Research Progress on Typical Fault Monitoring and Diagnosis of Aircraft Engine

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Abstract. As one of the core components of aircraft, whether engine could be operated normally will directly effect on the safety of aircraft. How to monitor and identity different fault condition about core components of engine plays a vital role in ensuring air safety and reducing maintenance costs as well as has important value in safety and economy. This paper summarizes the typical fault and monitoring means of aircraft engine, which can provide some references for related research.

Key Words: aircraft, engine, fault, diagnosis.

1. Introduction
Aircraft engine, a highly complex and sophisticated thermal mechanical, provides power needed for flight. With the rapid and high-level development of engine technology, the comprehensive flight performance of aircraft has been constantly improved and perfected. While due to its complex component parts, long-term service in high-speed, high temperature and high load of work environment contribute to corrosion, wear and failure condition easily which are very likely to cause a major safety accident resulting in aircraft destruction and human death[1]. Therefore, how to improve the safety performance of aircraft engines and to ensure their working reliability is becoming a high-profile issue [2].

Healthy status of aircraft engine is the most direct reflection of aircraft performance, analysis and diagnosis to each fault mode is a significant basis for maintenance, changing, formulation and implementation of spare parts strategies. Hence that, analyzing health status and studying its typical ways to monitor fault of aircraft engine are effective solutions to ensure safe flight. Based on this, this paper focuses on the research progress of typical fault monitoring and diagnosis technology of aircraft engine.

2. Significance of Aircraft Engine Fault Monitoring
Monitoring for aircraft engine fault is an essential work during normal flight and mission execution. Generally, aircraft engine fault monitoring refers to basing on process status information collected by fault monitoring system, analyzes and processes fault mode of essential parts of aircraft engine and obtain its characteristic parameters of its health state establishing a diagnostic model to diagnose the fault mode of key components and master their health state also fault information, then report the obtained information to the unit or ground crew timely so that they can do relevant maintenance work according to this information.

Mechanical system of aircraft engine is very complicated, results from this, monitoring its working condition effectively can ensure safety and reliability during work process, master the health status of
aircraft engine in time, and judge the fault modes accurately then provide related information to pilots and ground maintenance staffs, so that they can take effective measures to deal with potentially dangerous condition quickly and timely ensuring the working reliability of aircraft engine which has important practical value to aircraft flight safety.

3. Typical faults analysis and fault monitoring methods of aircraft engine

3.1. Typical Fault of Aircraft Engine
With the development of aircraft engines towards high performance, the increase of its parts and the random coupling of the faults during work progress lead to the increasing of aircraft engine fault modes and complex mechanism. Especially wide envelope of military aircraft, the plane engine operates under a bad environment conditions, high strength, large overload, so-long flight time and other job characteristics, leads to frequent multiple and dangerous fault, which are easy to give a rise to deviation of normal working state of engine and leads to the reduction of engine stability margin and deterioration of the working performance, even major flight safety accidents such as air parking. Therefore, according to the research and incomplete statistics, common engine failures probably can be divided into the following several categories:

3.1.1. Stability Fault. Excursion of engine normal working state and reduced stability contribute to aerodynamic performance instability and so that happen great-harm, fast-failure and difficult-recovery faults such as rotating stall, blade flutter, coupled vibration, surge, oscillating combustion, over-temperature, structural damage, air shutdown and so on. Stability failure is a key factor that affects the safety, reliability, and stability of whole aircraft engine in the whole development periods and service life terms.

3.1.2. Air Passage Fault. Surge, the main manifestation of airflow passage fault and an abnormal working state of the engine, is caused by the deviation of the air flow and the excessive compressor speed of the design state having a strong impact on the normal operation of the engine, it even can cause flameout in flight of engine in severe cases so that a significant safety accident would happen.

3.1.3. Vibration Fault. Vibration is a a vibration failure mode, which results from local resonance, fatigue break, rotating stall and surge, imbalance of high and low pressure rotor, change of heat bending concentricity of rotor, failure of sealing device, wear of blade, damage of gear and bearing, looseness of bearing seat and clearance of supporting structure, failure of elastic support, failure of squeeze oil film damper and other factors, it is the main fault mode of engine and has the major effects on reliability of engine.

