

# Research progress on electrostatic discharge law of aircraft and radiation signal detection technology

Huimin Wang, Xiaofeng Hu, Xining Xie

State Key Laboratory of Electromagnetic Environmental Effects, Shijiazhuang Campus, Army University of Engineering, Shijiazhuang 050003, China.

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**Abstract:** At present, the number of combat aircraft in China is huge and in a stage of rapid development, and the electrostatic discharge effect of aircraft during flight has become one of the important issues related to the reliability and safety of aircraft; At the same time, the use of electrostatic discharge radiation signals to achieve aircraft detection and positioning is also an urgent need to develop an effective means of dealing with stealth technology, with significant advantages and broad prospects for military applications. In this paper, from the aspects of the harm of electrostatic discharge to aircraft, the characteristics and radiation laws of electrostatic discharge of aircraft, and the detection technology of electrostatic signal of aircraft, this paper expounds the research progress at home and abroad, analyzes the new problems faced by the electrostatic discharge effect of aircraft and static detection technology, and looks forward to the next research and development direction. The analysis results show that the research hotspots of aircraft electrostatic discharge effect and static detection technology focus on the new mechanism of electrostatic discharge and new radiation signal detection technology brought about by new materials, new environments, new loads and new requirements, and the work that needs to be focused on urgent research mainly includes the study of the integrated characteristics of multi-source electrostatic discharge of aircraft, the long-distance detection of electrostatic discharge information, and the evaluation method of the effect of electrostatic discharge on the airborne electronic system, etc., which provide technical support for improving the reliability and safety of aircraft during flight.

**Keywords:** Aircraft; Electrostatic hazards; Electrostatic discharge law; Radiation field; Radiation signal detection.

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## 1. Introduction

Along with the tide of global information zed military reform, air supremacy and electromagnetic control have gradually become the key to winning or losing the war in local conflicts. Air-space weapons play a vital role in modern warfare because of their diversity of missions, the complexity of airborne equipment and the unique advantages of "condescending". Statistics from the famous British aviation professional magazine "International Flight" show that as of the beginning of 2014, the total number of combat aircraft (fighters, attack aircraft, bombers and fighter-bombers) in the world has exceeded 14,000, and it is in a stage of rapid development. However, while vigorously developing the aviation industry, the flight safety of aircraft has become increasingly prominent.

When flying at high speed, the surface of the aircraft will collide and rub with dust, ice crystals, raindrops, etc. in the air, thereby depositing a large amount of electrostatic charge on its surface, making the surface potential as high as 100 ~ 300kV. Due to the difference in material characteristics and geometry such as the surface skin, cockpit cover and antenna cover of the aircraft, the charging potential on the surface of the aircraft will be different, and when the potential difference reaches the breakdown threshold, electrostatic discharge such as corona and spark will occur. Long-term electrostatic discharge will cause oxidation, corrosion and breakdown damage to the surface material of the aircraft; The electromagnetic pulse generated by the discharge is in the radio frequency band, which will cause interference to the communication and navigation systems of the aircraft and seriously threaten the safe operation of the aircraft. In the 1960s and 1970s, the United States Militia I. missiles and Scout rockets, Europe's Euron II. and Hercules III. C rockets,

etc., have all appeared due to electrostatic discharge during flight, resulting in launch failures, China in recent years has also occurred due to electrostatic discharge electromagnetic interference caused by aircraft, carrier rockets and other electronic equipment failures, which shows the importance and urgency of the study of the electrostatic discharge effect of aircraft.

At present, the total number of combat aircraft in China is huge and in a stage of rapid development, the electrostatic discharge effect of aircraft in the process of flight has become one of the important issues related to the reliability and safety of aircraft, at the same time, the use of electrostatic discharge electromagnetic radiation information to achieve aircraft detection and positioning is also an urgent need to develop effective means to deal with stealth technology, with broad prospects for military applications. In this paper, we focus on the research progress at home and abroad from the aspects of the harm of electrostatic discharge effect to aircraft, the theory of electrostatic discharge of aircraft, and the electrostatic detection technology of aircraft, and systematically study the electrostatic discharge effect and electrostatic detection technology of aircraft and look forward to the development trend.

