

2.1. Keywords analysis of QAR data research in China

In order to ensure the authority and reliability of the literature, the Chinese literature collected in this paper was retrieved from CNKI, and the search keywords were: "QAR", "quick access recorder", "Quick access Recorder", the search scope for journals, and the search results were read and screened, eliminate irrelevant articles, the final determination of the number of Chinese literature is 220. The keyword cluster analysis was carried out, and the screening frequency was no less than 5 times. A total of 34 keywords meeting the conditions were obtained, and the following distribution diagram was obtained. After removing the search keywords such as "QAR" and "QAR data", the top 10 in the frequency ranking were Aero-engine (aero engine) 33 times, flight safety (28 times), flight data (24 times), fault diagnosis (23 times), fuel flow (19 times), data mining (13 times), feature extraction (10 times), regression analysis (10 times), anomaly detection (8 times) and flight quality monitoring (6 times).

Through keyword atlas analysis, it can be concluded that: 1) The research on aircraft components and fault diagnosis based on QAR data is the most concerned field of domestic scholars, among which the most academic articles have been published on the monitoring of engine and its components; 2)

Research on flight safety based on QAR data is another hot spot, including flight quality monitoring, risk assessment, etc.; 3) QAR data mining research is also a hot topic, including the improvement of the algorithm and the method of extracting characteristic parameters in QAR data; 4) The number of research articles on aircraft emissions based on QAR data is not too large, but it is also a key research direction that cannot be ignored.

2.2. Keywords analysis of QAR data research based on Web of Science

The literatures were retrieved from the Web Of Science(WOS), the search keywords were "QAR data", "Quick Access Recorder", the search scope was the core set of WOS since 1990, the result of manual screening of the articles, the final number of foreign literatures was 98. Also, the VOSviewer software was used to conduct keyword cluster analysis on the retrieval results, and the frequency of occurrence was set to be no less than 2. There were 34 keywords meeting the conditions, and the distribution diagram was as follows, and the retrieval keywords such as "qar data" and "quick access recorder" were deleted. Keywords that appeared most frequently were flight data 6 times, fuel consumption 4 times, deep learning 3 times, and pilots 2 times.

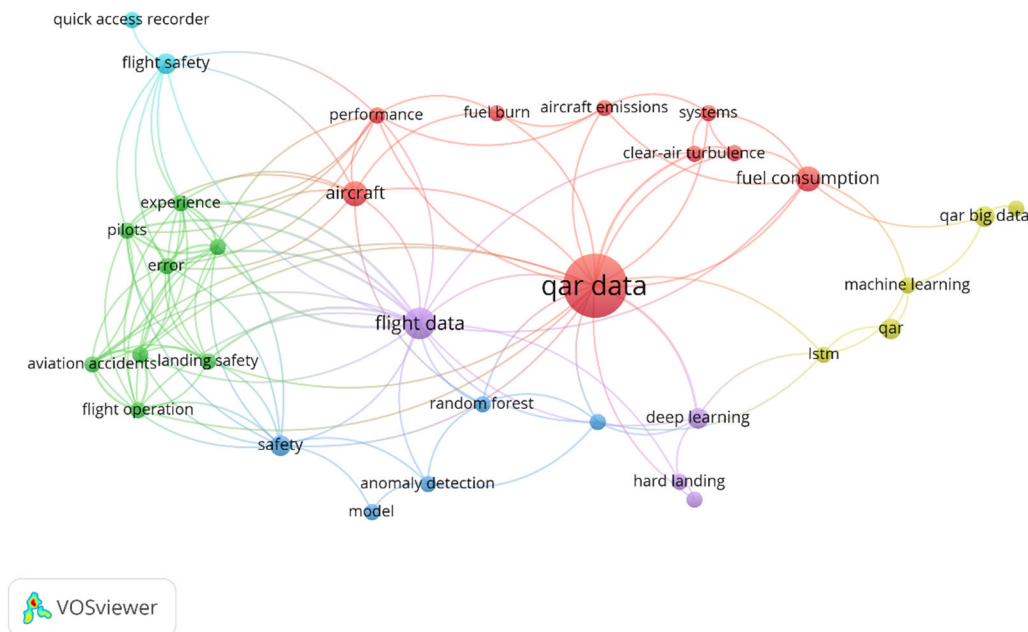


Figure 2. Keyword cluster analysis of foreign research literature

Through keyword atlas analysis, it can be concluded that: 1) Similar to domestic research, improving data analysis algorithm based on QAR data is the research focus of scholars; 2) Research on fuel efficiency based on QAR data is one of the hot spots of scholars; 3) Different from Chinese studies, the study of pilot safety operation evaluation based on QAR data is a hot topic in papers.

