A Integrated Vehicle Health Management Framework for Aircraft

------A Preliminary Report

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***Abstract*—Nowadays, aviation is getting more necessary for our daily life. Airplane is becoming an important method of passenger transport and cargo transport. Integrated health management of airplanes strongly influences the maintenance efficiency of civil fleets and military fleets as wells as drone fleets. This paper proposes a framework of airplane integrated health management that provides integrated health management of airplanes running in worldwide and monitors health status of flight in order to build a suitable mechanism for managing the real-time fault diagnostics, fault prediction, as well as intelligent maintenance decision of airplanes.**

Keywords- aircraft fleet, integrated health management, fault diagnosis, fault prediction, fault maintenance

I. INTRODUCTION

With the rapid development of the global aviation market, aircraft has become a common means of transport, thus to ensure the flight safety is of vital importance. Exciting studies have generally focused on fault diagnosis of a certain part (e.g. an aero-engine and an airborne electronic equipment). However, the findings of them have been far from satisfying the needs of aviation safety. For an airline company, normally, it needs to manage hundreds even thousands of airplanes that requires researchers to figure out how to implement integrated management on such a large amount of airplanes. In addition, it is also essential to improve reliability of a single airplane by judging the health status of this whole airplane. For these reasons, airline companies have to propose a unified method of integrated health management, by which to manage and maintain their airplanes' health, to truly improve aircraft safety and reliability and to accelerate the efficiency of preparation and completion of ground missions. Finally, it will bring about the realization of condition based maintenance and maintenance cost reduction.

Based on the above considerations, this paper gives a framework for IVHM (integrated vehicle health management). The framework is able to guide the airline companies to achieve respectively integrated vehicle health management on aircraft. Figure 1 shows the basic thinking of the framework.

(1)All flying airplanes send the important health information to the company's PHM data center. The information (refers to parameter data) comes from aero-engines, flight control systems, hydraulic systems, environmental control systems, landing gear systems, fuel systems, etc.

(2)After airplanes landed, they download both flight control parameters and sensor data to the company's aircraft maintenance department at the airport, meanwhile uploading them to company's PHM data center.

(3)After receive a variety of real-time information from landed aircraft, PHM data centers of airlines will store them to serve the future fault diagnosis and prediction.

(4)The integrated vehicle health management decision system then monitors and analyses the real-time health data coming from each flying airplane, and sends timely decision-making information to them (or pilots).

(5)Through some algorithms and calculations with the data of PHM data center, the integrated vehicle health management maintenance system will give advance notice to the airport maintenance department what they need to do.

