Comprehensive Experimental Research on Complex Electromagnetic Environment of Aircraft

Guansuo Tian*, Jun Zhou, Xiaosong Li, Dawei Li

China Academy of Launch Vehicle Technology, Bei Jing, 100076, China

*Corresponding author’s e-mail: 459701487@qq.com

Abstract. The battlefield environment that modern electronic information equipment faces during use is very complicated, which has become one of the main characteristics of the信息化ized battlefield. This article starts with the composition and characteristics of a complex electromagnetic environment, references relevant standards, introduces the definition and composition of a complex electromagnetic environment, and summarizes its characteristics. On this basis, this article introduces the general methods of complex electromagnetic environment tests, including digital simulation tests, semi-physical simulation tests, and full-physical simulation tests. Among them, in the full physical simulation test, an equivalent method is generally used to achieve it. At the same time, this article introduces test evaluation methods, including element-level evaluation and effectiveness-level evaluation. Combining engineering practice, this paper puts forward the difficulties of constructing a complex electromagnetic environment. It is an inevitable requirement for the development of weapons and equipment to carry out comprehensive experimental research on the complex electromagnetic environment of aircraft, and to be able to assess the combat capability of the product. It is also an objective requirement for the development trend of the information military.

1. Introduction

In the future, information warfare will be a five-dimensional integrated operation of "land, sea, air, space, and electricity". The war in the electromagnetic dimension will run through the entire war. In the future battlefield, battlefield reconnaissance and information transmission mainly rely on information networks supported by satellites, early warning aircraft, reconnaissance aircraft and unmanned aerial vehicles. This electromagnetic environment effect directly affects the survivability and use efficiency of the aircraft. The battlefield environment that modern electronic information equipment faces is very complicated, which is mainly reflected in the variety of frequency-used equipment and the complex and changeable electromagnetic environment; the difficulty in coordinating the deployment of equipment and the intensification of frequency conflicts[1]. Carrying out comprehensive test research under the complex electromagnetic environment of the aircraft can evaluate the combat capability of the product and provide suggestions for the development of the aircraft. It is the basic foundation for the improvement of the combat capability of the aircraft, an inevitable requirement for the development of weapons and equipment, and the development trend of the informationized army objective requirements.
2. Composition and characteristics of complex electromagnetic environment

2.1 Definition and composition of complex electromagnetic environment

The Institute of Electrical and Electronics Engineers (IEEE) defines the electromagnetic environment as the distribution of power and time in different frequency bands of a radiated or conducted electromagnetic emission level that a device, sub-system, or system may complete when performing its prescribed tasks, that is, the existence of Sum of electromagnetic phenomena at a given location\[2\].

The definition of the electromagnetic environment given by the US military standard MIL-STD-464A "Requirements for the Effect of the System's Electromagnetic Environment" is the spatial and temporal distribution of electromagnetic energy, which includes various frequency ranges, and includes radiated and conducted electromagnetic energy.

The national military standard GJB 6130-2007 "Battlefield Electromagnetic Environment Terms" gives the definition of "complex electromagnetic environment" on the battlefield [3]. It refers to an electromagnetic environment in which a variety of electromagnetic signals exist simultaneously in a certain air, time, frequency and power domain, which has a certain impact on the use of weapons and equipment and combat operations. The composition of a complex electromagnetic environment is shown in Figure 1.