## 2. The harm of electrostatic discharge to aircraft

The study of static electricity in aircraft began in the 1920s of the last centuries and was carried out to ensure flight safety. Because the electrostatic discharge generated by the aircraft in flight may cause the ignition and explosion of the aircraft fuel tank, the radiation generated by the electrostatic discharge also interferes with the communication and navigation systems of the aircraft. For example, in the 1940s, American scientists conducted research on how to reduce the

impact of aircraft static radio frequency interference on aircraft communications, R. Gunn pointed out that more than 1% of flight accidents each year are caused by static interference of aircraft, and through tests, the electrostatic power of aircraft and the square of flight speed are squared, or even proportional to the cubic; And with the increase of cloud density and particle density in the cloud layer, the electrostatic power generation on the surface of the aircraft increased significantly. They applied DC high voltage to two different types of aircraft, both monitoring continuous corona discharges and a small amount of spark discharge signals; In addition, they found that when the discharge voltage was 120kV, the interference of the discharge signal to the electronic device was similar to that of the test flight test.

Carrying a large amount of electrostatic charge is an inherent feature of aircraft, and the power is huge and difficult to eliminate. According to measurements, the carrying capacity of jet aircraft can reach 10-3C, and the carrying capacity of helicopters can reach 10-6~10-4C, and its potential is generally tens of thousands of volts, up to 500kV. These electrostatic charges will stimulate a strong electrostatic field in the surrounding space, and at the same time, because of mechanisms such as air breakdown, the electrostatic charges carried will continue to be discharged into the air, forming a strong gas discharge, and stimulating strong electromagnetic waves inside the aircraft and in space. Due to the universality and complexity of the electrostatic starting mechanism, no matter what means are used in the aircraft, the above electrostatic initiation and electrostatic discharge processes cannot be completely eliminated. Under harsh weather conditions, the static onset of the aircraft tends to be more intense, resulting in a more intense electrostatic discharge radiation field than normal flight. Picture 1 shows the American photographer Michael Yon shooting a CHU-47 helicopter landing at a mountain base ravaged by a sandstorm in Helmand province in southwestern Afghanistan. In 1970, I. M. Imyanitow pointed out that due to the gradual increase in flight speed, the electrostatic starting potential on the surface of the aircraft has increased from the initial 105 V level to the order of 10<sup>6</sup> V, and the starting current has also increased from the  $\mu$ A order to the mA level, posing a great threat to the safety and reliability of the aircraft.



Fig.1 Electrification by friction of helicopter

On the other hand, the electromagnetic waves excited by the electrostatic discharge of aircraft will interfere with the onboard electronic equipment. There are three main forms of electrostatic discharge on the surface of the aircraft: corona discharge, spark discharge and streamer discharge, as shown in Figure 2. Among them, the electromagnetic pulse generated by corona discharge is in the RF band, which will interfere with the communication and navigation system of the aircraft; The spark discharge energy is strong, it will oxidize and corrode the surface material, in addition, the strong electromagnetic pulse generated by it will couple into

the cabin through the antenna, holes and other ways, affecting the working efficiency of on-board electronic equipment; The flowing discharge electromagnetic pulse has a long duration, higher energy, and greater damage to the surface material, but due to the long rise time and low frequency of the discharge current, the interference with the aircraft is small. At the same time, the thermal effect caused by electrostatic discharge is also easy to induce accidental combustion and explosion of fuel. In 1977, the research report of the US Naval Aviation Command System pointed out that corona discharge is the main form of discharge of aircraft, and the repetition rate of electromagnetic pulses is as high as 105Hz, and the frequency range of electromagnetic pulses is 10 to 200MHz; And in rainy weather, the discharge electromagnetic radiation signal is more intense. In 1982, J.E. Nanevich et al. conducted a low-altitude test flight test of a certain type of jet fighter, and found that the interference generation mechanism of the aircraft mainly includes corona discharge, spark discharge, streamer discharge and charged particle flow, of which the corona discharge current is small, about 300~500 $\mu$ A, and the streamer discharge current is about 10mA; The interference generated by spark discharge is the strongest, followed by corona discharge, and the streamer discharge has the weakest interference with electronic devices due to the narrow frequency band. In 2011, On the basis of Vatazhin A.B.'s micro-discharge simulation of the surface of the aircraft radome, Temikv and Kanakovskiy of the Moscow Institute of Energy Engineering in Russia studied in detail the charged and humid aerosol cloud generated by artificial simulation and its discharge of the radar in the radome, pointing out that the movement of the aircraft radome in the cloud caused by strong charging may directly generate a medium breakdown electrostatic discharge on the radar antenna array, which poses a great threat to the radar detection efficiency and flight safety.

