

Cloud Based Architecture Solution for Aircraft Flight Data Recorder

Abstract

This paper models cloud based architecture solution for aircraft Flight Data Recorder (FDR). FDR is an on board equipment in the aircraft, it records many different operating conditions of the flight. With the data retrieved from FDR, a computer animated video reconstruction of the flight can be generated, the aircraft accident investigators can then visualize the last moments of flight before the accident. There may be instances when it may be difficult to retrieve FDR from the scene of an accident, or even, if retrieved, the data could not be retrieved because FDR might have been burnt beyond allowable temperature. As a result of this, there is a need for alternative source of data. The cloud computing concept could be extended to the aircraft system data network environment with every aircraft subscribing to the cloud resources to run their mission-critical applications. This paper models cloud based architecture solution for aircraft FDR by implementing private cloud computing. Unlike the existing Cloud Computing Platform of Aviation Industry (CCPAI) framework which provides a mechanism to monitoring aircraft management only, the proposed model in this paper will provide alternative data for aircraft accident investigators to work with in case of any aircraft mishap. Reliability of internet connection and availability of large bandwidth to support real time flight data transmission are envisaged as potential limitation of the proposed model

Keyword : Flight Data Recorder (FDR), cloud computing, mission-critical, CCPAI.

1. Introduction

The purpose of carrying out accidents or incidents investigation is not to apportion blame or liability but to give safety recommendations or airworthiness directives in order to improve safety in aviation and prevent future reoccurrence[1]. Capturing evidence at an accident site is an important task for the aircraft accident investigators in order to answer the major pertinent questions like what happened and why this accident happened. One of the major evidence that accident investigators always try to retrieve from the scene of any accident is Flight Data Recorder (FDR). FDR on board aircraft records many different operating conditions of the flight. Standards and Recommended Practices for aircraft accident inquiries are available in Annex 13 [2].

Flight Data Recorder (FDR), (popularly called black box, but not black in actual sense, it is orange in colour) on board aircraft records more than 1,000 in-flight characteristics that can aid in the accident investigation. After the retrieval of FDR, it is taken to decoding laboratory for decoding and analyses. With the data retrieved from FDR, a computer animated video reconstruction of the flight can be generated. The investigators can then visualize the last moments of flight before the accident [3]. But there are challenges facing the existing FDR. There are instances while it will be difficult to retrieve FDR from the scene of an accident, or if retrieved, data could not be retrieved because FDR has burnt beyond allowable temperature.

For example, Malaysia Airlines Flight 370 (MH370/MAS370) disappeared on 8 March 2014 [4], there has been no confirmation of any flight debris [5] and no crash site has been found talk less of retrieving FDR [6]. Even for some political reason or otherwise, result of FDR analysis may be tampered with because there is no alternative data to prove otherwise.

This paper presents cloud based architecture solution model for aircraft FDR using private cloud computing to serve as backup in order to provide alternative data for aircraft accident investigators in case of any accident. Reliability of internet connection and availability of large bandwidth to support real time flight data transmission are envisaged as potential limitation of the proposed model.

The rest of the paper is organized as follows; section 2.1 focuses on Flight Data Recorder, section 2.2 is on the challenges facing Flight Data Recorder, sections 2.3, 2.4, 2.5 and 2.6 focus on cloud computing, deployment of clouds, strengths of cloud computing and Cloud enterprise frameworks respectively. Section 3.1 focuses on the System Design while section 4.1 is on discussion. Related work and Future work are in sections 5.1 and 6.1 respectively. Section 7.1 concludes the work.

2.1 Flight Data Recorder

The aircraft accident investigators retrieve FDR from the scene of the accident wreckage; it is then taken to decoding laboratory for decoding, animation video reconstruction and analyses. Based on the data retrieved from FDR, a computer animated video reconstruction of the flight can be generated using several techniques. The first technique used when the first generation of FDR was introduced was data listings and plots which was used to examining the data particularly with a plot, then, mutual compatibility between parameters can be checked, for example, if the value of magnetic heading increases then the roll attitude parameter should show a bank to the right. The major limitation of this tool was that only a small number of parameters were being recorded, for instance, rate of climb and descent could not be obtained. Another technique used was total energy graph [7]. This was capable of producing a graph of total energy, that is, potential energy and kinetic energy versus time, which made it possible to estimate changes in aircraft configuration or engine thrust. Limitation was in the plots, only a small number of parameters were being recorded. Mini Computer Graphic Flight Recorder Analysis was another technique. The first flight recorder readout system for commercial aircraft in Australia was acquired in 1972 by the Air Safety Investigation Branch. It was called FRAN (Flight Recorder Analysis) system and consisted of a DEC PDP 11/0529 mini-computer. It was upgraded to use two graphics minicomputers; PDP 11/45 and PDP 11/73. To obtain the necessary performance, Hewlett-Packard Unix workstations were used. Though the tool was reliable but it was expensive.