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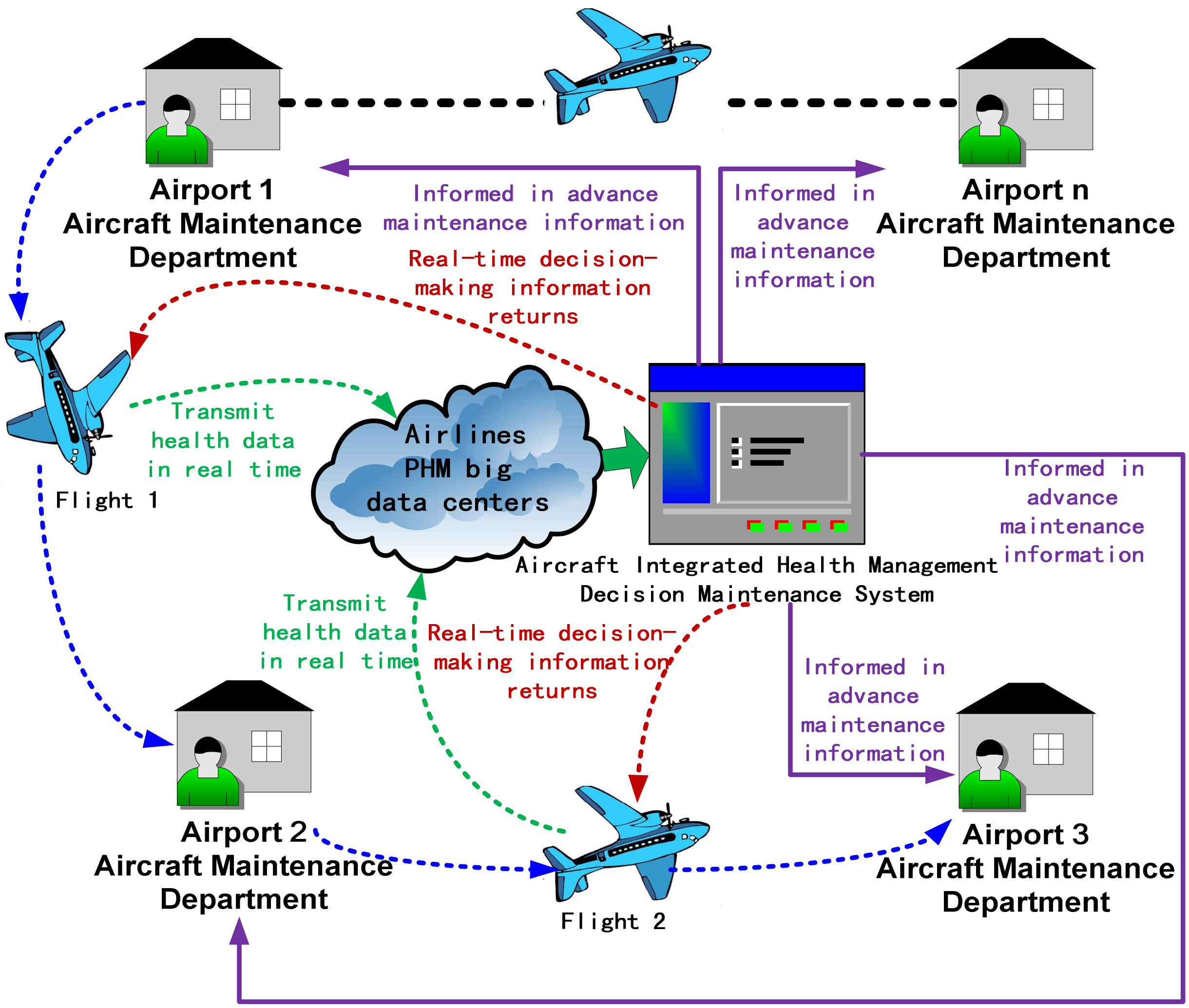

Figure 1. IVHM Framework for Aircraft

II. Related Work

Aviation(such as large aircraft, small aircraft, regional aircraft, cargo aircraft, drone, military aircraft, and civil aircraft,) plays a more important role in politics, economy, military, and other fields. Flight safety is becoming a critical issue in aviation. Most of the recent air crashes were led by different kinds of component faults, involving engine fault, navigation system fault, flight control system fault, and structural fault. Aviation companies, such as Boeing and Airbus, have diagnostic systems for flight safety. R&R, the famous aircraft component company, has diagnostic system for its aero engine. The diagnostic systems does improve flight safety. However, flight safety is a complex systems engineering that has a series of steps, including fault diagnostics, maintenance decision. The first step, fault diagnostics, can be done using modern models and algorithms. However, it is not satisfied with results of other steps without the help of big data analytics.

In recent ten years, many aviation companies and research institutions put large effort for the whole machine integrated health management technology. The most typical project is the Integrated Vehicle Health Management (IVHM) (2008-2012) of NASA. This project gave research goals with four aspects: system, task, component, and technique. Each goal had specific content, research focus, techniques, and prospection.

The research of health management theories[1-6] and essential algorithms for airborne system are getting more important because of the critical potential safety hazard of airplane and heavy loss of air crash. It needs real-time health monitoring for airborne system in order to identify critical faults leading to flight safety issues.

A large number of sensors are distributed in parts and sub-systems of an airplane, such as aero engine, power supply, breaking system. According to the data transmitted by the sensors, airborne system health management can monitor the health of airplane in real-time, evaluate situations, and then make decision for repair and maintenance.

Aerospace industry is facing large economics pressure. Airlines need to spend 31 billion US. dollars every year on maintenance of airplanes. Repair costs takes 10 to 20% of the total costs. Averagely, each one flight hour has 12 maintenance hours. In order to repair in time and reduce the operational costs, the health management system is supposed to make correct prognoses for the time and location of faults.

Airplane health management monitors subsystems of airplane in real-time. It analyzes data being collected by integrated sensors, extracts features, evaluates reliability and system status of airplane according to the features. Based on the evaluation, the airplane health management can correctly diagnose, isolate and predict the potential faults and aging parts. And then, it contacts with the ground system and ATC system for necessary repair work in order to guarantee that airplanes are available for flying assignments in the life-cycle.