![Figure 1. Composition of complex electromagnetic environment](image)

a) Our radiated electromagnetic environment

It consists of electromagnetic signals radiated by our equipment, mainly including radar detection signals, communication transmission signals, and electronic countermeasures equipment radiation signals.

b) Enemy radiation electromagnetic environment

The enemy's radiated electromagnetic environment mainly refers to the collection of various electromagnetic radiation signals that the enemy may release in close combat. Mainly include: detection signals emitted by enemy shipborne / airborne radar, enemy shipborne / airborne electronic jamming signals, enemy shipborne / airborne communication signals, reconnaissance detection signals of the terminal guidance section of enemy missiles, etc.

c) Civil radiation electromagnetic environment

The civilian electromagnetic environment mainly refers to the electromagnetic environment generated by some civilian radiation sources and facilities in the operational area, such as civilian navigation radars, radio and television transmitters, and other civilian wireless communications. At the same time, in addition to the communication signals transmitted by local radio stations in a certain area, there are also propagation signals generated by human, ground, and tropospheric waves generated by other regional radio stations.

d) Natural radiation electromagnetic environment

Natural radiation electromagnetic environment is the electromagnetic wave radiation generated by non-human factors. In the natural electromagnetic environment, static electricity, lightning, and
electromagnetic fields are the most important types of electromagnetic radiation. In addition, there are electronic noise, magnetic fields and electric fields on the earth's surface, cosmic radiation, and electric fields caused by solar activity. The natural electromagnetic radiation environment is one of the objective electromagnetic environment elements of the battlefield[4].

e) Radiation propagation factors
Radiation propagation factors involve various natural and artificial environments that affect the distribution of the electromagnetic environment and the propagation of electromagnetic waves. Unlike the radiation source, it does not actively radiate signals, but changes the electromagnetic environment by acting on the propagation of man-made and natural electromagnetic radiation. It mainly includes the ionosphere, geographical environment, meteorological environment, atmosphere and water, and various radiation propagation media constructed.

2.2 Characteristics of complex electromagnetic environment
There are many types of complex electromagnetic environment. There are many signal styles, vertical and horizontal airspace, continuous time domain, dense frequency domain, and energy fluctuations[5].

a) Interlacing
Both parties on the battlefield will interfere with the radar guidance system. The radar signal and the jamming signal are intertwined. Whoever can control and control it and serve them will gain the initiative of war.

b) Dynamic
Operation under high-tech conditions has enhanced mobility, mobility, and non-linearity, and the combat forces of both warring parties exhibit high dynamics. Therefore, the dynamics of high-tech battlefields also constitute the dynamics of the electromagnetic environment.

c) adversarial
Electronic countermeasures are the main symbols of informationized battlefields. Electronic reconnaissance and anti-reconnaissance, electronic jamming and anti-jamming, electronic deception and anti-spoofing, electronic stealth and anti-stealth, electronic destruction and anti-destroy have become the main combat methods to achieve their own combat intention, The struggle between the two sides for the right to use and control the electromagnetic spectrum is extremely fierce.

3. General test method
The test verification is generally carried out through three methods: digital simulation test, semi-physical simulation test, and full physical test.

3.1 Digital simulation test
Using signal-level mathematical simulation experiments and digital simulation technology to conduct interference countermeasure simulation research based on signal flow, which can provide a flexible and reliable simulation environment for the study of system interference countermeasures performance in complex electromagnetic environments, and also solve the application of external field / half physical simulation test evaluation Limitations. Signal-level mathematical simulation system, mainly by injecting target echo data and interference signal data collected from the sensor field test and semi-physical simulation test, to evaluate the process and anti-interference performance of the sensor, and more realistically reflect the resistance between the sensor and the interference signal Interaction process and adversarial results. A large number of simulation data can be obtained through signal-level simulation experiments.

For digital simulation experiments, a simulation platform needs to be built, as shown in Figure 2. When performing digital simulation in a complex electromagnetic environment, frequency sweep interference, noise AM interference, noise FM interference, single-tone interference and multi-tone interference are generally considered. In actual engineering applications, interference simulation can be performed in a combined state according to the index requirements.
3.2 Hardware-in-the-loop simulation test

Semi-physical simulation test is a large number of repetitive and exploratory simulation tests under various controllable states. It can provide verification and test environment for certain performance indicators of the system, and can obtain a large amount of test data and statistical analysis results. Hardware-in-the-loop simulation can comprehensively analyze and verify the anti-interference ability of the sensor, and can verify scenarios that cannot be achieved in the external field, which is an effective complement to the external field test. At the same time, a large number of hardware-in-the-loop simulation tests can provide credible data and model support for signal-level mathematical simulations.