In 1992, the software called 'Insight' Computer Graphic was developed by Flightscape Inc. and was converted to be used on PC. In 2005, Insight was adopted and flight recorder specialists operate the complete system on their laptops effectively giving them a portable flight recorder laboratory. Flight data decoding system OAZ is one of the decoding software, it operates in the WINDOWS environment on computer [8]. Nowadays, laptops run Insight animation and simulation for visualization purpose (fig.1).



Fig. 1: Laptop running Insight Animation

With animation, it is possible to place sequence of events into time perspective, link recorded data with ground features and correlate FDR data with other sources of data like radar data or eyewitnesses.

In practice, only the aircraft manufacturer will have access to the mathematical models required for simulations and accident investigation authorities would work cooperatively with the manufacturer to obtain the simulation. The major limitation for this latest tool is the conversion equations of thousands of parameters, development and validation of results before visualization in 3D of the actual output.

2.2 Challenges facing Flight Data Recorder

In case any aircraft accident occurred, the aircraft accident investigators rely heavily on the data retrieved from FDR to generate computer animated video reconstruction of the flight. But there are challenges facing the FDR that need be managed in order to improve its efficiency in the context of flight safety. One of the challenges is that it might be difficult to retrieve FDR, this is possible because the wreckage of the aircraft may not be seen or the aircraft is burnt completely without any wreckage left. Even if FDR is retrieved, it might have been damaged or burnt beyond allowable temperature, so retrieving valid data from it becomes impossible. Another challenge is political interference, the result of FDR analysis may be tampered with and there is no evidence to prove otherwise because there is no alternative data.

These challenges can be managed by combination of new technologies with existing ones and implementation of cloud based architecture solution for FDR.

2.3 Cloud Computing

The term 'cloud' has its origins in network diagrams that represent internet or various parts of it, as schematic clouds. Cloud computing was coined for what happens when applications and services are moved into the internet 'cloud'. It refers to the many different types of services and applications being delivered in the internet cloud. Gartner in [9] defines cloud computing as a style of computing where massively scalable IT-enabled capabilities are delivered 'as a service' to external customers using internet technologies. According to NIST (National Institute of Standards and Technology), cloud computing is on-demand access to a shared pool of computing resources [10]. It is an all-inclusive solution in which all computing resources (hardware, software, networking, storage, and soon) are provided rapidly to users as demand dictates [11]. It promises to revolutionize information technology (IT) and commerce by making computing available, in a fashion very similar to other utilities such as gas and electricity over the internet.

The major characteristics of cloud computing includes:

Shared infrastructure—It uses a virtualized software model, enabling the sharing of physical services, storage, and networking capabilities.

Dynamic provisioning—It allows for the provision of services based on current demand requirements. This is done automatically using software automation, enabling the expansion and contraction of service capability as needed.

Network Access—It needs to be accessed across the internet from a broad range of devices such as PCs, laptops, and mobile devices, using standard-based application programming interfaces (APIs).

Managed Metering—It uses metering for managing and optimizing the services and to provide reporting and billing information.

2.4 Deployment of clouds

The deployment of clouds can be divided into three core components [12]. These refer to three types of services as follows:

(i) **Private cloud** - As the name implies, a cloud used by a single company. This cloud is either entirely hosted or operated by the company itself or can be located at a co-hosting facility. Reasons for considering and choosing this approach for a cloud is the control and security of the platform itself (as viewed by the company or a hired operator).

(ii) **Public cloud** - Public cloud is deployed on a shared infrastructure. The cloud thus shares resources and hardware with different customers. These resources may be located in the same data center and may be operated by a third party. Here the security aspects of using a cloud become more apparent as multiple entities are sharing a common infrastructure. Securing the services provided in such a way as to limit the threat of information leakage should be considered as a priority.

(iii) **Hybrid cloud** - This is a mix of both a private and public cloud. A company can run its own cloud on its own hardware in-house, while utilizing as necessary resources such as computing power and storage resources in a public cloud operated by a third party [13].