Airplane health management is developed from Built In Test (BIT), and Vehicle Health Monitoring (VHM). With the development of monitoring techniques, the research focus of health surveillance theory has a transition from condition monitoring to health management [7]. It appears some new concepts, such as Prognosis and Health Management (PHM) [8,9], Integrated Vehicle Health Management (IVHM) [10,11], Integrated System Health Management, (ISHM) [12,13], Boeing Aircraft Health Management (AHM) [14], Health and Usage Monitoring System (HUMS) [13]. Moreover, based on the Condition Based Maintenance (CBM), the US Department of Defense proposed CBM plus (CBM+) that integrates CBM, reliability management, automatic maintenance and repair for overall planning and design of equipment health management , equipment status monitoring, maintenance decision, life prediction, logistics, and cost control.

Airplane health management involves intelligent detection, system-level evaluation, control and management. Based on the international standard OSA-CBM, Airplane health management system consists of 7 functional parts:

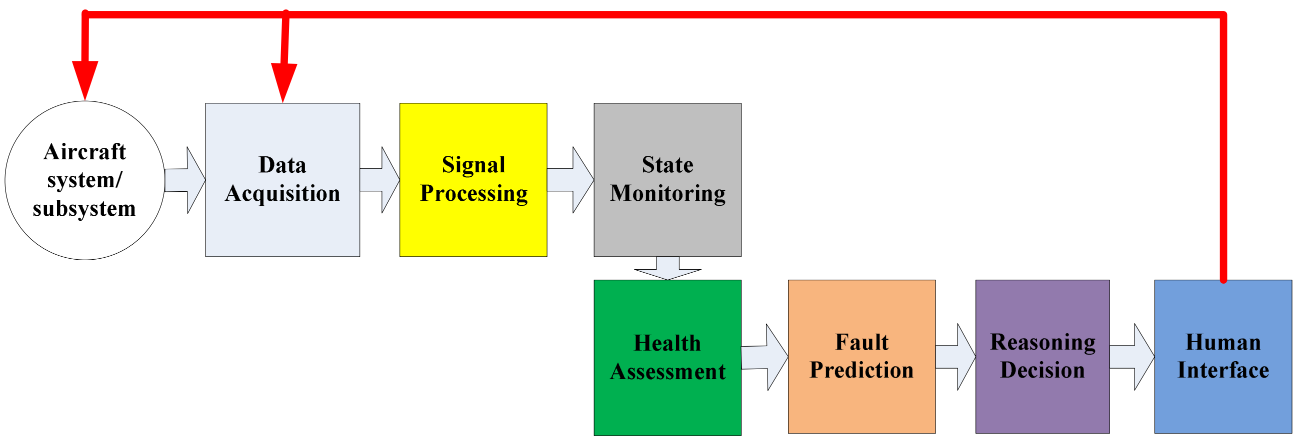

Figure 2. OSA-CBM structure for Airplane Health Management

Airbus developed AIRMAN (Aircraft Maintenance Analysis) by applying the concept of health management to real-time flight monitoring of airplane [15-20]. AIRMAN is the commercial software for airplane maintenance by negotiation of Airbus, airlines, and MRO (maintenance, repair and overhaul) venders. Since its introduction of in 1999, AIRMAN has been well accepted by aircraft operators. AIRMAN was developed by extending the early airborne maintenance system and is installed in airplanes of A320, A330, A340 and A380. AIRMAN is working on monitoring the flight status of airplane and send real-time data to maintenance department on ground. In this way, maintainers can identify faults before landing in order to reduce maintenance time as much as possible and guarantee punctual departure. People is able to visit AIRMAN everywhere by internet. AIRMAN provides portals for real-time maintenance data in centralized store and analytics data of airplanes or fleet. The portal can be easily integrated with the systems of airlines as valued knowledge for supporting the improvement of operational efficiency.

According to current research work, the development goals and trends can be summarized as follows: develop new signal processing techniques for high SNR monitoring method for emphasizing the status monitoring, performance evaluation, and fault prediction, meanwhile, reducing the false alarm rate; investigate the integration of intelligence data, inference techniques for accurately analyzing sensor data in order to improve the fault detection and prediction. To build precise fault models according to system status and environment; develop novel models for health evaluation and fault prediction for exactly describing trend of faults over time .

The airplane health management describes techniques above mentioned, such as fault diagnostics and fault prediction, in various aspects but system-level aspect. There is still a lack of an overall solution for airplane integrated health management.

