Research Status and Method of Aviation Sensor Performance Evaluation

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Abstract. Aviation sensor is an important guarantee for aircraft safety flight, ground test and flight test accuracy and reliability. In this paper, through the analysis of the problems existing in the actual working environment of aviation sensors, the necessity of evaluating the performance of aviation sensors in the actual working environment is clarified. Combined with the comparison of the research status of the performance evaluation methods of aviation sensors at home and abroad, the development direction of the performance evaluation research of aviation sensors in the actual working environment in the future is proposed.

Keywords. Aviation sensor, research scheme, working environment, performance evaluation

1. Introduction
In the field of aviation, in order to ensure the correct and safe flight of aircraft and complete various complex tasks, it is necessary to install corresponding sensors in the key parts of the aircraft and different airborne equipment systems. The number of various sensors installed on a modern aircraft is as many as hundreds or even thousands. Sensors are not only directly installed on the aircraft to ensure safe flight, but also widely used in various ground tests and flight tests, such as aircraft structural strength test, wind tunnel test, engine test, etc., to complete the measurement of some special parameters of aircraft. These sensors are collectively referred to as aviation sensors [1].

Although the development history of China’s aviation sensor is short, the domestic aviation sensor industry has developed rapidly in recent years, and the gap with foreign countries is gradually narrowing. With the wide application of new materials, new processes and new technologies in the aviation field, the development trend of aviation sensors is micro miniaturization, integration, intelligence and networking [2]. As a variable conversion unit in the five basic units of aviation test system, aviation sensor is used to measure the pressure, temperature, acceleration, speed, displacement and other important parameters of aircraft, various auxiliary devices and mission equipment. Its performance will directly affect the service life and flight safety of aircraft, the accuracy and reliability of aviation product ground test and flight test. Due to the variety of aviation sensors and high technical requirements, a large number of aviation sensors often work in the harsh environment of high temperature, high altitude and severe vibration. Therefore, it is necessary to use effective methods to
evaluate the performance of aviation sensors to ensure the accuracy of measurement data of sensors in the working environment.

In this paper, based on the problems existing in the actual working environment of aviation sensors, the status quo of performance evaluation methods of aviation sensors at home and abroad is compared, and a possible development direction is proposed for the performance evaluation methods of aviation sensors in the actual working environment in the future.

2. Current problems
With the continuous breakthrough of aviation technology, aircraft is gradually entering a new development stage of high temperature, high altitude and high speed. Many aerial sensors need to work in extremely harsh actual working environment such as severe vibration, high temperature, high pressure and corrosivity, which brings huge problems and challenges to the use of sensors. For example, the pressure sensor in the aircraft engine often needs to work in the unstable air flow environment with the temperature range of 600 ~ 800 °C, and the ambient temperature in the combustion chamber of pulse detonation engine is more than 1000 °C. Since the air flow contacts the combustion chamber, the pressure sensor plays an important role in controlling the gas and fuel mixture by detecting the air pressure. Once the test data of the pressure sensor is not accurate, the risk of aircraft out of control will be greatly increased [3].

The structure of modern aero-engine is more and more complex, and the aerodynamic performance of the engine is easy to be unstable in the working process. In order to maintain the normal operation of the engine, the anti-surge system is equipped on the aircraft. As a key component of anti-surge system, the surge differential pressure sensor can comprehensively judge the working state of the engine by measuring the difference between the total pressure and static pressure at the compressor outlet, combined with other relevant parameters. Therefore, the accuracy of the surge differential pressure sensor measurement data is directly related to whether the engine can work normally. Once there is a problem, it may cause serious consequences. Because surge differential pressure sensor is installed on the engine shell, its actual working conditions are often in the extremely harsh environment such as high temperature and violent vibration. At present, the performance calibration of surge sensor can only be carried out under the laboratory standard conditions. There is a lack of accurate evaluation method and measurement results analysis of surge differential pressure sensor under actual working conditions, so it is difficult to judge the performance of surge sensor in actual working environment.

In foreign aviation flight, there have been tragic accidents due to inaccurate sensor measurement data. In the Ethiopian Airlines crash in early 2019, the black box data of the crashed flight showed that the angle of attack sensor on the Boeing 737max mistakenly activated the automatic system on board, which led to the crash. Relevant research also shows that if there is water around the angle of attack sensor, when the aircraft flies to a certain height, the performance of the sensor may be affected or even malfunction due to the freezing of the high altitude cold environment. When the aircraft encounters bird impact, the sensor also has data error [4]. It can be seen that the performance of airborne sensors may change or even fail in complex actual working environment, and the performance evaluation method of sensors in laboratory conditions can not meet the requirements of actual conditions.

3. Domestic research status
In China, the research on the performance evaluation method of aviation sensor in the actual working environment is still in its infancy, most of which focus on the development of calibration device simulating the actual working environment and the use of certain technology to compensate the sensor’s sensitive environmental stress, and there is no complete sensor performance evaluation system.

3.1. Development of calibration device simulating actual working environment
Environment simulator

Sensor under test

Calibration system

Environmental parameter control system

Figure 1. Basic structure diagram of calibration system.

