2017 IEEE 11th International Conference on Semantic Computing

Civil Aircraft Big Data Platform

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***Abstract*—the aviation industry generates massive data every day. By analyzing the aviation big data, aviation manufacturers and airlines can optimize the flight of civil aircraft including risk reducing, operation optimization, and personalized services. Building a platform for storing and analyzing the aviation big data becomes an important task for civil aviation. This paper proposes a civil aircraft big data platform that works on facilitate the development of civil aviation. The platform collects data from multiple types of data sources, including aircrafts, airlines, and maintenance centers. The platform provides decision making support for civil aircrafts including maintenance plan, real-time alarm, health management, fuel saving, and airline schedule. The paper introduces the architecture of the platform and present applications to show how the platform facilitates civil aviation.**

Keywords- civil aircraft, Big Data platform, health management, fuel saving, airline schedule, maintenance plan

I. INTRODUCTION

Nowadays, the aviation industry generates massive data rapidly, e.g., the operational data in every day. The big data technology can deal with the data and bring opportunities for the aviation industry chain, including design, development, production, and operation. For aircraft manufacturing, the big data technology helps analyze the historical manufacturing data and suggest the light and reliable aircraft materials. For the aircraft design, the big data technology can suggest the optimal design ideas considering safety and reliability, comfort, and fuel consumption by analyzing the massive data generated in the flight test. For the operations, airlines can provide personalize services to users according to the recommendations of the big data technology. For the aircraft health management, the big data technology can provide fault diagnosis for aircrafts. It can forecast the possible faults by exploring the flight data. The big data technology can also propose the maintenance suggestions, namely predictive maintenance. However, there are open issues involving the following aspects: (1) Massive and complicated data items. There is no integration of the data items for storage and Management. Most of the existing Civil Aviation data are independent and heterogeneous unstructured data, including text documents, voices, images, and videos. It is hard to integrate the data for valuable analysis. This problem has become the bottleneck of the civil aviation applications. (2) Information security. International Civil Aviation Organization (ICAO) proposed the operational safety and information security as the primary objectives of civil air transportation. The application of big data techniques may bring certain risks to information security. In this paper, we propose a big data platform for civil aircrafts. The platform collects massive civil aviation data from multiple data sources and analyzes the big data using various approaches. The proposed platform provides frameworks for big data storage and processing. The platform manages data models and analysis models for providing different types of analysis services. Moreover, the platform provides application systems for civil aviation with the help of the analysis services.

The rest of the paper is organized as follows. Section 2 presents the related work of the research. The concepts of the Civil Aircraft Big Data Platform are introduced Section 3. Section 4 presents the architecture of the platform. Section 5 shows applications of the platform. Finally, conclusion and future work are given in Section 6.

Sponsors: (1) Special Project for Civil Aircraft, MIIT; (2) Fund of Shanghai Engineering Research Center of Civil Aircraft Health Monitoring.

II. RELATED WORK

Many aviation companies and research institutions put large effort into the big data technology for civil aircrafts [1][2][2][4][5][6]. Engine manufacturers applied the big data technology for optimizing the safety and operation. GE proposed the concept of “Industrial Internet” and launched the first cloud service platform “Predix” in the world. Predix can give abnormal alarm by analyzing the data of c.a. 35,000 engines. GE built fuel forecasting model by modeling and training a large amount of flight data. The model helped customers for fuel saving. Pratt & Whitney and IBM enhanced the performance monitoring of more than 4,000 commercial engines in service and improved the forecasting of engine maintenance using big data analytics. Rolls-Royce and Microsoft applied Microsoft Azure cloud platform for massive aerial data aggregation, integration, and analysis. It aimed at reducing airline energy consumption and enhanced operational efficiency.

Aircraft manufacturers used big data technology for guiding the aircraft production [6][7][8][9][10]. Airbus and Oracle jointly developed a Hadoop-based big data platform and a flight simulation analysis system in order to collect and analyze the flight sensor data generated during the test flight. Boeing and Carnegie Mellon University built a Boeing/Carnegie Mellon Aerospace Data Analytics Lab for a comprehensive upgrade of Boeing aircraft using artificial intelligence and the big data technology. The COMAC has started to build the big data platform for the data of the General Assembly Manufacturing Management Operation Center.