Figure 3. Hardware-in-the-loop simulation

There are three ways to generate a semi-physical electromagnetic environment simulation:

a) Use physical equipment to simulate complex electromagnetic environments
The physical equipment is used to simulate the radiation signal environment related to the working frequency band of the test equipment, and the signal simulator is used to simulate the influence of the transmission channel on the signal and the platform's motion characteristics, thereby realistically simulating the transmission attenuation and fading characteristics of the signal.

b) Using signal simulation equipment to simulate complex electromagnetic environments

Signal simulation equipment mainly includes instruments such as signal simulator, background signal simulator and signal generator. The signal simulator is mainly used to simulate signals of various modulation styles; the background signal simulator is used to simulate complex background signals; the signal generator can be programmed to set up, and mainly complete the special signals for specific needs.

c) Using physical equipment and signal simulators to simulate complex signal environments

Physical equipment and signal simulation equipment jointly complete the task of generating a complex electromagnetic environment. Generally, the radiation signal of the test object is produced by physical equipment, and the background signal is generated by the signal simulation equipment.

3.3 Full physical test

Full-scale tests can be performed under open field conditions (sometimes in microwave darkrooms). This test is to verify and assess the actual working (or flight) characteristics of the aircraft under the requirements of tactical and technical indicators under typical electromagnetic environment conditions, and to provide reliable test data under typical conditions for aircraft performance and effectiveness research.

The full physical and complex electromagnetic environment test of the aircraft uses real electronic equipment and countermeasure equipment and corresponding target radiation sources as cooperative targets under the geographical and meteorological environment conditions of actual combat, strictly in accordance with the prescribed tactical and technical requirements, and according to actual conditions. Operational requirements: Select the combat area, configure opposing equipment on both sides, and use other physical equipment in the test area to generate a complex electromagnetic environment close to actual combat in order to achieve a test effect close to actual combat conditions.

Due to the limitation of the time and space of the field, the external electromagnetic environment situation is usually configured from the perspective of equivalent simulation. The equivalent method includes the following aspects.

a) Area reduction method

Centralize frequency equipment in a relatively small area, increase the density of electromagnetic radiation sources per unit area, maximize the role of limited radiation sources, increase background noise and spectrum occupancy in the construction area, and increase frequency The equipment's self-interference and mutual interference artificially deteriorate the electromagnetic environment in the construction area.

b) Power equivalent method

By shortening the distance between the countermeasure equipment to achieve the equivalent of transmitting signals at the receiving point between low-power transmitting equipment and high-power equipment, this method can solve the problem of shortage of high-power equipment, which is conducive to improving the electromagnetic safety and confidentiality of the test.

c) Background equivalent method

Compare the measured data of the electromagnetic environment in the predetermined area with the construction area, and take measures to increase or decrease the electromagnetic radiation source in the construction area. This is equivalent to the natural electromagnetic environment and the electromagnetic environment formed by preset military and civilian electronic equipment, so that the electromagnetic environment background in the construction area. The noise and spectrum occupancy are similar to the predetermined area.

d) Modulation domain equivalent method
Use physical or analog equipment to compound the signal quantity and density of various modulation patterns in complex electromagnetic environments. Generally, a signal generating device is used to generate a certain number of signals with multiple modulation patterns in the corresponding frequency band, so that it can meet the requirements of signal patterns in a complex signal environment.

4. Test evaluation method

See Figure 4 for the test evaluation process under complex electromagnetic environment. Through comprehensive tests in a complex electromagnetic environment, technical indicators and operational effectiveness of wireless systems such as aircraft terminal guidance radar, satellite navigation systems, electronic reconnaissance systems, and data transmission systems can be evaluated. In the evaluation process, factor level evaluation and effectiveness level evaluation can be used.