This paper proposes a novel architecture of integrated health management for the issues of airplane health management, including safety, reliability, and cost.

III. AVIATION BIG DATA MANAGEMENT CLOUD PLATFORM

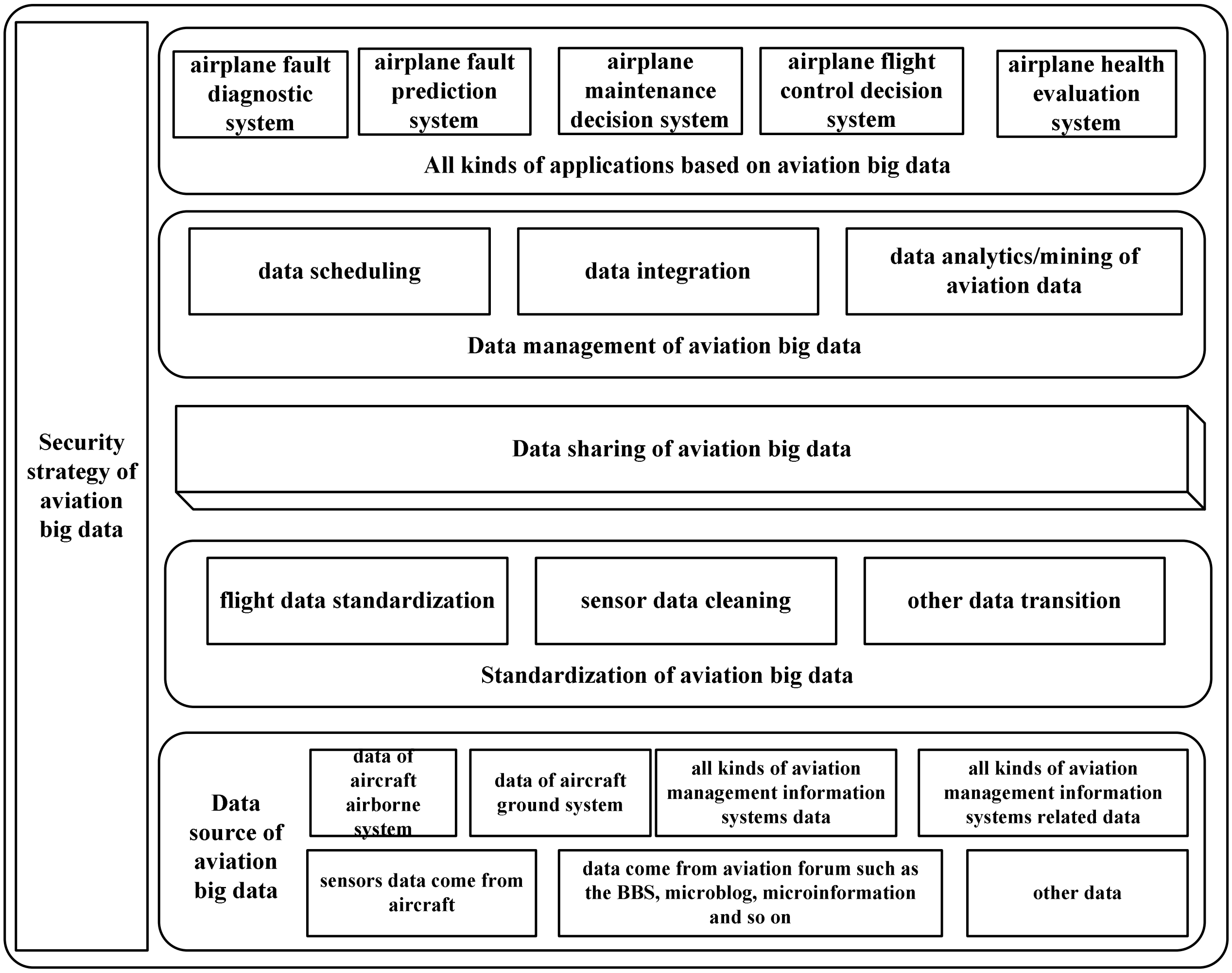

Figure 3. Aviation Big Data Management Cloud Platform

This platform includes the following seven parts. the data source of aviation big data, standardization of aviation big data, data sharing of aviation big data, data management of aviation big data, all kinds of applications based on aviation big data, the security strategy of aviation big data.