Cloud computing incorporates infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). Although, these are generally accepted groups of generic services, however, a number of other specialized services have also been suggested, some of which are implemented in this paper, these include; Storage as a Service, Database as a Service, Security

as a Service, Communication as a Service, Management as a Service, Integration as a Service, Testing as a Service, **Business Process** as a Service [14].

2.5 Strengths of cloud computing

Many companies are now delivering services from the cloud. Some notable examples are Google, Yahoo, Facebook, Hotmail, Microsoft **etc.** Cloud-based computing allows Internet-based resources, software, data and services to be provisioned on **demand using** a utility pricing model. The solutions provided are **architected for** scalability, because a cloud-based architecture can **provide the** ability to trade computation time against costs. Cloud is readily applicable to applications that require **frequent bursts** of computational activity. Nowadays many **individuals and** businesses use cloud-based services for email, web searching, photo sharing and social networking. **Scientists and** engineers use a similar paradigm to make use of **massive** amounts of computer and data handling **resources provided** by companies such as Amazon, Microsoft **and Google** [15].

2.6 Cloud enterprise frameworks

There are many enterprise frameworks, which share the same objectives but vary in focus, scope and intent. Each business sector (e.g. manufacturing, service and financial) operates differently **and has** its own objectives and goals. These frameworks or *architecture models* include:

- i. Zachman's Framework [16] - This is a widely used approach for **developing enterprise-wide** IS architectures and is considered as a reference model **against which** other frameworks can map themselves [17].
- ii. RM-ODP - This uses a well-understood object-modelling technique (OMT) and is developed by highly reputable agencies such as ISO **and International** Telecommunications **Unit** [18].
- iii. TOGAF - This is an industry standard generic framework and is **freely available** [19].
- iv. C4ISR /DODAF- These are frameworks developed mainly for the **use of** US Department of Defense [20] and [21].

The comparison and review of the best and efficient model are available in [22], [23], [24] and [25].

3.1 Systems Design

The cloud computing concept could be extended to the aircraft system data **network environment** with every aircraft subscribing to the cloud resources to run their **mission critical** or non-mission-critical applications. The proposed Cloud based architecture solution for Flight Data Recorder model answered the following strategic questions adapted from [26] that are required to be addressed before any airline **embark on** integration of FDR with the cloud computing. The questions are as follow:

- i. **Can the vendor facilities support aircraft FDR system specifications?**
- ii. Which Database Management Systems (DBMS) are required? Is there a vendor-maintained "image" that supports the DBMS?
- iii. **How much memory and processing power is required?**
- iv. Does the vendor provide sufficiently powerful machines, and is there room to grow?
- v. What is the choice of the service, private, public, or hybrid cloud?
- What impels the decision?
- vi. Do the aircraft management tools available support management in the cloud? Are there upgrades available?
- vii. Do management satisfied with the vendor's documentation of its compliance with SAS 70 and ISO 27001?
- viii. Does ICAO (International Civil Aviation Organisation) certify the vendor specifications?

In other to address the challenges facing the existing FDR mentioned in section 2.2, such as inability to retrieve the black box from the wreckage of the accident or difficulty to retrieve the data from FDR, maybe because it has burnt beyond allowable temperature, this paper presents cloud based architecture model for FDR to serve as a reference or backup to FDR to improve efficiency of the FDR analysis. This will enable the accident investigators to compare the result of decoded and **analyzed data** from the FDR, if **retrieved with** the one from cloud database, for video reconstruction of the aircraft before the accident.

In this paper, private cloud computing adapted from [27] and [28] **is modified** and implemented (fig 2) using private **Google** cloud storage architecture.

Every new modern airplane is expected to have IP address for communication over the internet via the Communication as a Service at the cloud end. Management as a Service monitors the data storage in the database and ensures integrity, availability and adequate retrieval whenever need

232 arises. The management as a Service includes extraction of enforceable rules, use of **sticky** policies,
 233 automated policy enforcement and active monitoring of data as employed in[29]. Because of the
 234 sensitivity nature of the flight data, Security as a Service ensures adequate security for the data; it
 235 ensures the protection of the data and allows only authorised users with right privilege to access the
 236 database.
 237

238 In this model, the model FDR includes interface with vendor/provider (Google Cloud) automating
 239 service providers' who is in compliance with data protection laws and regulations and technical
 240 requirements in cloud computing. A unified directory and other components of security architecture
 241 such as automated provisioning, incident detection and response are employed for security purposes.