When the performance of the sensor is significantly affected by environmental factors, such as temperature, humidity, air pressure, vibration, etc., the calibration performance of the sensor in the actual working environment is different from the conventional calibration in the laboratory. On the basis of the conventional calibration in the laboratory, the simulation of environmental impact factors is also needed. By combining the environmental simulation technology with the measurement and calibration technology, the simulation is realized Development of calibration device for international working environment. A typical calibration system for simulating actual working environment is generally composed of environment simulation device, environmental parameter control system and sensor calibration system, as shown in Figure 1.

Xueming Dong and others from Beijing Great Wall Institute of Metrology and testing technology of China Aviation Industry Group Corporation carried out the research on Calibration Technology of high-speed large g-value inertial system, installed high-speed turntable that can rotate in both horizontal and vertical directions on the centrifuge, and completed the development of acceleration and speed compound calibration device; Xueming Dong and others took the centrifuge as the main body, combined with vibration table and temperature Control test device and air pressure device, completed the development of acceleration, vibration, temperature, height composite calibration device. Xueming Dong and Guan Wei of Beijing University of Aeronautics and Astronautics also introduced a composite system composed of centrifuge and shaking table into the field of accelerometer calibration. The centrifugal vibration system was used to reproduce the composite acceleration composed of constant acceleration and sinusoidal acceleration, and a compound calibration device for centrifugal vibration system was successfully developed, and the highest constant acceleration for calibration can reach 40g The frequency range of sinusoidal acceleration is 20 ~ 2000Hz.

At present, the development of sensor calibration device in actual working environment has not covered all sensor parameters, and some measurement systems and measurement calibration devices no longer have good adaptability and measurement accuracy under the involved changing environment or limit environment due to their calibration principle, calibration technology, calibration software and methods The calibration device is not suitable for simulating the actual harsh environment or is difficult [5]. Therefore, the development of sensor calibration device simulating the actual working environment has limitations, which can only meet the performance evaluation requirements of some sensors, some parameters and some environmental factors.

3.2. Sensor performance compensation technology

Some aviation sensors have been found that some environmental factors will affect their performance in the actual use process. A large number of sensors are made of metal or semiconductor materials. Due to their inherent sensitivity to temperature changes, the initial zero point and output sensitivity of sensors will drift when the ambient temperature changes. In order to weaken the influence of external
environmental factors on the performance of the sensor, people have carried out the research on the sensor compensation technology, among which the more common is temperature compensation.

Hardware compensation and software compensation are mainly used for temperature compensation of variable sensor and piezoresistive sensor. Hardware compensation includes bridge arm parallel resistance method, bridge arm thermistor compensation method, series and parallel thermistor compensation method outside bridge, etc. Hardware compensation usually selects the corresponding temperature compensation element according to the test data of the sensor in high and low temperature environment to compensate the initial zero point and output sensitivity drift of the sensor. The common software compensation methods include interpolation, least square fitting, BP neural network algorithm and so on. Software compensation is based on the real-time environmental temperature collected by the temperature measuring element. The algorithm of zero point, sensitivity and temperature change of the sensor is integrated into the high-speed single-chip microcomputer to realize the real-time temperature compensation of the sensor. Hardware correction cannot be used for complex algorithm compensation, and the compensation circuit is also easily affected by electromagnetic environment. In contrast, software compensation method has high precision, wide application range and simple debugging, so it has become a common method for sensor temperature compensation.

Strain gauge balance is a kind of force sensor, which can be used for six component force measurement of aero-engine vectoring nozzle. In the performance test of aero-engine vector nozzle, the temperature of strain balance will be affected by the heat transfer and radiation of combustion chamber. Zhan Haihua of Chongqing University adopts the method of combining strain gauge with temperature self compensation function and series compensation resistance on the measuring bridge to compensate the temperature of the variable balance, so as to ensure the stability of the balance performance.

In order to reduce the impact of the actual working environment on the performance of the aerial sensor, the design and development unit of the sensor adopts effective compensation methods for the sensitive environmental stress of the sensor, such as the common temperature compensation, and gives a certain calibration curve, which improves and improves the technical performance and application range of the sensor to a certain extent, which is conducive to the optimal design of the sensor. However, this kind of compensation method, especially for the influence of multiple environmental factors, cannot fully and accurately describe the comprehensive and dynamic influence of environmental factors on the performance of the sensor under test, so it is necessary to strengthen the research in this field. In addition, the development of new sensors, such as sapphire high-temperature pressure sensor and high-temperature piezoelectric vibration sensor, can also be carried out from the direction of new materials and new structures, so as to enhance the environmental adaptability of the sensor and solve the problem that the sensor performance is easily affected by the environment.

4. Performance evaluation method

At present, many progresses have been made in the development of sensor calibration device and sensor performance compensation technology for simulating time working environment in China, but there are still some limitations. Combined with the research status of aviation sensor performance evaluation at home and abroad, the performance evaluation method of sensor in actual working environment can be studied from the following directions in the future.

