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ABSTRACT

Earhart is a blockchain powered solution that transforms how the trustworthiness and traceability of aeronautical records is stored and used. The Earhart Blockchain Solution provides features that helps the aviation ecosystem in the accomplishment and implementation of all the regulatory and compliance framework. This solution allows multiple immutable digital twins and an innovative concept of on-chain transactions that allows instant data sharing, monetization and acquisition.

DISCLAIMER

- This whitepaper describes an ongoing project.
- This whitepaper is not a financial advice.
- This whitepaper describes a validated but not yet regulated process.
- This whitepaper describes the Earhart team goals and not the aviation regulators and/or authority's objectives or future policies.
- Earhart does not modify, change or adapt the aviation ecosystem data. The data content is full responsibility of the stakeholders.

OVERVIEW

Civil aeronautical industry is one of the most regulated sectors worldwide. Every single aspect of the aircraft and who performs actions on it is regulated. The accomplishment of these regulation relies in a very strict register of individuals, aircraft and companies logs and records.

When every point of the regulations is fulfilled, it is said that the aircraft is airworthy. When some point of the regulations is not accomplished it is said that the aircraft is not airworthy, grounded or most common said AOG. When this happens, or the requirement is fulfilled, or a special authorization given by the authority is granted to permit flight. The continuing monitoring of the airworthiness of every aircraft is very hard and time consuming, and frequently involves a lot of resources, mainly human, which leads to one new field of study of Human Factors or Managing Human Errors [1]. The processes automation here proposed will unleash humans from records management and will enhance safety through record keeping and control. It will also help in the liquidity of all aeronautical players releasing resources.

One key point of the regulations is the record keeping. Nowadays, the record keeping is done in centralized ledgers without the ability to communicate with other systems. Aviation regulators require that record keeping is performed in order to keep the traceability and accountability of every action taken in the industry[1,2]. Since the ledgers don't communicate with each other's, this type of work is made essentially by manpower which give origins of many errors. Besides the time of reassessment of the information is much higher, these errors can put at stake the aircraft safety and impact the economic resources of the industry. The technology used for the centralized ledgers, mainly paper and non-standard software's, can give origin to data lost, wrong data, corrupted, deterioration, or even changed or adulterated. On rare occasions, falsification of licenses is a problem [7,8,9,10,12]. This data management costs to all aviation industry many millions of USD annually.

One specific example is when an aircraft changes owner or operator, often called phase-in, a very hard, stressful, and timekeeping process is performed. A lot of resources are deployed to verify the conformity of every single aircraft record. Since aircraft owners or operators use different ways to control the airworthiness, these processes are not lean to perform and usually take months. Reconstructing the aircraft history is very expensive and time-consuming process, and often requires huge expensive human resources, materials, and aircraft ground time. This is a multimillion-dollar worldwide industry in which considerable savings can be made through a more

[1] EASA Requirements: M.A.305, AMC M.A.305(e), M.A.306, M.A.503, M.A.801, M.A.901, CAMO.A.220, CAMO.A.315, CAMO.A.325, 145.A.55, 21.A.55.

[2] FAA Requirements: CFR Part 11, CFR Part 26, CFR 21.2, CFR 21.137, CFR 21.142, CFR 21.2, CFR Part 25, CFR 43.2, CFR 43.9, CFR 43.11, CFR 43.17, CFR 91.417, CFR 91.419, CFR 91.421, CFR 91.1027, CFR 91.1113, CFR 91.1427, CFR 91.1439, CFR 91.1441, CFR 91.1443, CFR 145.12, CFR 91.161, CFR 91.219, CFR Part 249.

efficient record keeping processes and interconnecting the individual ledgers. This will highly improve the flow of information, traceability, and accountability in all aviation practises.

When all requirements are fulfilled, it is said that exists a Proof of Airworthiness.

ACRONYMS

AI – Artificial Intelligence

AOG – Aircraft on Ground

APU – Auxiliary Power Unit

CAMO – Continuing Airworthiness Management Organization

CFR – Code of Federal Regulations

DOA – Design Organization Approval

EASA – European Aviation Safety Agency

ERP – Enterprise Resource Planning

GSE – Ground Support Equipment

FAA – Federal Aviation Administration

IATA – International Air Transport Association

ICAO – International Civil Aviation Organization

LH – Left Hand

MH – Man-Hours

NFT – Non-Fungible Token

OEM – Original Equipment Manufacturer

SKU – Stock Keeping Units

UI – User Interface

UTC – Universal Time Coordinated

DEFINITIONS

Accountability – The responsibility of every individual and/or organization. By regulations, in the aviation industry every action must have an accountable.