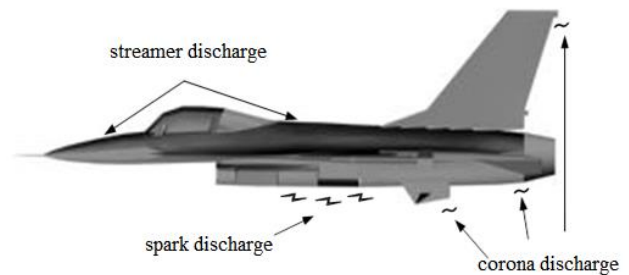


Fig.2 Main forms of electrostatic discharge on the surface of the aircraft

### 3. Research on electrostatic discharge characteristics and radiation laws of aircraft

The study of the characteristics and radiation laws of electrostatic discharge of aircraft is the basis of the evaluation of electrostatic discharge effect and the detection technology of electrostatic discharge of aircraft. The flight environment faced by the aircraft during flight is complex, including low temperature, low pressure, charged particles, etc., at the same time, the complex structure of the aircraft, different material characteristic parameters and a variety of working conditions will have an important impact on the flight electrostatic discharge process. Therefore, the electrostatic discharge of aircraft is a very complex physical process.

In the 1960s, the U.S. Army Aeronautical Laboratory studied the physical phenomena and processes of corona

discharges in aircraft and analyzed the current characteristics of corona discharges when they occurred. Studies have shown that the discharge threshold voltage of the discharge needle on the aircraft is affected by the length of the discharge needle and the radius of curvature of the tip of the discharge needle, which can be expressed by the following calculation formula:

$$E = \frac{2V_c}{R_i \ln\left(\frac{4C}{R_i}\right)}$$

Wherein, C is the length of the discharge needle, VC is the discharge threshold voltage of the discharge needle, Rt is the radius of curvature of the tip of the discharge needle, and E is the electric field strength of the discharge electrode.

Capacitance is an important parameter to characterize the amount of charge on the surface of the aircraft, the Instrument and Control Laboratory of the Department of Aeronautical Engineering of Princeton University in the United States uses the spherical model and the elliptical model to calculate the capacitance of the aircraft in flight, pointing out that the capacitance to the ground in flight is negligible, and the capacitance size depends only on the size of the aircraft, such as the capacitance of the H37 (long l = 25m, diameter d = 6m) aircraft is about 460pF. Scholars at Wuhan University of Technology used the moment method [10] to find a capacitance of 400pF when flying in the air of a certain type of aircraft and 1.3nF when parked on the ground.

A Russian scientific and technical report entitled "Multi-Passive Systems Determined by Aircraft Coordinates Using "Stealth" Technology[11] states that the discharge process carried out by the discharger is accompanied by pulsed radiation of electromagnetic waves, and at the same time, the power of this radiation can vary between tens of watts and tens of kilowatts under different conditions, and the radiation is a stable feature that accompanies any aircraft during the flight in the atmosphere. Experimental studies have shown that modern wide-body aircraft will from 1.3 to 1.5C of electricity on the surface within 10 to 15 seconds. In the humid atmosphere, this process is 3 to 4 times faster. Studies have also proved that the discharge current is between 0.0001 and 0.3A. Experiments on modern high-speed military aircraft yielded similar results. It is also pointed out that the charge value that can be evaluated to achieve discharge should be between  $4.5 \times 10^{-6}$  to  $1.5 \times 10^{-4}C$ . The report also proposes an equivalent process of corona discharge and electromagnetic radiation, and the signal generated by the discharge can be described by the following formula:

$$S(t) = \sum_{k=1}^K Ak(t) \sin(\omega kt + \psi k)$$

where Ak(t) is the amplitude factor and k is harmonic.

$$\omega kt = \frac{1200 \pi k t}{D}$$

D is the aircraft part size associated with the discharge device;  $\psi k$  is the initial phase of the vibration. As can be seen from the above formula, the aircraft corona discharge radiation is related to the shape and size of the aircraft.

