided waste caused by repeated construction. The investment and modernization funds of the key ranges between the year 1994 and 2013 are as shown in figure 1, in which the blue line represents the investment in military buildings while the red one means the investment in modernization. The test resources and capabilities of the US military were improved further [7].

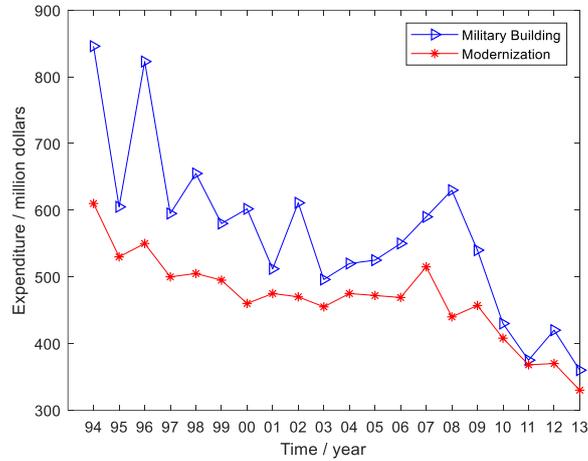


Figure 1 The investment funds of the key ranges

According to statistics in recent years, 24 key shooting ranges of the Ministry of National Defense support about 2000 test projects every year. The indirect funds for key shooting ranges (including investment, military personnel and institutional operating funds) are about US \$3 billion per year. Figure 2 shows the operating expenses of key shooting ranges in fiscal year 1994-2013 (calculated at the constant dollar price in fiscal year 2013), in which the red line refers the direct funds, while the blue line refers the funds of the organizations .

Considering that the development test and combat test are essentially mission-oriented to test the capabilities of weapons and equipment, if combat environment factors are introduced in the development stage, and new equipment is assessed under extreme border combat conditions, the equipment defects will be corrected more timely, which will reduce the incidence of problems in the combat test phase, and improve the efficiency of equipment development. In 2012, the U.S. Department of Defense proposed the "Shift Left" plan, which strengthened the model and concept of integrated testing further.

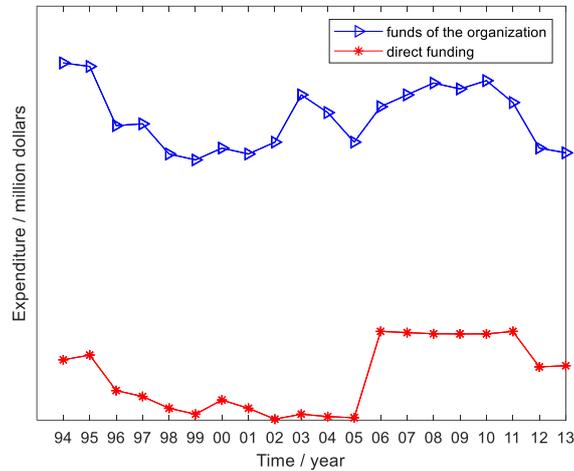


Figure 2 The operating expenses of key shooting ranges

4. Analysis of the development law of the US military T&E system

4.1 National military strategic needs are the first driving force for the development of the T&E system

T&E serves the construction and development of weapons and equipment, and the construction and development of weapons and equipment is closely related to the country's strategic layout and military needs. During World War I, in order to test the technical performance of the U.S. Army's conventional weapons and objectively evaluate the performance of the hostile country's equipment, the United States established the first equipment testing ground—Aberdeen Proving Ground. Before and after World War II, in order to meet the country's war preparation needs and rapid development of weapon systems, the US military's T&E system has also developed rapidly. Each branch of arms has set up specialized T&E institutions, and a large number of highly specialized weapons test sites have emerged. During the Vietnam War, the U.S. military recognized the difference between combat effectiveness and weapon performance, putting forward the concept of effectiveness evaluation and combat test, and established a combat T&E bureau that directly served the procurement decision-making of the Ministry of Defense. After the Cold War, the strategic situation of confrontation between the two poles was broken. The U.S. military began to tighten the financial expenditure of T&E. Its T&E system began to develop in the direction of refinement. The idea of integrated test was proposed and realized the unified management and construction of test resources. In recent years, with the continuous improvement of the military strength of China and Russia, in order to maintain strategic advantages, the U.S. military has proposed the third offset strategy, accelerated the transformation of emerging technologies into weapons and equipment, and reformed the equipment T&E system again. The development T&E and Experimental Resource Management Center is separated from the acquisition division. Throughout the development history of the US military's T&E work, it is not difficult to find that every major change in its T&E system is closely related to changes in its strategic environment and military needs. The

country's T&E system should closely serve the country's military strategic needs and provide support for the realization of the country's strategic goals and equipment construction needs.

4.2 The progress of T&E theory and technology is the basis for the development of T&E system

From budding to rapid development and then to maturity, the US military's T&E system cannot be built without the continuous deepening of the understanding of the T&E system. This process of deepening understanding is the process of continuous development of T&E theory and technology. In the early days of the U.S. military's T&E, the T&E was mainly to check whether the weapons and equipment could meet the design requirements. There was a lack of understanding of the type, timing, and management mechanism of the T&E. The T&E generally stayed at the performance test level. After the Vietnam War, the U.S. military realized the important role of combat effectiveness and applicability, and the theory of effectiveness evaluation also developed rapidly. It is required to carry out moderate and accurate effectiveness evaluation in major procurement projects. This also promoted the concept of combat test to a certain extent, and then promoted the reform of the US military's T&E organization. At the same time, the development of test design methods, detection collection methods, data processing methods and efficacy evaluation methods all have an important impact on the development of T&E systems.