4.1. Full combination of environmental simulation technology and measurement calibration technology

To carry out the performance evaluation of the sensor in the actual working environment, we need to make full use of the environmental simulation test technology and measurement calibration technology according to the actual working conditions of the sensor, such as high and low temperature, humidity and heat, low pressure, acceleration, vibration, impact, etc., to carry out the performance calibration test of the sensor under different environmental stress conditions, so as to evaluate the sensor measurement results under different environmental stresses The effect of fruit. Beijing University of Aeronautics and Astronautics, the Fifth Institute of electronics of the Ministry of information industry, and the 301
Institute of China Aviation Industry Corporation are the main force to carry out environmental simulation tests in China. The main research institutions of measurement and calibration technology are metrological calibration laboratories.

Therefore, universities and institutions that carry out environmental simulation technology research and measurement and calibration technology research should actively seek cooperation, fully combine the two technologies, and make efforts for the performance evaluation research of aviation sensors in the actual working environment. Beijing Great Wall Institute of Metrology and testing of China Aviation Industry Corporation has been engaged in the research and development of professional calibration technology and calibration device for long-term, thermal, mechanical, inertial, electrical and other professional calibration technology, and has built an environmental testing laboratory with vibration, high and low temperature, low pressure, impact, salt spray, rain and other environmental test simulation equipment. The Institute has fully played its own advantages, and has been in the acceleration, flow rate. The measurement calibration and detection ability under the conditions of temperature, humidity and vibration environment is realized on the parameters such as pressure, force value and electric quantity.

4.2 The method of combining theoretical analysis with simulation test

Usually, the sensor is regarded as a black box, and its output is tested by giving different input values. The input-output relationship of the sensor is obtained through data analysis. This method can intuitively test the performance changes of sensors under different environmental stresses, but for some aerial sensors. Due to the limitation of technical conditions and many other factors, the research on sensors is still in the primary stage. There is a lack of in-depth theoretical analysis on the structure and working principle of the sensor, and there is also a lack of data support and systematic research on the influence degree and mechanism of the sensor measurement performance in the actual working environment. Therefore, from the analysis of the structure and working mechanism of the sensor, the complex structure of the sensor should be simplified. The finite element analysis method and other numerical analysis methods should be used to model and simulate the sensor or its main components. By applying different environmental stresses to the model, the change rules and reasons of the sensor measurement performance are analyzed theoretically.

On the one hand, simulation software can be used to simulate all kinds of environmental stress (including extreme environment) without destroying the sensor. Through theoretical analysis, the non-influencing factors are eliminated, and the environmental stress that affects the performance of the sensor is selected, and the essential characteristics and laws of a certain type of sensor are found to save the research cost. On the other hand, the simulation results of real environment can modify the simulation model, optimize the model structure, and verify and improve the theoretical analysis results. The combination of theoretical analysis and simulation test can achieve the effect of supporting and complementing each other.

4.3 Establishment of aviation sensor database

Aviation sensors are classified and sorted according to different uses such as engine, airborne system, ground and air test, and the performance index requirements and operating environment conditions of sensors in different parts are mastered. After accumulating a large number of sensor theoretical research experience and test data, the research results of other sensors with similar structure or working principle can be used as reference basis for the comprehensive performance evaluation of a certain kind of sensor, which provides strong support for rapid identification of sensor sensitive environmental stress and prediction of its performance affected by environment trend, which greatly shortens the analysis time. It can save the cost of manpower and material resources, provide the basis for the establishment of aviation sensor database, and provide technical support for aircraft designers in sensor selection, design, acceptance and use.

5. Conclusions
With the continuous upgrading of the aviation equipment manufacturing industry, the demand for aviation sensors is also greatly increased. A large number of aviation sensors are used in the actual complex environment, which brings new challenges to the sensor performance evaluation technology. Based on the problems existing in the actual working environment of aviation sensors, combined with the research status of performance evaluation of aviation sensors at home and abroad, this paper puts forward the development direction of performance evaluation research of aviation sensors in the actual working environment in the future, which provides strong support for the rapid development of aviation sensors in China.

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References
[1] Y. Hai, C. Li, Y. Q. Shang, “Research status and development trend of aviation sensor performance evaluation”, Metrology & Measurement Technology, 2020, vol. 40, no. 2, pp. 1–6.
[2] J. B. Xu, G. P. Liang, J. S. Xu, “Application progress of wireless sensor network technology in aviation field”, Industrial Control Computer, 2018, vol. 31, no. 1, pp. 75–77.
[3] J. S. Wang, X. Z. Chi, “Development and trend of special sensors”, Measurement Technology, 2019, vol. 39, no. 4, pp. 57–63.
[4] R. Yang, Y. Rui, M. Y. Xu, et al., “Optimization of Aviation Wireless Sensor Network based on Discrete Cuckoo Search Algorithm”, Materials Science and Engineering, 2020, vol. 926, no. 1, pp. 021–025.
[5] L. Angelo, B. Alberto, B. Manuela, et al., “Preliminary Design of a Model-Free Synthetic Sensor for Aerodynamic Angle Estimation for Commercial Aviation”, 2019, vol. 19, no. 23, pp. 1551–1560.