3.1.4. Stable Combustion Fault. Mechanical kinetic converted by the heat energy in its combustion chamber contributes to the normal operation of the engine. Combustion in aircraft engines is the coupling and interaction of physical and chemical processes. The main factors affect the normal operation of combustion chamber are fuel atomization and evaporation, turbulent transport, finite rate chemical reaction, high temperature radiation and particle motion characteristics, etc. In addition, the combustion chamber is affected by many other factors, such as temperature, height, and airflow distortion and so on.

3.1.5. Fatigue Fracture Fault. Fatigue fracture fault usually occurs on engine blades, and the common parts are the maximum steady-state stress point and the highest temperature point of the blade, vibration nozzles, the vulnerable parts, the connecting and contacting parts.
3.1.6. Control System Fault. The control system fault of the aircraft engine is manifested in the fault alarm of the software system during the operation of the engine, which leads to the faults of aircraft engine such as starting interruption, flameout in flight and so on.

3.2. Main methods of aircraft engine fault monitoring and diagnosis

3.2.1. Composition and working principle of aircraft engine fault monitoring system. The fault monitoring of aircraft engine mainly consists of airborne equipment and ground equipment. Airborne equipment generally includes sensors, signal regulators, data acquisition systems, data transmission and recording devices, data processing systems, alarm and simple print processing devices, etc. Common fault monitoring systems includes Aircraft Integrated Data System (AIDS), Engine Indicating and Crew Alerting System(EICAS), etc. Ground equipment mainly consists of transmission equipment, decoding equipment or data processing equipment, ground maintenance station, computing center and corresponding software system for status monitoring and fault diagnosis. Data acquisition system would collect the sensor signal in accordance with the sequence and time and transmit to the airborne recording device, some parameters can do preliminary processing through the airborne computer of data, given real-time fault warning in the cockpit and print various reports engine when it is necessary, also has a development of Space Radio Communication System (Datalink), transmits the flight test data to the ground maintenance computer center directly to conduct a comprehensive and in-depth analysis of data in real time, the analysis results are directly fed back to the crew, and the necessary maintenance work shall be timely notified to the destination port of the aircraft and all preparations shall be made. Thus, these reduce the aircraft standing time on the ground greatly and the flight delay rate. In the future, satellite communication technology will be used to allow aircraft to exchange information with maintenance bases anywhere in the world.

3.2.2. Key technology of aircraft engine fault monitoring. At present, with the continuous deepening and progress of research, engine monitoring and fault diagnosis theory have been constantly developed and improved. According to incomplete statistics, the key technologies can be summarized as follows:

The key technologies of signal processing and feature extraction mainly include multi-signal separation technology, noise elimination technology, feature generation and extraction technology, nonlinear dynamic analysis technology, time-domain processing technology, frequency-domain processing technology, spectral analysis technology, non-stationary signal processing technology, and wavelet analysis technology, etc.

Condition monitoring and fault diagnosis of key technology is mainly divided into graphical diagnostic methods (such as the major fault graph, fuzzy fault graph, the retina figure, etc.), integrated information fusion diagnosis methods (such as the use of data filtering algorithm, characteristics, many methods of fusion method of weak classifier fusion algorithm), statistical decision methods (e.g., decision tree, decision well, fisher discriminant method, etc.), artificial intelligence methods (e.g., neural network method, expert system, etc.), evolutionary computation methods (for example, a cloud model evolutionary computation trend monitoring and diagnostic classification method), signal detection method (e.g., singular value detection, wavelet detection, etc.), statistical learning methods (e.g., support vector Machine, all kinds of learning machine), covering learning method (from the perspective of cognitive science research of fault diagnosis of new machine learning theory), dynamic diagnosis method, the dynamic model of fault analysis methods, such as a variety of detection, isolation, identification algorithm etc. Comprehensive monitoring engine technology should make full use of all kinds of information fusion theory in order to improve the level of fault diagnosis.
4. Current situation of aircraft engine fault monitoring and diagnosis and research

4.1. Current situation of oversea research

In order to reduce the plane accident probability, ensuring the safety and reliability of the flight, researching the monitoring of aircraft engine health state has always been concerned by domestic and researchers. Fault monitoring of PHM system has been applied to the engineering practice early in abroad, such as the United States Department of Defense, National Aeronautics and Space Administration(NASA) especially attach importance to the study of health management system, their PHM system has long been applied in the F-35, the fourth-generation advanced fighter of the United States, which greatly guarantees the safety and reliability of the fighter and significantly improves the operational efficiency of the fighter. At the same time, because it can quickly locate the fault mode reducing the maintenance investment significantly [8].