4.3 The development of equipment technology promotes the development and perfection of T&E technology and theory

Weapons and equipment are the integration of high and new technologies in various eras. To verify and evaluate military technology and to test and assess weapon systems, T&E technology must meet or exceed the technical level of the test subjects. From the index verification of simple equipment such as artillery, to the comprehensive effectiveness evaluation of complex weapons such as tanks and aircraft, the resource conditions and theoretical technologies of T&E are also continuously developed and updated. For example, the US military's F-35 test requires a high-complexity and high-intensity electromagnetic environment, but the US military's original range resources cannot reproduce this electromagnetic environment in open airspace, so it proposed an electronic warfare infrastructure improvement plan to ensure that the F-35 can conduct experiments in combat confrontation environment. Nowadays, as emerging technologies such as digital twins, artificial intelligence, big data, and the Internet of Things begin to land in the military field. The US military's T&E is developing in the direction of integration, networking, and virtualization. "Logical shooting range" and "distributed LVC test range" are also come into being. The development of the T&E system and the development of equipment technology complement each other, and the development and progress of equipment technology has also become an important driving force to promote the continuous progress of T&E theory and technology.

5. Apocalyptic suggestions

5.1 The construction of T&E should proceed from an overall perspective to avoid waste of resources

The T&E of weapon equipment is closely related to the research and development department, procurement department, using troops, relevant colleges and universities, and the test resource management department. In the stage of rapid development of T&E theory and technology, various military branches and departments often independently invest in the development of resources such as test sites, instruments and equipment, and related technologies so as to form capabilities quickly. On the one hand, it has promoted the development of the T&E system by leaps and bounds. On the other hand, repeated investment and construction of experimental resources have also occurred, which leading to a situation that experimental resources are scattered, fragmented, and incompatible with each other. At the same time, the lack of effective planning of decentralized investment construction is not conducive to the formation of systematic T&E capabilities, and is not conducive to the deepening of T&E theory and technology.

In response to this problem, the U.S. Department of Defense adopts top-level plans such as the test and evaluation resource strategic plan, the military test and evaluation master plan, and the test and evaluation technology investment plan to provide route guidance for the development of test and evaluation technology, which plays a significant role in the refined development of its test and evaluation system. Our country's T&E work is currently in a stage of rapid development. Top-level planning should be fully done according to our country's strategic needs and the actual development of weapons and equipment of various arms, so as to form a good situation of unified planning and deployment of the military commission and coordinated construction and development of various arms. Top-level planning is the guiding direction for the healthy development of the T&E system.

5.2 Make good use of the selective "shift left" strategy, and introduce the combat environment and tasks into the development T&E process reasonably

At present, the main task of our country's development T&E is to verify whether the various indicators of equipment can meet the design requirements, which is also known as performance test. This stage is generally carried out by the research department or the industrial department, and the verification of most indicators is completed under laboratory conditions. Although this can make a more accurate assessment of various indicators, it is difficult to avoid the exposure of some indicators during the combat test phase, which will lead to delays in the progress of the finalization and combat test. In response to this problem, the U.S. military has introduced a "shift left" strategy, which bringing the combat environment and mission requirements into the development test phase, and the problem is solved effectively. At present, our country's weapons and equipment are developing rapidly. If the "left shift" strategy is used indiscriminately, although it is conducive to more rigorous inspection of equipment performance, it also puts forward extremely high requirements for the environmental construction capabilities of development test, which increases the difficulty and the cost of developing test greatly. Therefore, according to the actual situation of weapons and equipment, the indicators to be evaluated should be distinguished in the preparation stage of performance test program. The indicators related to the combat test stage closely should use the "left shift" strategy. The indicators that are not affected by the environmental conditions of the combat test, or are less

affected by the environmental conditions of the combat test should follow the traditional performance test method, The quality and efficiency of development T&E will be improved through selective "left shift".

5.3 Maintain the independence of combat T&E and enhance the authority and objectivity of combat test

Development test and combat test are the T&E contents that must be completed before the mass production of weapons and equipment, and the two complement each other and are indispensable. At present, we have a full understanding of the importance of development test and combat test, but the traditional T&E methods are still used in the organization and management mechanism of the two tests, and the equipment development department and production department are still important participants in the two types of T&E square. In this regard, the U.S. military attaches great importance to applying the concept of checks and balances to the management of modern equipment construction. Combat test is independent from equipment procurement, combat system, and service management, and is directly under the leadership of the Minister of Defense, which improves its strategic position. Moreover, the equipment development T&E and test resource management center has also been separated from the equipment procurement, realizing the complete independence of the T&E and equipment procurement. These experiences were acquired by the U.S. military in exchange for painful lessons in the war. At present, our country has established a special management department for T&E. In the future, we should study the organization and management mechanism, technical support department, test implementers, and environment construction methods of combat T&E further, so as to improve the independence and objectivity of combat test continuously and give full play to the important role of combat T&E.

6. Conclusions

T&E is the touchstone for the development of weapons and equipment, and a key step to ensure that weapons and equipment have good combat effectiveness and applicability. In the field of T&E, the U.S. military carried out research earlier, accumulated a lot of useful experience in continuous exploration practice and the baptism of war, and gradually formed a relatively advanced organizational management system, test theory and technology, and T&E operate mode. On the basis of sorting out the key links in the reform and development process of the US military T&E system, this paper analyzes the laws and internal mechanisms of its development and reform. And according to the actual situation of our country's current test and identification work, some suggestions are put forward, which can provide a reference for the healthy and rapid development of our country's T&E system.

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