(1)Data source of aviation big data

It mainly includes: the data of aircraft airborne system; the data of aircraft ground system; all kinds of aviation management information systems data; all kinds of aviation management information systems related data; all kinds of sensors data come from aircraft; all kinds of data come from aviation forum such as the BBS, microblog, microinformation and so on; the other data.

(2)Standardization of aviation big data

All these aviation big data are heterogeneous. And so, we need to execute the work of aviation big data's standardization. And so, we need to execute the work of aviation big data's standardization in order to improve usability of the data. This layer focuses on: flight data standardization, sensor data cleaning, and other data transition. As a result, we get flight data of standard format and sensor data of standard format.

(3)Data sharing of aviation big data

This layer works on sharing the aviation data stored in centralizaed or distributed data center.

(4)Data management of aviation big data

This layer concerns data scheduling, data integration, and data analytics/mining of aviation data. The aviation data scheduling trandfers data to the corresponding data notes according to data access hotspot by using techniques like CDN in order to improve data access and query overall. The aviation data integration mehtod integtates the data coming from different data centers through a unified approach for samless data access.

(5)All kinds of applications based on aviation big data

It includes following subsystems: airplane fault diagnostic system, airplane fault prediction system, airplane maintenance decision system, airplane flight control decision system, and airplane health evaluation system.

(6)Security strategy of aviation big data

Aviation data stronly effects the flight safety. Security strategy is one of essential points, particularlly for the longterm store including no data change and no lost files. It needs a sophisticated cloud security strategy.

IV. Aviation Big Data Sharing Platform

There are two modes in aviation big data sharing platform. One is centralized mode that stores all aviation data in a data center and centrally manage the data sharing; another is distributed mode that stores data in data centers of different aviation institutions and separately manage the data sharing. Although centralized management has benefits of data integration and management, it may lead to critical security issues and privacy problems. The aviation institutions can hardly trustfully store their data, particularly the confidential data, in a data center they cannot fully control. By the distributed mode, aviation institutions store data in their own data centers. Although they can control security strategy, there exist big challenge for data integration. We introduce details of the both modes in next sections.