242 **Aircraft transmission:** In the model, aircraft transmits different  ating conditions of the flight to
 243 FDR on board the aircraft and dedicated private Google cloud architecture.

244
 245 **Client Device:** Authorized clients are granted permission to access the system whenever there is a
 246 need to retrieve stored data about a particular aircraft using Flight Data Retrieval services.

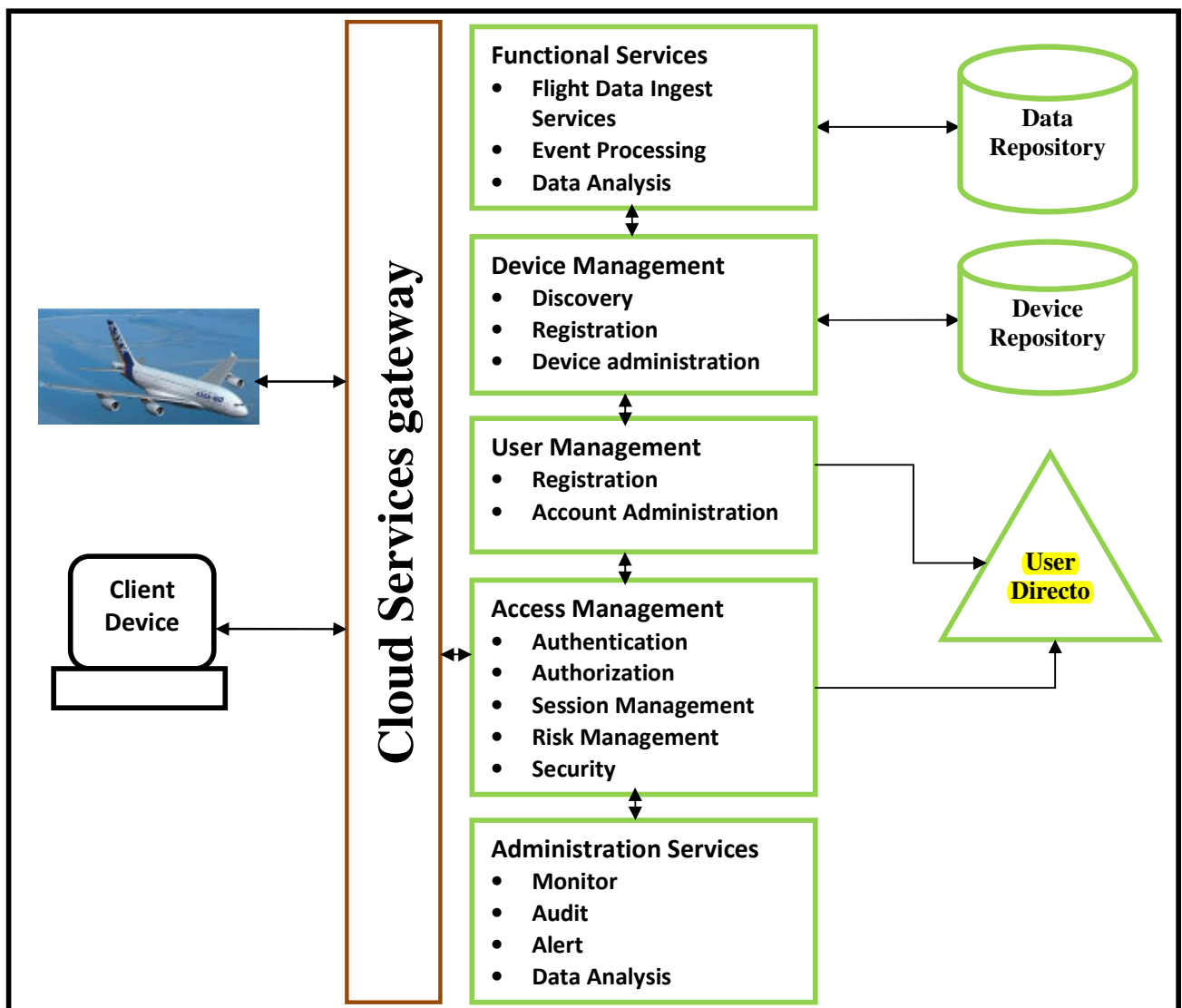


Fig. 2 Cloud based architecture solution model for Aircraft Flight Data Recorder

Functional Services: In this unit, major services of our proposed Cloud based architecture solution for FDR are carried out. It includes Flight Data Ingest Services, where data are collected and stored on Data Repository, processed and analyzed. It includes specific Flight Data Retrieval services use by clients. As mentioned in section 2.2, one of the challenges is that it might be difficult to retrieve FDR, because the wreckage of the aircraft may not be seen or the aircraft is burnt completely. In the case of Malaysia Airlines Flight 370 which disappeared as mentioned in section 1, although Inmarsat used SATCOM to analyze the time difference between the transmission of the ping and the aircraft's response in order to determine the aircraft's distance from the satellite which resulted in the plotting of two arcs referred to as the "northern corridor" and "southern corridor" where the aircraft might have been located at the time of its last complete handshake at 00:11 UTC[30], still no crash site has been found. With our