978-1-5090-4284-5/17 $31.00
DOI 10.1109/ICSC.2017.51

Airlines used the big data technology to improve the user experience and data sharing [11][12][13]. China Eastern Airlines constructed a big data platform in order to improve the users' experience of the entire travel. Air China built an airborne data platform, which can improve the statistics and analysis of aircraft fuel chain. The platform allowed the rigorous monitoring for flight process, data quality, and overrun events. The platform provided data sharing between departments by integrating production data and operation data.

ISIR lab [14] studied an aircraft antifreeze system with 120,000 copies of sampling data of temperature, pressure, flow, system variables. ISIR lab constructed six neural networks using the improved Artificial Neural Network (ANN) method. It generated the diagnostic results according to the outputs and sent the results to pilots, Airport Command Center (ACC), or fault-tolerant system.

Xu and Kumar [15] presented big data-based machine learning method to build a predictive analysis algorithm for continuous monitoring of the health of Auxiliary Power Unit (APU). Chandramohan et al. [16] presented the architecture of aeronautical big data analysis for integrating and analyzing the data from different data sources. Frantis [17] developed a big data system for air force that contains the data from the aircraft data logger, military route planning systems, logistics information systems, and meteorological data.

The state-of-the-art research work shows that the hot topics of aviation big data research: fault diagnosis based on big data, and big data transmission and communication for aircrafts.

III. CIVIL AIRCRAFT BIG DATA PLATFORM

We propose the civil aircraft big data platform (see Fig. 1). During the flight, the flight data is transmitted to the civil aircraft big data platform in real-time by the air-ground data link based on demand or at regular intervals. The data include aircraft position data and aircraft health monitoring data. After landing, all parameter data are sent to the data center with the off-line ways. The data center analyzes the flight data in real time and returns the results of the aircraft health decision. The data center sends maintenance data and maintenance recommendations to the aircraft maintenance center, which will return the results of the maintenance to the data center. The data center uses the operational data of airports and the aircraft flight data to provide the real-time tracing of aircrafts and give suggestions of the flight arrangement.