A. Centralized Aviation Big Data Sharing Platform

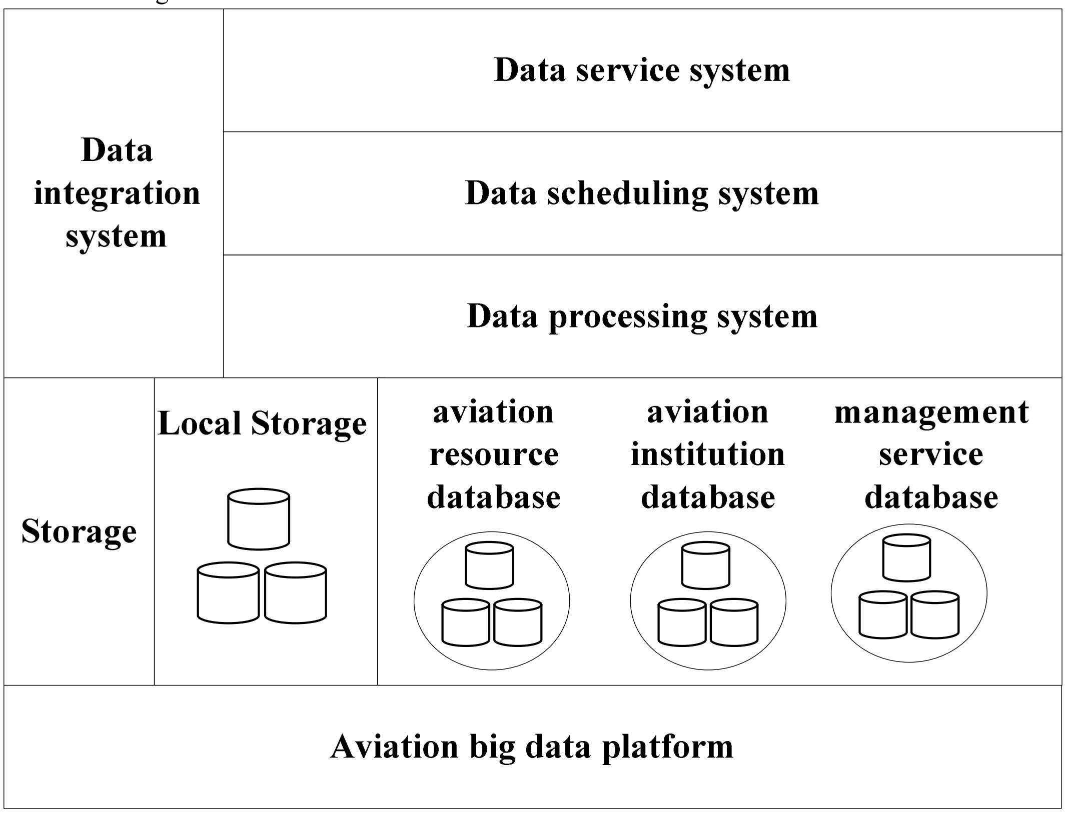

Figure 4. Centralized Aviation Big Data Sharing Platform

Figure 4 illustrates architecture of the Centralized Aviation Big Data Sharing Platform.

(1) Aviation big data platform. The platform depends on a cloud environment and manage the aviation big data overall.

(2) Storage: local storage, aviation resource database, aviation institution database, management service database.

(3) Data processing system. It processes data according to standards.

(4) Data scheduling system. It transfers aviation data between server racks as well as between storage nodes.

(5) Data service system. It provides services for data usage, e.g., data mining.

(6) Data integration system. It integrates and manages local data.

B. Distributed aviation big data sharing platform

The distributed aviation big data sharing platform is more complicated than the centralized mode. Figure 5 shows the concept of the platfoem consisting of following parts:

(1) Aviation big data center. It consists of aviation big data management platform and data center of headquarter. The aviation big data management platform works as a data management center, but the data center of headquarter is just like data centers of other aviation instations for sharing data.

(2) Various types of network (VPN/Internet/mobile network). The goal is to connect data centers by VPN, Internet, and mobile network in order to build an uniform aviation big data sharing platform.