![Figure 4. Test evaluation process under complex electromagnetic environment](image)

4.1 Factor-level assessment

The element-level evaluation is oriented towards the evaluation process of technical indicators. Using this method, each technical indicator of the wireless system of the aircraft can be evaluated individually and quantitatively through comprehensive tests. In order to evaluate the technical indicators of the aircraft wireless system in a complex electromagnetic environment, it is necessary to construct a dynamic test or simulation environment based on the technical principles of the influence of single or multiple elements of the complex electromagnetic environment on the generation and transmission of aircraft wireless system information. By analyzing and processing the test data, the evaluation effect of each technical index is determined.

When conducting an element-level assessment, the indicators of the aircraft wireless system need to be decomposed from a general perspective. The aircraft wireless system involves the generation, acquisition, transmission, and processing of signals during the work process. Among them, the link that is easily affected by the complex electromagnetic environment is the acquisition and transmission of signals.

Signal acquisition mainly includes antenna reception, low-noise amplification, mixing, filtering, and IF amplification. Therefore, decomposing the signal acquisition is to analyze the complex electromagnetic environment impacts that filters, amplifiers, and mixers may receive. Signal
transmission includes transmission, filtering, amplification, receiving and other links, and its decomposition is mainly to analyze the influence of filters and amplifiers.

4.2 Effectiveness layer evaluation
The effectiveness layer evaluation is a qualitative evaluation, which is a measure of whether the system can meet the requirements of a specific task under the influence of a complex electromagnetic environment. It reflects the ability of the aircraft wireless system to complete a prescribed task under the influence of a complex electromagnetic environment. And actual capabilities.

According to the composition level of the evaluation object, the performance level evaluation can be further divided into several small levels, including single system performance level evaluation and multiple system performance level evaluation in complex electromagnetic environment. Commonly used evaluation methods include analytic hierarchy process, system effectiveness analysis, fuzzy comprehensive evaluation, and gray whitening function method.

5. Difficulties in Building a Complex Electromagnetic Environment
a) Simulation of actual combat environment
At present, when constructing a complex electromagnetic environment, it is mainly based on the assessment of tactical and technical indicators. The complex electromagnetic environment constructed in this background is a typical electromagnetic environment, which is different from the actual combat environment. In addition, the lack of comprehensive information on the performance indicators of weapons and equipment in other countries will also affect the simulation of the actual combat environment.

b) Hierarchical construction of complex electromagnetic environment
At present, when constructing a complex electromagnetic environment, we start with enemy equipment and threats. Directly replace the equipment with equipment, and try to simulate the battlefield environment as realistically as possible. In this way, it is only qualitatively close to the complex electromagnetic environment of the battlefield, but it cannot be hierarchically structured. As a result, it is impossible to evaluate the adaptability and combat effectiveness of weapons and equipment in different complex electromagnetic environments. At present, the construction of a complex electromagnetic environment is still in the development and improvement stage. The current hierarchical evaluation index system mainly considers spectrum occupancy, time occupancy, and space coverage, and does not consider signal density, modulation style, polarization, etc., which may affect electronic information systems. The impact of the signal environment parameters, the indicator system is not complete. The classification of the complexity of the electromagnetic environment of the aircraft is still in the research stage, and there is no normative guidance for the construction of the environment. At present, the general requirements for the development of the aircraft also lack the corresponding quantitative indicators, and the grading of the environment for the assessment test lacks traction.

6. Conclusion
This article starts with the composition and characteristics of the complex electromagnetic environment, analyzes the general methods and experimental evaluation methods in the complex electromagnetic environment, and refines the difficulties in constructing the complex electromagnetic environment. Comprehensive experimental research in a complex electromagnetic environment requires a combination of theory and experimentation. Through experiments, the theory is continuously improved, and the theory is used to further promote the development of experiments.

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