proposed model, even if the FDR could not be retrieved, exact content of FDR can be retrieved from the cloud. With the data retrieved from the cloud, a computer animated video reconstruction of the last flight can be generated, the aircraft accident investigators can then visualize the last moments of flight before it disappeared.

Device Management: Authorization to connect to the cloud, secure access rules enforcement, registration and management of changes to the network are maintained in device management. All these are stored on Device Repository and managed from the project dashboard (fig 3).

User Management: Account administration which includes granting of appropriate permission rights and registration using user directory are handled in this unit (fig3).

Access Management: Flight data record is very vital; access management enforces security policy for application access by authorized users and the APIs that can be used on the architecture to accessing the functionality of the system.

Administration Services: The services render here have to do with monitoring the health status of the system components, provision of auditing and reporting of functions.

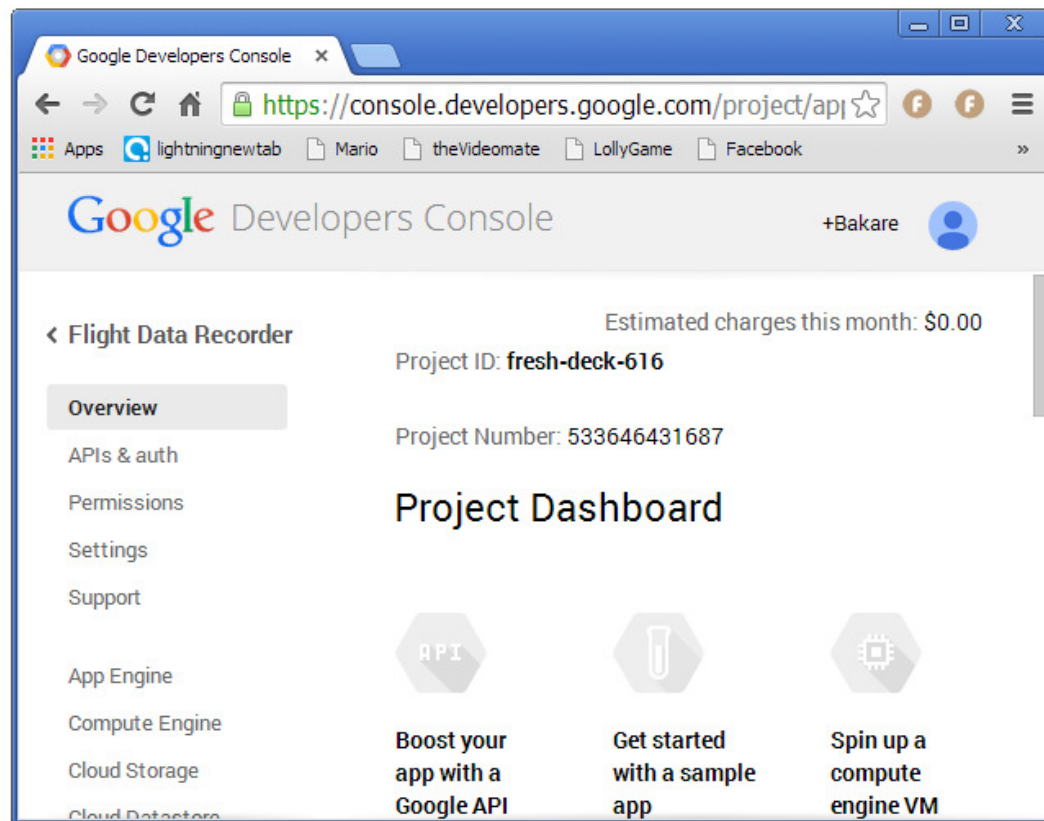


Fig. 3: Private Google Cloud Architecture dashboard for FDR

Cloud offerings are inherently global, highly available and large bandwidth capabilities are ensured for data aggregation and dissemination, dataset resides in a globally accessible cloud resources, this makes it to become a valuable resources for aircraft manufacturer and airlines.