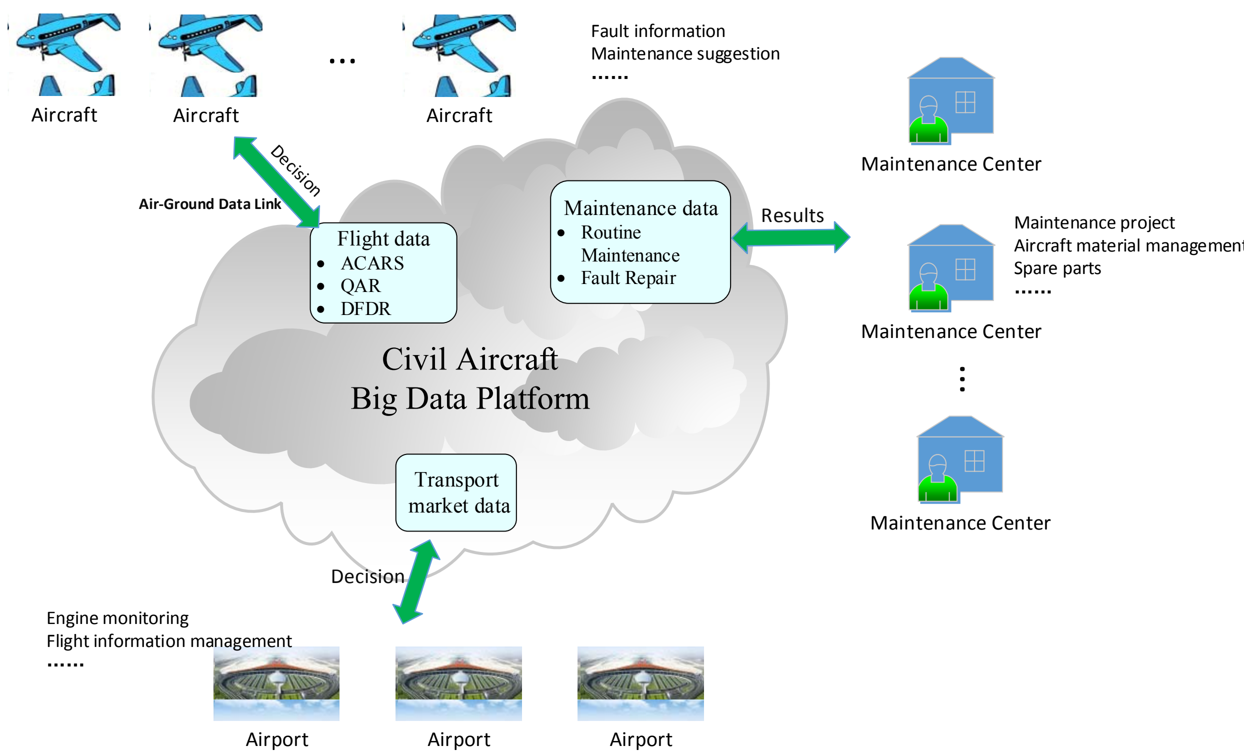

Fig. 1 Scenario of Civil Aircraft Big Data Platform

A. *Aircraft Data Link Communications*

The air-ground data link system of civil aviation consists of three main parts (see Fig. 2): airborne data communication equipment, ground operation control center, and ground information processing system. The airborne data communication equipment sends aircraft monitoring data to the ground units, and receives data from the ground units. The ground information processing system focuses on analyzing the real-time data, and monitoring the status information and fault information of the aircraft. The ground operation control center works on information transmission between the airborne data communication equipment and the ground information processing system. The core of the air-ground data link system is the ground operation control center that is responsible for filtering, interpretation, and maintenance of the communication signal management. In this way the communication signal can be automatically transmitted between air and ground.

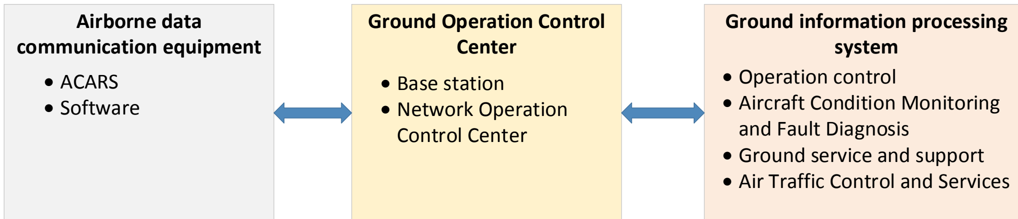

Fig. 2 Air-Ground Data Link

There are two main types of air-ground transmissions: radio communication and data transmission. Radio communication includes high frequency (HF) communication and very high frequency (VHF) communication. HF communication has a large communication range. It is used for communications between aircrafts as well as communications between aircraft and ground. VHF communication works on a communication within the visual range. It can provide voice and data communications between air crews and ground, and between crews in different aircrafts. Data transmission has two types: aircraft communication addressing and reporting system (ACARS) and satellite communication system. The ACARS system is a data link communication system that manages flight data and maintains operational data, including crew identity, takeoff and landing information, engine performance, flight status, and maintenance information. Satellite communication system provides an air-ground transmission of data and voice between satellites and ground. Satellite communications can transmit better-quality data and voice data than the radio communication systems.

B. Date Acquisition System

The aircraft dataset includes flight data, maintenance data, and transport market data.

The data sources of flight data include ACARS (Aircraft Communications Addressing and Reporting System), QAR (Quick Access Recorder), and DFDR (Digital Flight Data Recorder). ACARS is a type of aircraft flight data. ACARS has three message types: Air Traffic Control (ATC), Airline Operations Control (AOC) and Airline Approach Control (AAC). It consists of airborne equipment, service provider and ground handling system. The data parameters and types of packets are defined by airlines and monitoring centers. Aircrafts transmit the data to the monitoring centers with a certain frequency by the air-ground data link. The data include the following types:

- Flight parameters, e.g., flight height, flight Mach number, flight position.
- Engine monitoring parameters, e.g., EGT margin, fuel flow, high pressure speed, low pressure speed.
- System health monitoring parameters, e.g., flight control and avionics.
- Extended information, e.g., pilot operations, BIT information, and on-board on-line monitoring data.

Using 128MB~640MB of memory, QAR can continuously record the raw data up to 600 hours of flight. It can collect hundreds or even thousands of data simultaneously, which cover most of the aircraft operating parameters. QAR is mainly used for routine maintenance, flight inspection, performance monitoring and flight quality monitoring.