3. Classification and Sorting of QAR Data Related Studies

Through the analysis of keywords, combined with the four

elements of the comprehensive management of civil aviation safety, the research on QAR data at home and abroad is summarized into five aspects: 1. Research on airplanes; 2. Research on QAR data; 3 Research on pilots; 4. Research on environmental impact; 5. Research on management. The following is a review of these five aspects of research.

3.1. The research on airplanes

The research directions of airplanes and its related parts based on QAR data include fault detection of engine and its components, monitoring of fuel consumption efficiency, fault monitoring of airborne equipment and monitoring of

aerodynamics of airplanes. The following are the researches in these four directions respectively combed and elaborated.

3.1.1. Fault detection of engine and its components

The performance of civil aviation engine directly affects the performance, reliability and economy of aircraft, which is an important embodiment of a country's science and technology, industry and national defense strength. Among the researches based on QAR data, the amount of researches on engine are the most. Early researchers were mainly composed of technical staff of airlines. Limited by the decoding system and computer technology provided by airlines, they could only monitor some parameters of engines [1,2]. With the development of computer technology, researchers can use QAR data to discriminate and monitor the state of the engine in different flight stages [3-5]. Monitoring data types are becoming more comprehensive and monitoring accuracy is becoming higher, which is conducive to avoiding the occurrence of unsafe state of the engine. In addition to monitoring the engine, researchers began to conduct in-depth mining and analysis of QAR data: Cao Huiling from Civil Aviation University of China obtained the exhaust temperature (EGT) margin of CFM56-7B engine by converting relevant parameters of QAR data, and then established the recession model of the engine by segmentally fitting [6]. Then, an engine anomaly detection system was developed by combining QAR data with support vector machine (SVR) algorithm [7], and an evaluation model of engine health state was established by combining the relevant parameters of QAR data with the analytic hierarchy process (AHP) and grey correlation analysis [8]. With the deepening of the research, other researchers began to study the aircraft power system based on the principle of thermodynamics: analyze the parameters related to the aircraft engine bleed air system and auxiliary power system from the QAR data, and carry out fault detection and prediction [9,10]. Based on QAR data, specific unit components of the engine are studied, such as the complex structure and regulation rules of turbine blade [11,12], rotor [13] and adjustable vent valve [14-16], and the prediction model is obtained through mathematical simulation. Continuous detailed research can enable airlines to make more accurate maintenance plans for the engine and its specific components, ensure the normal operation of the engine, and improve the safety management level of airlines. .

3.1.2. Monitoring of fuel efficiency

The need to improve the efficiency of monitoring fuel consumption and control fuel costs has existed since the invention of airplanes. After QAR devices were widely installed on airplanes, researchers began to mine the parameters related to fuel efficiency from QAR data. In the initial research, mathematical statistics were used to model and analyze the fuel consumption of the engine during take-off [17], cruise, landing and ground taxi [18].

On this basis, Cao Huiling et al. [19] used multivariate statistics algorithm and MATLAB platform to establish a simulation platform applicable to various engine models to estimate fuel consumption of each segment. At the same time, with the development of big data theory and computer algorithms, the research of new algorithms based on correlation degree and signal decomposition began to appear. At the same time, the proposed and continuous optimization of neural network and machine learning algorithm [20,21], researchers applied the method of processing big data to the research of fuel consumption and the establishment of

prediction model. The establishment of fuel consumption model can better estimate engine performance, control fuel saving flow, and make more accurate prediction of fuel consumption, but there are also time consuming and workload problems. Different from the above modeling and simulation analysis methods, Ye[22] et al. proposed a method based on the inherent mechanical characteristics of the engine without modeling. By using QAR data to match flight conditions, fuel flow prediction is carried out. This method greatly reduces the verification time and cost, and provides a new way to study QAR data.