Scholars from the School of Ordnance Engineering elaborated on the theories of frictional power-up, engine exhaust injection and other starting motor theories during the flight of the aircraft, and discussed several discharge methods and corresponding treatment methods.[12] It is pointed out that because the body will produce broadband electromagnetic interference when discharging, affecting the normal work of the airborne receiving equipment and radio

communication, it is necessary to strictly ensure the connection part of the adjacent metal on the body and the conductive channel of the insulation material in the nose part. The China Ship Research and Design Center elaborated on the mechanism of static electricity generation during fixed-wing aircraft flight [13], and calculated the surface charge distribution density of static electricity when the aircraft was flying in the air and docked on the ground according to the equipotential surface equation of the fixed-wing aircraft surface. Zhang Jun et al. [14] of Xidian University studied the electrostatic discharge on carbon fiber composite aircraft, analyzed the generation mechanism of electrostatic discharge on composite aircraft, and simulated the accumulation of static electricity on composite aircraft and the radiated electric field generated by electrostatic discharge of electrostatic charges on aircraft according to the discharge current pulse waveform.

Accompanied by the electrostatic discharge process will produce strong electromagnetic radiation, the main characteristics are: (1) electromagnetic pulse rise time is very short, narrow width, high peak, its energy distribution in a very wide frequency band; (2) Electromagnetic pulses are random. As early as the 1980s, foreign scholars paid attention to the strong electromagnetic radiation generated during electrostatic discharge, which had a certain impact on electronic equipment. Subsequently, a large number of scholars have conducted fruitful research on theoretical models and detection methods of electrostatic radiation fields. Martin Rowe has experimented with evidence that the presence of a radiation field causes electronic devices to deviate from electrostatic discharge conduction immunity experiments [15]. The famous Japanese scholar M. Professor Honda pointed out that non-contact electrostatic discharge is a new source of electromagnetic interference, which can pose a serious threat to electronic equipment. [16] In 1984, Perry F. Wilson proposed that the frequency composition of a short-gap spark discharge radiation field could reach 2 GHz [17], indicating that the electrostatic discharge radiation field has an extremely wide spectrum. David Pommerenke systematically studied the relationship between electrostatic discharge current and spark arc length, proximity speed of discharge current, and the difference in electromagnetic fields generated by different types of simulators, measured different distance fields from near to far, and obtained a large number of measurement data [18].

Perry F. Wilson was the first to conduct a comprehensive study on the theory and simulation of the electrostatic discharge radiation field[17], and concluded that the size of the radiation field is related to the amplitude and rise time of the discharge current, of which the near field is determined by the amplitude of the electrostatic discharge current waveform, while the far field is determined by the rate of change of the current; An equivalent dipole model for simulating the radiation field of electrostatic discharge is proposed, which lays a simulation foundation for studying the radiation interference of electrostatic discharge on electronic devices. Bendjamine then tested the size of the magnetic field at different locations from the ESD discharge point by testing the magnetic field size, which can be represented by the radiation field generated by the electric dipole. In 1990, Tabata and Tomita proposed an electrostatic discharge electric field model with two spherical electrodes, [19] which fully considered the field components generated by the charge during the discharge, but ignored the field generated by the

current and could not correctly calculate the far field. When calculating the radiation field of electrostatic discharge, S. Ishigami proposed a dual-source model, that is, the field is seen as a superposition of the field produced by the two parts of the discharge arc and the current on the discharge electrode [20]. In China, Bi Zengjun et al. proposed a modified electrostatic discharge spark electric dipole model, and used this model to qualitatively analyze the characteristics of the electromagnetic field generated by the electrostatic discharge spark [21], he also used the FDTD method to study the radiation field generated by the electrostatic discharge current injected into the thin wire, established a numerical model, and calculated and analyzed the radiation field characteristics and the influence of the wire radius and wire length on the radiation field [22].

A. James Kozlowski in 1990 measured the electrostatic discharge radiation field with a truncated transverse electromagnetic wave horn electric field antenna and a hemispherical antenna [23], using an ESD simulator to target the current on a horizontal grounded metal plate, and measured the attenuated oscillation at a frequency of about 200 MHz. In 2001, Pascal Leuchtmann of Switzerland and Jan Sroka of schaffner, a well-known ESD simulator manufacturer, measured the electromagnetic field generated by the simulator and obtained a pulse waveform of about 20 ns wide around the simulator when it was discharged at 2 kV. GP. By testing the transient magnetic field of electrostatic discharge radiation generated by different electrostatic discharge generators, Fotis found that the farther away from the point where the electrostatic discharge occurred, the smaller the rate of change in the magnetic induction density generated over time, the smaller the magnetic field strength, and the magnetic field strength in the far field area was inversely proportional to the distance between the test point and the discharge power supply; Moreover, the radiation field generated by different electrostatic discharge generators is different, and the radiation field generated by the same generator is also different when testing the tested equipment through different angles.