Airworthiness – A generic term implied to define the suitability for a safe flight. The aircraft airworthiness is related to the interaction of many individuals, organizations, OEM's, installed parts and aircraft condition. There is the initial airworthiness which is related to the aircraft design and manufacture. There are then the additional airworthiness specifications and the continuing airworthiness, which is related to the aircraft status and operation. To achieve the airworthy status, an aircraft must fulfil all the requirements given by the OEM's, CAMO's, Authorities and Regulators.

Airworthiness Instructions – An instruction given in order to the aircraft maintain its airworthy status. These instructions can be issued by Authorities, Regulators, OEM's, CAMO's, DOA or Maintenance Service Centres.

Airworthiness Requirement – All the requirements that an individual, organization or aircraft must fulfil. The requirements are given by Authorities, Regulators, OEM's or CAMO's.

AOG – This term can be used in many frameworks. Here, it means that the aircraft is not able to fly due to not accomplishing at least one airworthiness requirement, or that the aircraft is not airworthy.

Authority – It is a State institution whose mission is to supervise the air industry. The scope of work of each authority is not the same in all States, it depends on the autonomy given by the regulators, which in some situations are the same entities. Their scope of work varies with the license's approvals, maintenance planning supervisions and approval, auditing, and general supervision for the regulation's accomplishment. It can also in some cases issue regulations.

Calendar Time – It is the projection of time into a specific unit, such as hours, days, months, etc. This time counting method is usually between installation and removal, or between a finding and its correction. It has no relation with operation time.

CAMO – An organization which is responsible for supervising the aircraft airworthiness. It can employ several dozens of persons to monitor and maintain all the data that are issued and generated by its operation. It's also under their responsibility to monitor the aircraft configuration, reliability and maintenance.

Certifications – Are all individuals, aircraft, organizations, parts, etc. must acquire to be fitted to work, fly, or be installed in an aircraft. There are many types of certifications and entities who issued them. Some are not valid from entity to other entity. Mainly, all certifications are paper issued.

CFR – The FAA code for every regulation.

Flight Cycles – Is a take-off and landing. Example, a take-off and landing are 1 (one) flight cycle. It is a used to measure life of aircraft and components.

Flight Hours – For every calendar hour that aircraft spends flying it counts 1 (one) flight hour. If the aircraft is not flying, i.e., on the ground, this counting is stopped It is a used to measure life of aircraft and components.

Man Hours – The number of working hours carried out by individuals.

Module – Is the term used to divide every main role of each organization in their scope of work.

OEM – Is the organization that holds the patent for any specific product or part. Some may delegate to third parties the manufacture or assembling, but they are accountable for every designed product.

Operation Time – The time that a certain equipment or part is operating. It is a measure used to acquire parts life in service.

Part number – Is an alphanumeric code which identifies a certain part in the aircraft. There cannot be two identical part numbers that correspond to two different components. The part numbers are given by the OEM's and standard organizations. In most cases the part number can reflect their configuration.

Parts – It is a generic term used to define something that is installed in the aircraft.

Regulations – Are all the rules and requirements issued by the regulators and authorities that must be accomplished to be in an airworthy condition.

Regulator – Are the organizations which create all regulations and/or the airworthiness instructions. Their role is to keep the pace of the evolution and constantly updating their requirements for a safe air travel. The scope of their instructions are individuals, aircraft, aircraft products and services, organizations, and authorities. Their instructions are then accomplished by the applicable ones which are monitored by the authorities.

Serial number – It is generally a unique sequential numerical code that traces the identity of a specific and unique part within all its universe.

Service – Is a term used to tell a type of maintenance work accomplished in an aircraft. It can be inspections, repairs, replacements, lubrications, servicing, etc. These services can be accomplished initially by the OEM or during aircraft operation by the service centres/maintenance providers. The instructions that lead to the services are usually given by the CAMOs, but can also be given by the Service Centres, Authorities, OEM's, or Regulators.

Service Centres – Are all the maintenance providers. To be an approved maintenance provided, it must be accomplished all the applicable regulations. A Service Centre can only work on its scope of work, i.e., only on the aircraft's models, parts, engines models, type of work that are certified too.

Traceability – It is the process to trace every installed part or every action taken in the aircraft or process related to an action approval and accomplishment.

Type Ratings – It is usually the specific model of an aircraft, engine, part or specific service or a combination of those. The type ratings are commonly attributed to pilots, engineers, or service centres. Only who holds a specific type rating can carry out actions on the product.

OBJECTIVES

Earhart Solution knows how difficult is to change an ERP in the aviation ecosystem. To avoid human and economic resources inefficiencies, Earhart do not aim to replace the current existing ERP's, but to develop a solution to work connected on in parallel with the industry ERP's.

Having this in mind, Earhart Solution is building a solution for the aeronautical ecosystem to protect and enhance the data sharing within the aviation industry. With this is possible to increase the data safety and security, as well as the increase in the data trustworthiness, making possible to trace all type of data back to its birth.