In addition to engine fuel, lubricating oil and other oils are also important to ensure aircraft flight safety. Wang et al. [23] built a model by mining parameters such as oil consumption rate in QAR data to judge the health of aeroengine lubrication system.

3.1.3. Airborne equipment failure monitoring

In addition to the research on engine power system faults, Wu Renbiao et al. [24] developed a fault diagnosis simulation system for airborne equipment based on Simulink and Microsoft Visual Basic 6.0 software. Through monitoring various parameters of QAR data, they found fault symptoms. This enables maintenance personnel to perform troubleshooting, restricted operation, or replacement in a timely manner to ensure flight safety.

Among all the studies on airborne equipment, the air conditioning system of aircraft is the key research object. By monitoring and fault detection of the flow of aircraft air conditioning components [25], researchers classify the working state of the air conditioning system and establish a degradation assessment algorithm based on the physical characteristics of the air conditioning system, so as to achieve the purpose of monitoring and evaluation of the air conditioning system of aircraft. To facilitate airlines to arrange flight schedules and maintenance schedules.

3.1.4. Monitoring of aerodynamics of aircraft

The aerodynamic model of civil aircraft has been determined after its manufacturing. However, structural fatigue or corrosion caused by long-term flight will lead to minor changes in the aerodynamic model of the aircraft. Accurate acquisition of relevant parameters of the aerodynamic model from QAR data is conducive to safe flight operation of aircraft in different environments [26]. It has important practical significance such as flight simulation, maintenance information guidance and accident warning and recurrence.

Through combing, it is found that the research of aircraft and its components based on QAR data has made some achievements. And the research develops from a certain system to a certain part of the system, the research object is more and more detailed; It is beneficial to establish the decay model of the system or component based on the physical characteristics of each system or component of the aircraft, which is conducive to the arrangement of flight planning and maintenance plan of airlines. Monitoring combined with fault detection model can effectively detect the fault of aircraft systems and components. The monitoring of specific aircraft components and performance attenuation prediction are the development trend of QAR data for aircraft research.

3.2. The research on QAR data

QAR equipment records all data related to flight in the course of flight. The study of the data itself can dig deeper information in it, and improve the monitoring efficiency of

flight process and the utilization rate of QAR data of airlines. With the rapid development of the civil aviation industry, the quantity of QAR data is also increasing rapidly. Research on QAR data itself runs through the research on aircraft, management, environment and pilots based on QAR data. Meanwhile, with the development of computer technology, research methods on QAR data are also improving.

At the early stage of the application of QAR equipment, airlines can only use the aircraft performance monitoring software provided by the aircraft manufacturer to carry out decoding, analysis and calculation of the collected data, and can only carry out aircraft performance monitoring based on the results. Due to the poor software analysis ability and the different analysis software used by different airlines, a large amount of QAR data is wasted. In order to solve this problem, one of the earliest ideas is to establish a database with higher storage efficiency. Researchers start from the perspective of reducing QAR data, respectively using compressed sensing theory, wavelet transform, cluster analysis and other methods to establish a new QAR data storage system, so as to store QAR data better and prevent data from being overwritten and wasted. Another idea is to improve the decoding speed of QAR data from the perspective of data processing speed, using dynamic linked list, the establishment of automatic decoding system and other methods, so as to improve the utilization of QAR data. At the same time, researchers analyzed the abnormal data in QAR data and carried out denoising, detection and correction to improve the reliability of the data [27].

QAR data records all the data in the flight process. However, in the research process, only a certain class of problems are analyzed, so only parameters in the QAR data that are highly relevant to the analyzed problems need to be found for analysis. This step is called feature extraction of QAR data. Feature extraction is the most basic step in all current QAR data-based research, which can greatly simplify the amount of data analyzed. There are qualitative and quantitative methods to extract characteristic parameters. The qualitative method mainly refers to the selection of relevant parameters according to expert opinions. Quantitative method refers to the use of computer mathematical methods to extract the relevant parameters. Qualitative method and quantitative method should be unified and complement each other. The development of quantitative analysis methods is described below. The quantitative method of feature extraction is mainly based on association rule analysis, time series, regression model, neural network, ball vector machine, cluster analysis [28] and other mathematical methods for feature extraction of QAR data. With the continuous development of machine learning theory, researchers have begun to use deep confidence network, convolutional neural network combined with short and long term memory network, Transformer network and other technologies based on deep learning [29] to improve the feature extraction method of QAR data, so as to improve the utilization rate of QAR data.