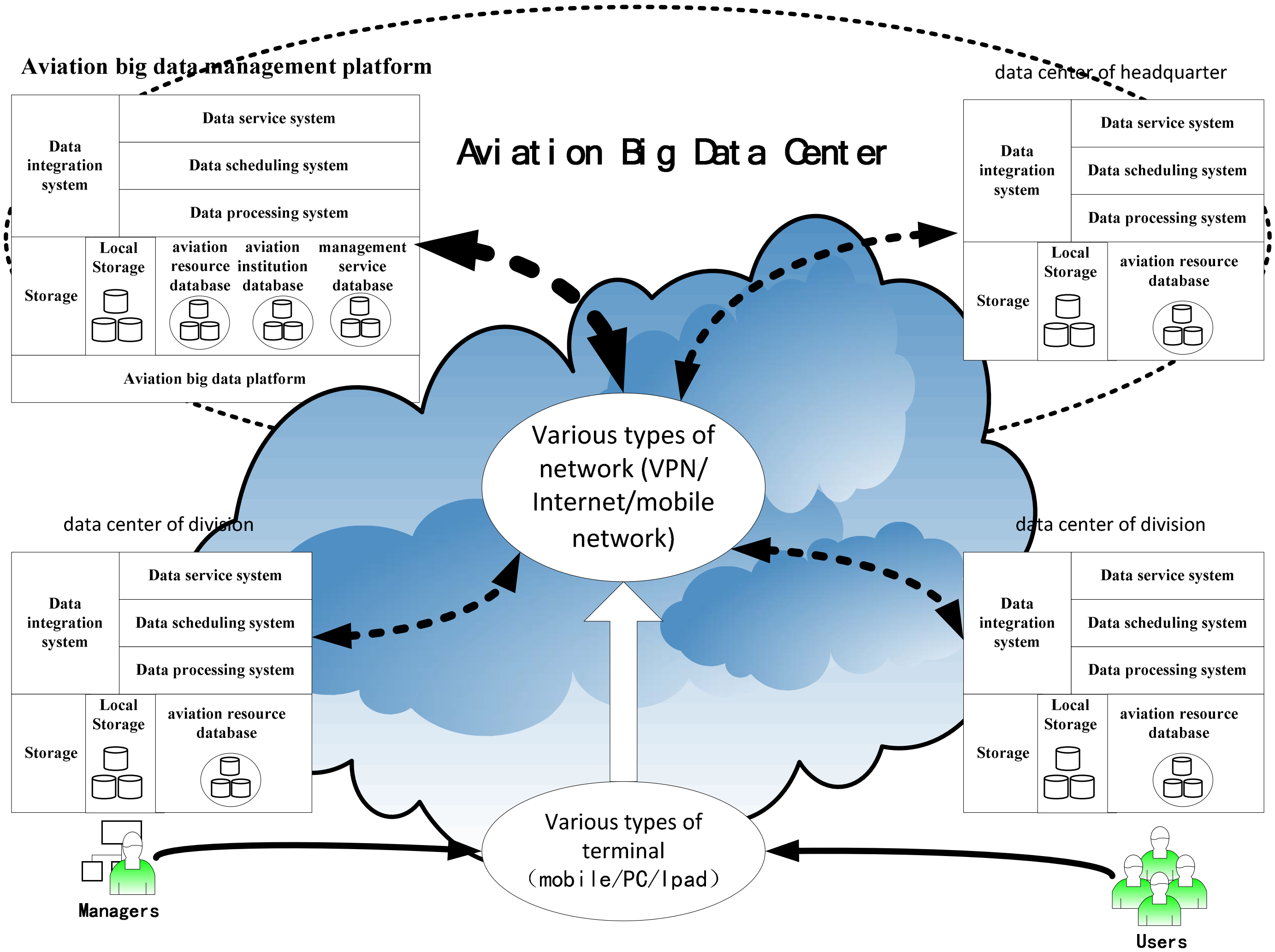

Figure 5. Distributed aviation big data sharing platform

V. INTEGRATION OF DISTRIBUTED AVIATION BIG DATA

Data integration of centralized aviation data is relative easy because all data are stored in one data center. It only needs to integrate data between server racks or between storage nodes. In contrast, the distributed aviation big data platform has more complicated integration approaches. It consists of the following parts:

(1) Users give basic requirements, such as how to find that the aircraft need to mantainance.

(2) Module of requirement evaluation and integration. It estimates resource for users' requirements and integrates services.

(3) Aviation big data directory. This is the point of distributed avaiation big data integration that manages all files of data centers. By index, users are able to find desired files stored in different data centers.

(4) Local cloud resource directory. It manages directory of cloud resouce in local data center. Users can find aviation resources stored in local data center.

(5) Resource scheduling. Once desired aviation data resources are located by index, it needs to transfer the resources. Due to a large number of users, there will be a large mount of data transitions. The resource scheduling can improve the efficiency of the data transitions.

(6) Standard specification of data service. Data services use the standard specification for better data service integrations.

(7) Standard specification of data processing. Data are processed according to standard specifications in order to standardize aviation big data and provide services.

VI. SECURITY STRATEGY OF AVIATION BIG DATA

The security mechanism extends the traditional KPI models in order to satisfy data integrity, number integrity, non-repudiation, and confidentiality of aviation big data. Figure 6 shows the security mechanism of aviation big data.