There is tendency that many aircraft may fly at the same time; infrastructure of the cloud should cope with predictable demand and unpredictable demand.

4.1 Discussion

The proposed model offer many benefits compare to traditional ways of keeping flight data only on FDR on board aircraft. Cloud offerings are inherently global, highly available and have large bandwidth capabilities, making them ideal for data aggregation and transmission via the internet. Most countries don't have laboratory to analyse data from retrieved FDR, it is of recent that Aircraft Accident Investigation Bureau (AAIB) in Nigeria acquired the equipment for FDR laboratory analysis, this makes Nigeria to be the only country in West Africa that has that facility, most of the time other countries used to take the retrieved FDR to overseas countries for analysis. Along the line, the result may be tampered with to serve some people interest. But using a cloud-based architecture solution, sharing can be as simple as changing access within the parties that have access to the data.

Many air born aircraft belong to the same airline or manufacturer can transmit data at the same time thereby challenging burst capability, cloud computing offers near-instant scalability which is quicker

and reliable than purchasing many FDR on board the aircraft allowing cloud application to scale beyond what is easily achievable. When the crowded sky or workload declines, cloud computing permits the scaling back of resources.

When accident occurred, FDR might not be retrieved, in some instance, it may be retrieved but damaged or burnt beyond allowable temperature. At times, for political reason result of FDR analysis may be tampered with and there is no alternative data to proof otherwise. Cloud-based architecture solution model for FDR encourages a modular design which allows output data to be easily compared. With this model, aircraft manufacturers or airline may not necessary wait for disaster to occur or disaster recovery plans, because for every flight, they have flight data performance of the aircraft independent of on board equipment which will enable them to take preventive or proactive action to resolve problem to avert disaster.

5.1 Related Work

Notable IT firms like IBM and Google have created the new computing paradigm, cloud computing that will allow big companies to open doors to Web 3.0 which refers an important and long term trend-computing over the internet. The integration of cloud computing into aircraft design was modeled in [31]. Their framework, Cloud Computing Platform of Aviation Industry (CCPAI) efficiently provides a mechanism of monitoring management and security unlike the proposed model which will serve as an alternative to on board FDR. Jastiet., *al.*, [32] explored the possibility of using cloud services for aircraft data networks. The authors evaluated the performance issues involved with the aircraft mobility and dynamic resource transfer between servers when the aircraft's point-of-attachment changes. The authors predicted that using cloud computing concepts would encourage many carriers to offer new services within the aircraft.

T-systems provides flexible and variable provisioning of IT resources through the cloud computing solution "Dynamic Services for SAP (Systems, Applications and Products) Solutions" for Jet Aviation. Some of the SAP applications include; SAP FI (Financial Accounting), SAP PM (Plant Maintenance), SAP SD (Sales and Distribution), SAP PP (Production Planning), SAP HR (Human Resources) and the industry-specific SAP iMRO solution for inspection, maintenance and repair. The cloud data center at the Langenthal location utilizes virtualization-based pooling effects and is connected to all of Jet Aviation's international locations [33]. Allegiant Travel Company has licensed the AirVaultMx Records Management Solution on January 21, 2014 to provide it with a new web-based aircraft mission critical maintenance record system [34].

6.1 Future work

Possible future work includes real time analysis of cloud based FDR using Full-System Multiprocessor Deterministic Replay for flight recorder.

7.1 Conclusion

This paper presents cloud based architecture solution for aircraft Flight Data Recorder (FDR) by implementing Google private cloud computing to serve as a backup or alternative data when FDR on board the aircraft could not be retrieved, retrieved but damage or burnt beyond allowable temperature.

Integrated cloud-based FDR architectures encourage a modular design which allows output data to be easily compared. With this model, aircraft manufacturers or airlines may not necessary wait for disaster to occur or disaster recovery plans, because for every flight, they can retrieve flight data performance of the aircraft from cloud database, independent of an on board equipment which will enable them to take preventive or proactive action to resolve problems in order to avert disaster.

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