Emerging services such as cloud computing, the Internet of Things, and social networks have contributed to an unprecedented increase in the type and scale of data in human society, and the era of big data has officially arrived. Data has changed from a simple object to a basic resource. How to better manage and utilize data has become a topic of general concern. The scale effect of big data brings great challenges to data storage, management and analysis, and changes in data management methods are brewing and occurring.

3.3. The research of pilots

The pilot is the pilot of the aircraft, and the operation of the pilot is closely related to flight safety. In civil aviation production activities, potential hazards and events can be referred to as over-limit events, and pilot over-limit behavior can be understood as potential pilot operations that may cause accidents.

Research on pilots based on QAR data is often conducted indirectly according to parameters related to overrun events. Typical overrun events include excessive pitch Angle and sideslip Angle during takeoff and landing. If the over-limit event is not found and improved in time, heavy landing, tail rubbing and other unsafe events may occur [30,31], or even cause serious losses. By counting the occurrence frequency of QAR over-limit events as the evaluation standard, the safety risk assessment method is introduced to establish a model to analyze the QAR data, so as to evaluate, analyze and warn the flight operation of pilots. The pilots with poor evaluation results are focused on and the training requirements are put forward for them. Airlines can also take the evaluation results as one of the bases for year-end performance rewards and punishments [32].

At the same time, some researchers also proposed that psychology [33] and QAR data should be integrated to evaluate the operation of pilots, and the mental and psychological state of pilots should be fully considered. Different pilots have different ability to bear risks, and external pressure may also have an impact on the operation of pilots, so the comprehensive evaluation should be conducted. With the deepening of the research, a more comprehensive consideration of various factors in the work of pilots, so as to comprehensively evaluate the flight level of pilots will become the development direction of pilot research using QAR data in the future.

3.4. The research of environmental impact

As aviation has grown rapidly, so have emissions from aircraft. With the enhancement of global environmental awareness and the vigorous implementation of the green development of civil aviation in China, the issue of aircraft exhaust emission has gradually attracted the attention of researchers, and the study of aircraft emission pollution has become a hot topic based on QAR data.

The pollutants emitted by aircraft engines mainly include gas pollutants and particulate pollutants. Since the calculation of particle pollutants is more complicated than that of gas, the initial research focused on gas pollutants. Researchers obtained engine emission index and emissions by using parameters such as temperature, humidity, altitude, speed and fuel flow in QAR data, evaluated aircraft diffusion based on the results [34], and provided a basis for its emission control measures. With the construction of airport economic zones in recent years and the public's extensive attention to air quality, researchers began to monitor and evaluate aircraft emissions in the airport area by combining engine performance data with airport atmospheric environment parameters [35] [36]. With the development of technology and the attention paid to the impact of particle pollutants, researches on particle pollutants began to emerge in large numbers. Cao Huiling [37] et al. summarized the researches on gas pollutants and evaluated the black carbon emission characteristics of the whole flight segment of an aircraft considering the performance differences of engines, combustion quality and external environmental conditions. It provides more accurate

basis for aircraft emission monitoring and equivalent replacement of airworthiness compliance verification.

The research on aircraft emissions based on QAR data can propose emission reduction methods for airlines from a scientific perspective, such as improving fleet mix, optimizing scene operation procedures, adjusting route and cruise mode, etc. Different researchers pay attention to the emissions or pollutants in different flight stages. All researchers are trying to obtain more accurate emissions, but there is still no model that can accurately calculate the accurate emissions of different pollutants in different flight stages. With the deepening of the research on aircraft exhaust emissions, the emissions of both gas and particulate pollutants will become more and more accurate, and the impact will be more predictable, enabling airlines to make more accurate plans for energy conservation and emission reduction.