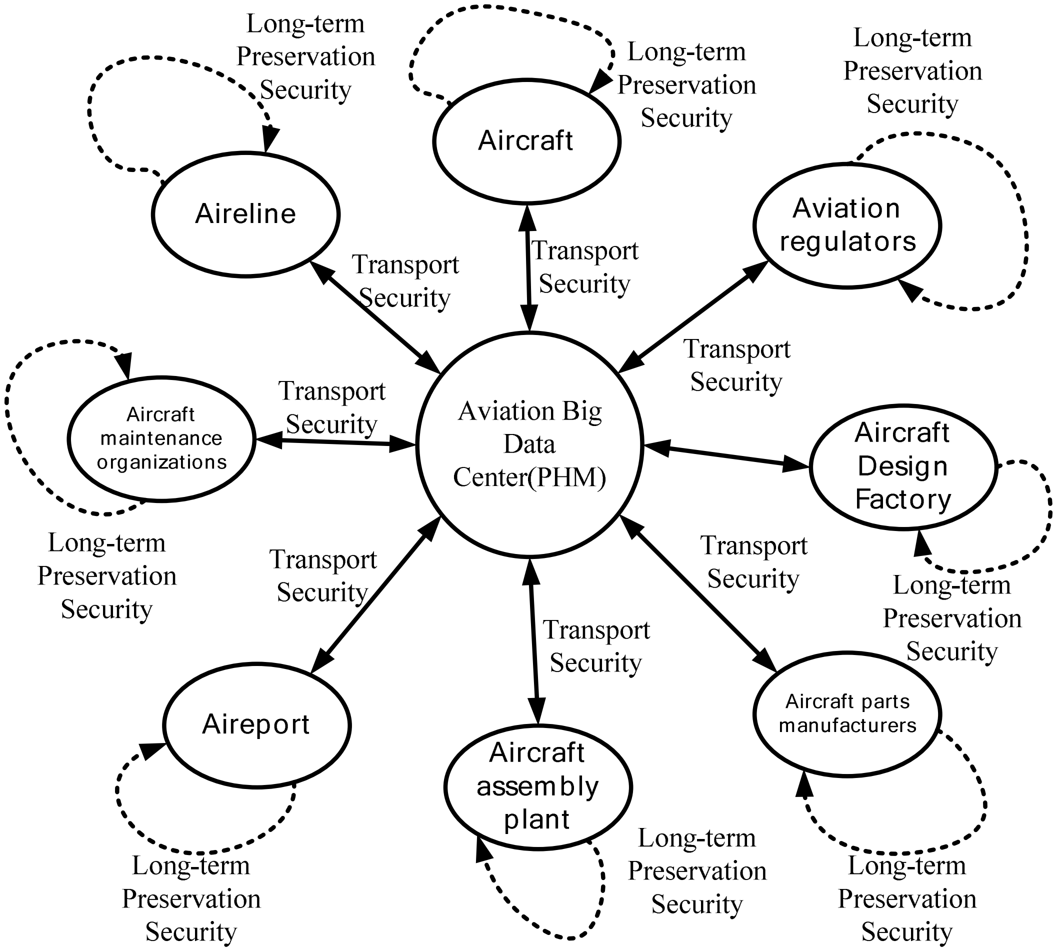

figure 6. Security Strategy of Aviation Big Data

VII. AVIATION BIG DATA ANALYTICS AND MINING

Aviation Big Data Analytics and Mining consists of following parts:

(1) Data pre-processing. It includes parallel data transformation, visual data transformation, data compression, serial data transformation, 2-D difference predictive method, data normalization, sample processing, data statistics (implemented by R language).

(2)Data mining algorithms. It includes: clustering algorithms, classification algorithms, regression algorithms, association algorithms, abnormally detection, decision tree method.

(3) Knowledge representation of aviation big data. It represents the knowledge of aviation data with the help of describing methods such as aviation domain experts and ontology.

(4) Various types of intelligence aviation data. It includes: logs, comments data, item base, user profiles, knowledge base, rule base. This layer needs to collect users' evaluation, commentsm, and behavior of users for later analytics.

(5) Data mining engine of aviation big data. It includes: policy manager, decision manager, study manager, and log service.

(6) Interface of aviation big data mining. It includes status manager, and application service. By the interface, the results of data mining of aviation data can be presented at the front-end.

VIII. APPLICATION BASED ON AVIATION BIG DATA

It includes the following typical applications:

(1) Airplane fault detection system. It diagnoses faults of airplane by fault detection algorithms with the help of aviation big data, such as fault diagnostics for aero engine, for environment control system, Hydraulic system.

(2) Airplane fault prediction system. Airplane fault prediction is a big challenge of airplane integrated health management. The prediction system forecasts the trend of faults according to historial aviation data for supporting to forecast the airplane faults.

(3) Airplane maintenance decision system. For airplanes, there are a set of complicated maintenance questions: when to

change parts, when and where to repair, where to purchase parts. Airplane maintenance decision system is build to help answer the questions. Using the decision system, status of airplanes and fleets can be controlled at any time for realizing Condition Based Maintenance.

(4)Airplane flight control decision system and health evaluation system. The flight control decision can be done by analyzing aviation data, particularly, historical flight data. It evaluates the integrated health of airplanes and obtain standard health status reports.

IX. APPLICATION BASED ON AVIATION BIG DATA

This paper proposes a novel airplane integrated health management framework considering the big data technology. The framework provides health management of airplanes and fleets running worldwide and supports to evaluate flight status in real-time. The framework provides an effective mechanism for real-time fault diagnostics, fault prediction, airpplane intelligent maintenance desicion system, as well as airplane health evaluation. In the future, the work is supposed to focus on the following areas:

(1) Implementation of fault prediction algorithms, including model based airplane fault prediction algorithm, data-based airplane prediction algorithsm, and knowledge-based fault prediction methods.

(2) Model of big data analytics center based on integrated global flight data， including data storage model, data sharing model, data integration model, data analytics model.

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