The DFDR is used to provide important flight parameters recorded in the previous flight. It records aircraft parameters and system data for the last 25 hours. The recording signal comes from other systems and sensors of the aircraft. It records "air data" such as flight attitude, flight path, flight speed, acceleration, latitude and longitude, heading, fuel consumption, landing gear retraction.

Maintenance data describe the machine state and help determine whether faults exist. The data are used for aircraft maintenance on the ground, including transit check, routine maintenance, and fault maintenance. The data include aircraft state, aircraft subsystem state, fault state. The data have the following characteristics:

- Massive, with the strengthening of QAR data download capabilities and the expansion of ACARS applications, the scale of data set has expanded to range from 100G to several TB.
- Multi-type, structured data, unstructured data, semi-structured data.
- Fast rate, maintenance activities uninterrupted, maintenance data real-time, rapid collection.
- Low-value, single data may not be much value, but the huge amount of data is of great value.

Transport market data, including accommodation, tickets, and income, are used for marketing analysis.

C. Big Data Security

The information security is a critical issue of big data mining and cloud computing applications of aviation. The aircraft big data need high-level security in order to ensure the security in data storage and transmission.

Air-ground data transmission is important to the safety of aviation flight. In order to ensure the communication security, the civil aircraft big data platform adopts the digital certificate in the identity authentication of air-ground data link. The digital certificate guarantees the integrity and authenticity of information transmission using digital signature.

The platform ensures the security of the databases. The platform provides data security policies, including identity authentication, storage encryption, access control, integrity verification, and security audit. Moreover, the platform uses the ideas of block chain for improving the data sharing security. The blockchain technique depends on the distributed database techniques and cryptology. The raw data cannot be modified in the blockchain so that it can keep the data unchanged and trustful.

IV. ARCHITECTURE

We introduce the architecture the platform in this section. We design the architecture following the standards of cloud computing platform (see Fig. 2). The architecture contains three layers: IaaS, PaaS, and SaaS.