3.5. The research of management

The use of QAR data can improve the management efficiency of airlines: Researchers use high-precision synthesis and integration, cluster analysis methods to analyze QAR data and flight route data; Airlines can find existing problems based on abnormal data, arrange flight plans and optimize routes [38], reduce flight delays [39], and improve the benefits of airlines.

In addition to improving efficiency, relevant managers can obtain flight quality-related parameters such as flight track from QAR data and evaluate flight safety at different flight stages by combining risk assessment model and other methods [40,41]. Airlines can timely discover flights and routes with poor flight quality and propose targeted improvement measures. Data mining and machine learning methods are adopted to evaluate flight quality, which greatly improves the accuracy of flight quality assessment and is conducive to improving flight quality and flight safety [42].

In addition, some research results of the above mentioned studies on aircraft, QAR data and management work will also have certain reference significance for management work, such as the research on the designation of maintenance plan in aircraft research, which can also improve the efficiency of management work to a certain extent. In the future, studies on management using QAR data, whether safety management or efficiency management, will integrate the above mentioned studies on aircraft, QAR data, pilots and environment to comprehensively improve the management ability of management.

4. Problems and Future Research Directions

Through the above combing, some problems and development directions of QAR data research at home and abroad can be summarized, including:

1) Research using QAR data is becoming more and more comprehensive. Among them, monitoring the health of various system components of aircraft and monitoring the flight quality are the main research areas at present. At the same time, with the development of theories related to human factors and green development, researches on pilot pressure and environmental protection have emerged in large numbers, which have become the hot spot of QAR data research in recent years. With the deepening of the research, further mining of the parameter information of QAR data to specifically study the work and attenuation characteristics of

a certain part of an aircraft, or pilot operation and aircraft exhaust emissions will become the development direction of QAR data research in the future.

2) Research on QAR data requires a relatively professional and extensive knowledge reserve. No matter the research of aircraft, QAR data, pilots, environment or management, there is a problem that the accuracy and speed of data processing by mathematical statistics can not meet the requirements of the increasing amount of data. At present, the method of machine learning is widely used for data analysis. While the algorithms used in data analysis continue to improve, there is a trend of multidisciplinary integration of research, which requires a high knowledge reserve of researchers. For example, in the study of pilots, they should not only be familiar with the relevant operations and parameters of aircraft flight, but also master the data processing methods to process and analyze QAR data. Further research also requires researchers to master the relevant knowledge of psychology and risk assessment. Interdisciplinary knowledge reserve has become a necessary quality requirement for researchers.

3) There is still room for further mining of QAR data. QAR data parameters are numerous, different research objects need to study different parameters, and the relationship between parameters has not been fully studied at present, it can be combined with relevant theories and algorithms in data mining, applied to the mining of QAR data parameter association. The second chapter of this paper classifies the researches based on QAR data, but in fact, each category does not exist independently, but there are potential connections, and these connections need to be further explored by researchers. With the deepening of the research, two or more aspects of the above five aspects should be combined into the research. For example, the research on aircraft exhaust emissions mentioned in 2.5 can be applied to the management work and can be a direction of future research.

4) Over-emphasis on QAR data exists. Since our civil aviation regulatory authorities begin to use QAR data to analyze and evaluate the flight quality of flights, airlines have begun to attach importance to the QAR data and link it with the pilot's performance. As a result, pilots have many flight operations to ensure the good appearance of QAR data, which may lead to operation conflicts and the possibility of unsafe incidents. This requires airlines to pay reasonable attention to QAR data, and should not only rely on QAR data to evaluate pilot operations. In the future, more parameters should be added for comprehensive evaluation of flight quality.

5. Closing Remarks

With the official arrival of the era of big data, QAR data has changed from a simple processing object to a basic resource for airlines and Civil Aviation Administration. How to better manage and use QAR data has become a topic of general concern. Making full use of the existing value can effectively improve the efficiency of airlines and enhance the work efficiency of regulatory authorities. In this paper, the research results of QAR data are introduced. In order to facilitate sorting, five categories of aircraft, QAR data, pilots, environment and management work are sorted respectively. In addition, this paper also points out the problems existing in the current QAR data and points out the development direction of future research.

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