Since the beginning of the 21st century, the development of aircraft engine PHM technology in foreign countries has been greatly accelerated, and the research on aircraft engine health monitoring has been gradually deepened. Typical researches among them are: Jaiwon, ey. al in the process of PHM technology research for system the problem of high failure rate of the engine to improve the safety and reliability in the process of aircraft engine flight, in improving the stability of the system at the same time reduce the incidence of engine, its engine fault monitoring were elaborated in details. In the study the technology has been proved in engineering application [9]. Salahshoor studied the health status of engine fuel pump to some extent, PHM system was firstly introduced into engine fuel system, which provided an effective technical solution for fault diagnosis of aircraft engine and had high engineering application value [10, 11].

In recent years, in order to achieve the "enhanced maintenance based on state," the United States all services offered some plans and initiatives and carried out several projects. The new projects introduce some new and improved maintenance technology and the application method into the engine fault maintenance practice. In the engine monitoring management system of JSF project, choosing a set of engine sensor subsystem includes detection system of gas-path debris detection I EDMS DMS and motor loss detection system. In addition, the American Society of Automotive Engineering (SAE) E - 32 aviation gas turbine monitoring committee developed and issued a series of guidelines, which has played a good role in guiding and promoting the development of aero engine condition monitoring and fault diagnosis, including aviation gas turbine engine monitoring system guides, limited monitoring system, the oil system monitoring guide, vibration monitoring system guide, the service life monitoring system and parts management guidelines, etc.

4.2. Current Domestic Research Situation

Domestic engine health monitoring technology started late, have not reached the mature applications condition, yet. The relevant research work on health condition monitoring and fault diagnosis of large aircraft engines carried out by civil aviation companies and colleges in China has achieved initial results. The ground of the real-time diagnosis avionic subsystem ARDMS of Northwestern Polytechnical University, Beijing University of Aeronautics and Astronautics and Avic Qianshan Avionics, send back real-time flight data to the ground terminal through space data-chain, after processing of ground terminal, the data will be distributed to the engine subsystem achieving the effect of closed-loop real-time health monitoring. At the same time, domestic colleges and universities carry out a series of related theory research work, such as a control system based on Kalman Filter Sensor Fault Diagnosis, based on the fault diagnosis expert system for aero engine vibration testing, engine gas path fault diagnosis based on neural network, etc. Compared with foreign countries, domestic aircraft engine health condition monitoring still is at the theoretical level. At present, many research results are mainly focused on fault diagnosis, and the integrated system of online real-time status monitoring is rarely reported.

Despite the rapid development of China's aviation industry in recent years, aircraft engine is a complex systems engineering, the application of engine condition monitoring and diagnosis technology is just getting started. Especially for the newly developed high-performance engine, implement of state
monitoring should be listed as important technical and tactical indicators, we will carry out comprehensive research in this area. But in general, the domestic work is not enough, it is urgent to learn from the successful experience of foreign countries in a planned and step-by-step way, to develop and promote our own engine health status monitoring and fault diagnosis technology for adapting to the needs of the development and aircraft. Now serving military aircraft and civil aircraft engines do not have a complete engine status monitoring and diagnosis system, yet. How to develop an effective monitoring and diagnosis device for burst fault based on the existing engines and ensure that the operating state of the engine is evaluated with fewer effective parameters are becoming a difficult problem.

5. Conclusion
With the development of aviation technology, the reliability of aircraft engine is increasing. But increasingly complex structure, high strength, large overload, long flight time, strong fault coupling and so on result in many fault modes and complex mechanism of the aircraft engine, which can easily lead to the change of engine working point, the decrease of engine stability margin and the deterioration of performance, and lead to multiple and dangerous faults. Through monitoring engine, we can effectively evaluate and control the use of the engine to determine the engine and its unit body, the state of the residual life and spare parts, detection, evaluation, segregation engine failure and inspection, adjustment of correction; We should track the changing trend of engine state, support the decision of engine life management and logistics protection, improving the reliability, maintainability, guarantee and economy of aircraft engine effectively, and ensuring flight safety.

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