The School of Ordnance Engineering conducted systematic research on contact electrostatic discharge and air-type electrostatic discharge radiation fields, [25] and Dr. Zhu Changqing developed an ultra-wideband pulsed electric field test system and conducted practical tests on the electrostatic discharge radiation field. PLA University of Science and Technology has done a lot of research in pulse field testing, of which Xu Yuanzhe et al. [27] for the current sensors used for pulsed electric field measurement are mostly unipolar forms, can only measure the electric field in the direction of semi-space, unipolar direction, developed a three-dimensional flat panel structure sensor that can be used for pulsed electric field measurement, which is composed of a three-dimensional electric field antenna and an optical transmitter, which can measure the three-dimensional pulsed electric field simultaneously and in full space.

#### **4. Research on the detection of electrostatic discharge radiation signals of aircraft**

Due to the prevalence of electrostatic discharge in space vehicles, this provides us with research ideas for target detection and identification using electrostatic discharge. When an electrostatic discharge occurs at the end of the

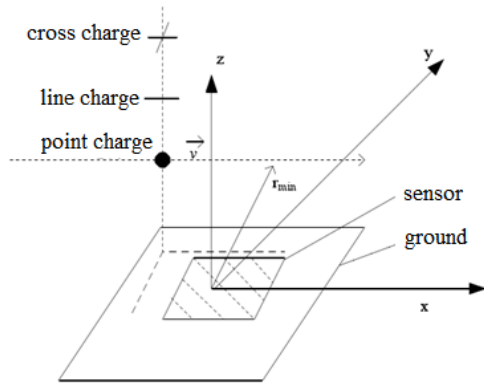
aircraft, this discharge will generate an avalanche current in the air, generating a current pulse on the airframe, the airframe is like a pulse transmission line, and the electromagnetic radiation generated provides a theoretical basis for the use of electrostatic discharge information to detect the aircraft.

The use of electrostatic discharge information to achieve passive detection and positioning technology of aircraft is an urgent need to develop an effective means of dealing with stealth technology, which has significant advantages and very broad prospects for military applications: First, for high-speed targets in the air (such as stealth aircraft, helicopters and missiles), the electrostatic discharge information generated by various reasons always exists and cannot be eliminated, so the existing stealth technology is ineffective for the electrostatic detection method; Secondly, because the passive electrostatic target detection does not emit electromagnetic signals, it has good self-concealment and improves the survivability of the battlefield; Third, since the flight target has obvious electrostatic discharge electromagnetic pulse characteristics, the information can be effectively extracted. Therefore, the detection technology will be widely used for passive detection of stealth aircraft, various fighters and missiles.

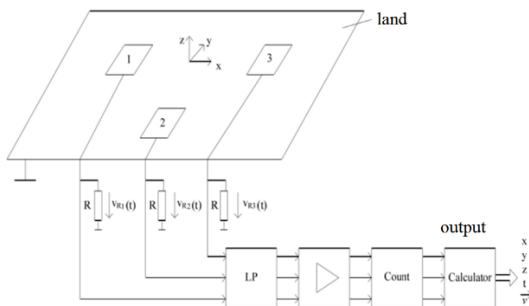
The use of static electricity to detect the object of air movement originated from the study of electrostatic fuzes, which are actually a detection device for aircraft. Electrostatic fuze research began in Germany in World War II,[28] followed by research on electrostatic target detectors in the United States and the former Soviet Union. Since the 1960s, the United States has developed electrostatic fuzes for mortar shells, electrostatic fuzes for 105mm anti-tank shells, and electrostatic fuzes for 40mm air-to-air shells. Russia (including the former Soviet Union) has also conducted long-term research on electrostatic target detection devices, developing fixed-wing jets that can detect fixed-wing jets at a distance of 400 meters and cruise missiles at a distance of 200 meters. Since the 1990s, Beijing Institute of Technology has taken the lead in the study of the charging characteristics of objects, high-sensitivity sensors, and the use of finite element modeling and simulation techniques to analyze targets (aircraft, missiles, etc.). Bai Yuxian et al. adopted the detection current detection method, established an electrostatic fuze detection model according to the relationship between the target, the environment and the fuze, and pointed out the way to improve the detection sensitivity [30]; By analyzing the detection principle of passive electrostatic fuzes, the directional detection basis is obtained and verified by finite element simulation method [31].