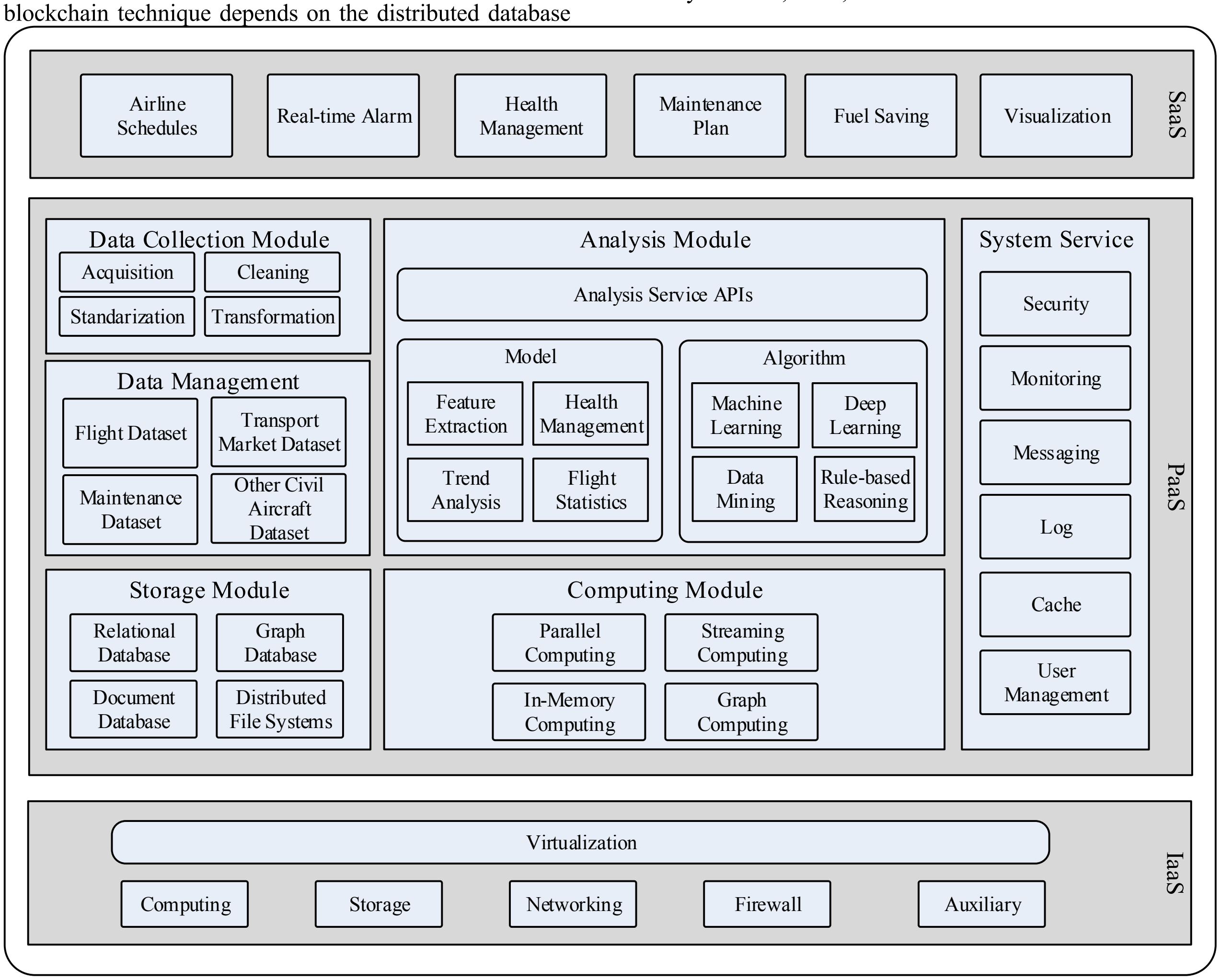

Fig. 3 Architecture of Civil Aircraft Big Data Platform

A. *IaaS*

This layer provides infrastructure of the platform, including computing devices, storage devices, network devices, firewall devices, and auxiliary devices. In the platform, we apply the virtualization techniques to build virtual computer clusters. The software systems and modules of the PaaS layer are deployed and installed over the clusters.

B. *PaaS*

PaaS layer provides the major modules of the platform.

*1) Storage Module:*management of the data store. The platform provides relational databases for structured data, e.g., MySQL Cluster, graph databases for graph-based data, e.g., geographical structure of airlines, document databases for big documents, e.g., MongoDB, and distributed file systems for unstructed data, e.g., images.

2) Computing Module: management of the computing frameworks to effectively implement the analysis methods. Parallel computing works on batch processing of massive data. We apply hadoop map-reduce as the parallel computing framework. Streaming computing focuses on real-time services, e.g., online airline statistics. We deploy Spark Streaming as the streaming computing framework. In-memory computing concerntrates on the high-speed processing for medium-scale data. We use Apache Spark as the In-memory computing framework. Graph computing is good at running graph-based algorithms. We apply Spark GraphX as the graph computing engine.

3) Data Management Module: management of domain datasets. We organize the collected data into different data sets according to the data sources, namely domain datasets. There are three basic domain datasets:

- Flight Dataset: the flight parameter from the aircraft. The data sources include ACARS, QAR, and DFDR.
- Transport Market Dataset: data from airports and airlines, including tickets, accommodation and income.
- Maintenance Dataset: line maintenance, shop maintenance, base maintenance, maintenance data consisting of transit check, routine maintenance, fault maintenance.

4) Analysis Module: management of analysis methods. There are three parts in the module:

- Model Unit: management of the models for feature extraction, health management, trend analysis, and flight statistics.
- Algorithm Unit: management of the algorithms in the field of machine learning, deep learning, data mining, and rule-based reasoning.
- Analysis Service APIs Unit: APIs for invoking the analysis services of the platform.

5) System Service module: management of system level components including security services, the performance and utilitiy monitoring of the system, messaging systems, e.g., Apache kafka, log systems, cache systems, e.g., Redis, and user management.

C. SaaS

SaaS layer provides applications and services for users.

1) Airline Schedules: management of weather, flight, passenger, delay. Airline schedules is reasonable for reducing flight delays.

2) Real-time Alarm: real-time monitoring of aircraft flight signals. If the threshold range is exceeded, system will alarm.

3) Health Management: integration of advanced sensing technology, communication technology, computer technology, diagnosis, and prediction technology to achieve aircraft fault diagnosis and integrated management of full-aircraft health.