In 1978, Professors H.Trinks and J.L. Ter Haseborg of the Federal Defense University in Hamburg, Germany, conducted a systematic study on the detection of electrostatic fields in aircraft[32], and they studied the charging and discharging phenomenon during bullet firing in the laboratory, and derived the theory and influencing factors of the electrostatic starting and discharging motors of flight targets. In order to perform theoretical calculations of the aircraft charge, the aircraft is equivalent to a point charge, a linear charge, and a cross charge (according to the mechanism of the fuselage and wing), as shown in Figure 3, and the electrostatic field generated by the surface charge of the flight target is detected by ground sensors. In addition, they designed a system consisting of three electrostatic detection sensors distributed in an equilateral triangle, as shown in Figure 4. When the aircraft flies over the sensors, the three sensors arranged

below will sense the electric field generated by the charge of the aircraft fuselage, giving signals  $VR_1(t)$ ,  $VR_2(t)$ , and  $VR_3(t)$ , respectively. The signal  $VR(t)$  relies on the altitude and speed of the aircraft and has a low frequency ( $f_{max} = 5\text{Hz}$ ), so a low-pass filter is used in the signal processing section. Where  $f_c = 5\text{Hz}$ , this can suppress the high-frequency interference signal. After the filtering is completed, in order not to lose the detection accuracy, the signal is amplified. Through subsequent calculations, parameters such as flight height  $h$ , flight path direction  $\theta$ , flight speed  $v$  and so on can be obtained. By conducting a large number of tests at the airport, it is concluded that the detection distance is within 100m, and by expanding the sensor area, the detection distance can be increased to 1000m.



**Fig.3** Equivalent charge distribution of charged aircraft



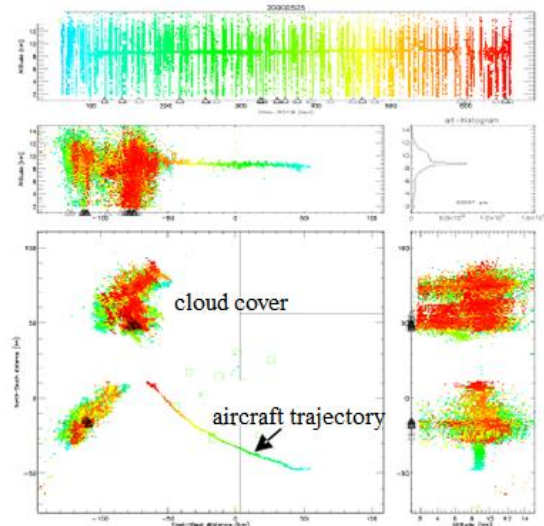
**Fig.4** Aircraft electrostatic detection sensor distribution and signal acquisition block diagram

The main principle of the three-dimensional lightning observation system LMA (Lightning Mapping Array) developed by New Mexico Tech in the United States is to use GPS system and time difference technology to locate the VHF radiation source, so as to obtain the three-dimensional spatio-temporal distribution characteristics of the lightning occurrence and development process, typical system as shown in Figure 5. The time resolution of the system is 50ns, the spatial accuracy can reach 50~100m, its center frequency is 63MHz, and the bandwidth is 6MHz. In the STEPS experiment in the summer of 2000, the radiation generated by many aircraft as they passed through the clouds was observed, and the trajectory of many aircraft in the clouds was obtained, as shown in Figure 6. Through a large number of experiments, the following conclusions have been drawn: the aircraft can produce electromagnetic radiation of different intensities during the process of passing through the clouds, and its intensity is between 1 and 10 kW, or even higher, and it is roughly inversely proportional to the number of radiation sources detected. Radiation is produced by the electrostatic discharge process on an aircraft and is characterized by electromagnetic radiation similar to that produced by

lightning discharges. The amount of charge carried by the cloud-piercing aircraft is positively correlated with the flight speed of the aircraft and the scale of the ice crystal particles, and the radiation generated at an altitude of 10 to 12 km is the strongest. When an aircraft passes through different cloud systems, the radiation generated depends not only on the material of the aircraft surface and the speed at which the aircraft flies, but also on the type of cloud system, where the aircraft receives a greater charge due to the collision and friction of ice crystal particles on the surface of the aircraft, resulting in a stronger radiation. The LMA system can be used to passively measure aircraft that generate radiation due to electrostatic discharge on the ground, which provides a reference for long-range detection of aircraft electrostatic radiation signals.



**Fig.5** LMA typical test system



**Fig.6** Three-dimensional structure of the radiation source of the aircraft

Zank, Paul, and others successfully developed the aircraft electrostatic discharge test system in 2001. The system is a static and static detection system, which uses multiple miniature sensors to test the electric field interference generated by the electrostatic discharge of the aircraft fuselage. The system is arranged around the aircraft runway, and the aircraft static telecommunications sensors are obtained through distributed sensors to test the electric field interference generated by the electrostatic discharge of the aircraft fuselage. The system is arranged around the aircraft

runway, obtaining static information about the aircraft through distributed sensors and transmitting the test data to the airport terminal computer. The system can sense whether the aircraft has a significant accumulated charge, find whether the aircraft electrostatic discharge system is ineffective, and verify whether the ground discharge equipment is working properly. Chen Xi et al. of Beijing Institute of Technology used a planar circle array to conduct passive ground electrostatic detection, established a positioning equation based on the relative position relationship of each detector in the array and the relationship between the output signal of the detector and the distance of the target, and analyzed the positioning accuracy[35] Through the study of the spatial electric field distribution of aircraft discharge needles, the mathematical analysis of the spatial electric field distribution was established, the formula of the space electric field potential and electric field strength of the electrostatic discharge needles was obtained[36], and a vertical vibration electric field sensor array of MEMS thin film electrodes was designed to locate the target position of the fuze [37].

## 5. Conclusion

At present, a series of studies have been carried out at home and abroad on the theory of aircraft charge and discharge motors, radiation field theory and test, radiation signal detection and processing methods, etc. With the rapid development of air and space weapons, the study of the electrostatic discharge effect of aircraft needs further exploration. In the future, there are still some problems in the field of electrostatic discharge of aircraft that deserve attention: 1) New materials: With the rapid development of material technology, composite materials are widely used on aircraft, the research on the electrostatic discharge characteristics of new materials is lagging behind, and the electrostatic properties and electrical parameters of composite materials and their electrostatic properties and electrical parameters in the flight environment are worth further study. 2) New environment: With the expansion of the aircraft flight space, the electrostatic discharge characteristics of the aircraft under various conditions such as large temperature difference, low air pressure, plasma, and low-energy electron radiation deserve our attention. 3) New payload: With the diversified development of the form, function and mission nature of the aircraft, the sensitive components such as high-power components, antennas and data link systems have put forward new requirements for the protection ability of the electrostatic discharge effect of the aircraft.

Combining the above characteristics, there are still many aspects of the research on the electrostatic discharge law and radiation signal detection of aircraft that need to be further improved and solved:

(1) Study on the multi-factor co-effect of electrostatic discharge of aircraft. The electrostatic onset and discharge environment of the aircraft in the flight process is obviously different from the ground environment, and the research on the charging and discharging motor of the aircraft is continued, and the research on the combined factors of low temperature, low pressure, plasma and low energy electron radiation on the electrostatic discharge synergy effect of the aircraft is strengthened, and the electrostatic characteristics of composite materials in various environments and their influence on the electrostatic discharge law of the aircraft are further explored.

(2) Exploration and test research on the theory of long-

distance detection of electrostatic discharge information of aircraft. Based on the military needs of modern warfare and the technical characteristics of passive detection of electrostatic radiation information of aircraft, a theoretical model of passive detection of long-distance radiation information of electrostatic discharge of aircraft is established, and the test method is optimized to improve the sensitivity and reaction speed of the test.

(3) Method for evaluating the effect of electrostatic discharge of aircraft on airborne electronic system. At present, the study of electrostatic discharge effect of airborne electronic systems at home and abroad mainly uses electrostatic discharge mannequins to evaluate the harm of human contact with electrostatic discharge on airborne electronic systems during ground assembly, which is very different from the electrostatic discharge effect of electronic systems during flight. Therefore, it is of great significance to carry out the research of the electrostatic discharge model of the aircraft and establish the evaluation standard of the electrostatic discharge effect of the airborne electronic system to improve the antistatic electromagnetic interference ability of the airborne electronic equipment during the flight.

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