4) Maintenance Plan: fault prediction model is built using historical maintenance reports, remote diagnosis data, and flight parameters data. With the help of forecasting analysis, airlines can correctly adjust the route arrangement, plan.

5) Fuel Saving: fuel saving analysis improves airline profits using big data analysis.

6) Visualization: visualization of the civil aircraft big data. Visualization methods can show graphical representations for big data. The visualized big data are intuitive and easy to understand. The platform provides various visualization methods for the data of civil aircraft. The airline statues visalization shows the instant geographical positions of aircrafts on the virtual earth and the corresponding weather situations. Health situation visualization presents the physical structure of the aircraft as a basic layout and shows the health situations of the aircraft components on the layout. This visualization method can show faults of components in real-time as well as the criticality of the failure. Visualization of the maintenance shows the graphic information for the parts to be repaired in a civil aircraft and the maintenance history.

V. Applications

A. Flight Arrangement Based On Big Data Analysis

The normality of flight is important to the operating costs and profits of airlines. In order to reduce flight delays, improve service quality, and reduce operating costs, airlines look for good ways to arrange flights. The main factors affecting the flight delay include weather, aircraft type, route, flight order, air traffic control, airline planning, airport security capabilities, operation model, passenger density, and passenger composition. The civil aircraft big data platform works on the important tasks of flight arrangement including real-time flight position tracking, flight arrival time forecasting, weather analysis, flight, marketing analysis. The platform can optimize the flight management and reduce delay time and fuel consumption.

B. Aircraft Fault Diagnosis And Health Management

There are a large number monitoring equipment and sensors in an aircraft. During flight, massive data can be obtained by a high frequency and long sampling. For example, for a flight of the Boeing 787, the data of the cabin pressure, altitude, and fuel consumption are over 0.5 TB. The big data-based intelligent fault diagnosis system analysis can explore the hidden information in the aircraft big data in order to find the warning signal of the potential faults and monitor the health status of the aircraft. The civil aircraft big data platform can monitors performance degradation of the aircraft, predicts the future reliability, diagnoses the mutation fault, alarms the gradual failure. With the application of big data and the development of artificial intelligence, PHM technology has two key transformations. First, Sensor-based diagnostics to predictions based on intelligent systems. Second, Event/Time-based maintenance (scheduled maintenance) to state-based maintenance.

C. Maintenance Plan

The use of big data and PHM technology can achieve intelligent maintenance of aircraft. The civil aircraft big data platform provides aircraft health monitoring, fault diagnosis, and fault prediction by trend analysis for aircraft flight data and historical data. The platform can predict the next time node of maintenance inspection of the aircraft. Airlines can take actions in advance for the possible maintenance, such as maintenance plan making and repair parts ordering in order to enhance maintenance productivity and reduce maintenance costs.

D. Fuel Saving System Based On Big Data

The civil aircraft big data platform can help airline choose reasonable alternate field by analyzing flight plan data, actual flight data, load balancing data, airport weather conditions, pilot operation, and engine fuel loss. The prediction model of the platform can predict the amount of fuel consumption of each flight according to a large number of flight data. In this way, the amount of backup oil carrying becomes more reasonable and residual oil after landing can be optimized for reducing fuel costs.

VI. CONCLUSION

The civil aviation can generate massive data. The aviation industry is beneficial from the aviation big data, e.g., reducing flight risks, facilitating manufacturing, improving services, and reducing cost. Thus, building an integrated big data platform for civil aircraft becomes a critical issue. In this paper, we propose a civil aircraft big data platform. The platform provides management and analysis of aircraft operating around the world. The platform monitors the aircraft operational health status in real time, and reduces operating costs. In the future, we will focus on the following work: (1) the big data-based aircraft diagnosis and prediction algorithms; optimization of the algorithms using deep learning methods; (2) construction of big aircraft data analysis center, particularly the security of the platform. We will focus on investigating enhanced security of aviation data sharing using the block chain technology.

ACKNOWLEDGMENT

We would like to thank all colleagues and graduate students who helped for our work. This research was partially supported by (1) Special Project for Civil Aircraft, MIIT; (2) Fund of Shanghai Engineering Research Center of Civil Aircraft Health Monitoring.

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