The Earhart challenge is separated into two different and major phases. The first, and more important is the building of the blockchain framework, where all records and transactions will be made. The second is to develop and incentivise the technology adoption within the aeronautical industry, working together with all stakeholders to fulfil all the requirements.

USE CASES

Earhart Solution offers a series of applied and integrated use cases for the aviation ecosystem. This use cases, or applications, are all built on top of a blockchain technology which ease how the data operations are carryout. Earhart Solution offers the following use cases:

1. **Permanent Recording**

   Substantiation: Blockchain allows permanent and immutable data transactions. When certain piece of data is placed in the Earhart Blockchain Solution, it will be there forever, it will not be possible to change or modify it. In the case of a mistake or data update, a new transaction needs to be made with the new data, quoting the previous transaction. This procedure complies with all the regulators requirements.

2. **Data Connectivity between Stakeholders**

   Substantiation: In the event of two different stakeholders need to share data, they can recur to Earhart Blockchain Solution since the end user can have sure about the data source, and it was not modified in between. This feature is useful in possible disputes, namely in insurance, assurance, compliance, auditing, and indemnity circumstances.

3. **Cheap, Safe and Hi-Speed Data Transfer**

   Substantiation: Using Earhart Blockchain Solution cost fractions of USD cents and within fractions of seconds all the data is placed in the blockchain and immediately available. The data safety is one of our main concerns, and because so, all the data that is placed in the blockchain is previously encrypted using state of the art encryption standards. So, only the data owner, or the stakeholders that he decides to, will be able to see any piece of data.

4. **Data Trustworthiness**

   Substantiation: Since Earhart Solution uses a blockchain powered solution, it is possible to verify if any piece of data has been changed or adulterated (intentionally or not). This feature will bring trustworthiness to all the data that is used in the aeronautical ecosystem and will enhance the overhaul aviation safety.

5. **Digital Twin**

   Substantiation: Data protection is a major concern in all the aviation ecosystem, and this data worth millions for all the stakeholders, since the lost or the compromising of this data can put at stake and seriously disrupt all type of the operations. Digital twining the data using a blockchain technology will protect all the important data. Making it virtually impossible to be hacked or lost.

6. **Traceability and Back-to-Birth of all data**

   Substantiation: Traceability and back-to-birth of all aeronautical products are a mandatory requirement by all aviation regulators and authorities. To perform this type of operations it is necessary many resources, particularly when dealing with aeronautical products that has more than a certain age. Since that all the data in Earhart Solution platform uses a blockchain powered solution, it is very easy to perform these requirements, and can be made only in a few minutes.

7. **Individual and Organizational Auditable Digital Certifications**

   Substantiation: Both individual and organizational certifications can be placed under Earhart Solution Blockchain platform to bring trustworthiness to all carry out actions. This feature is important if any organization desires to link the employees and/or organization certifications to all the actions. This will enhance the auditing procedures and can ultimately be automatized.

8. **Auditable Digital Initial and Recurrent Training Records**

   Substantiation: There have been within the aviation industry situations where individuals fake or force their training. In the situation where the individuals have their training within Earhart Solution Blockchain platform, it will not be possible to fake or forge any training. It will be also possible to maintain an updated CV of all actions carry out by the individuals, for example, carried out maintenance actions or flights performed (with flight hours count).

9. **Real Time Airworthiness Status**

   Substantiation: The organizations ERP's can give all the information about a certain aircraft or component, but the use of these ERP's are limited to the organization. In the aviation ecosystem it is frequent the need for partial or all the airworthiness status for a certain aircraft or component. In the case where all information is available within Earhart Solution Blockchain platform, it can be shared or linked to other ERP's to be able to have a real time airworthiness status.

10. **Enhanced Aircraft Phase-In/Out with Two-Clicks data operations**

    Substantiation: Aircraft Phase-In's and Phase-Out's can take from several weeks to several months, and it is a very demanding process since usually take a lot of human and economic resources. Earhart Solution Blockchain platform can ease a lot this process from the data side. If all the relevant information is available at the platform, the data can be shared with the lessor or the new operator, and within in seconds and effortless, it can be available to all stakeholders that requires it, maintaining the traceability and back-to-birth properties.

11. **Improved auditing and compliance processes**

    Substantiation: For auditing and compliance purposes, usually it is granted to the auditors' access to the physical records or limited access to the ERP's. This procedure can take a lot of time since the auditors spend more time to browse for the relevant information than analysing its content. In the case where all the relevant information is made available in the Earhart Solution Blockchain platform, the organizations can share the relevant data with the auditors easing by several orders of magnitude the auditing process.

12. **Improved certification, leasing, warranty, and insurance claims response time**

    Substantiation: When exists disputes, all the intervenient recurs to their ERP's for evidence. The problem appears when one of the intervenient does not recognize the validity of that information, since it can be easily manipulated. Within the Earhart Solution Blockchain platform, besides being neutral to all disputes, the cornerstone of blockchain technology does not allows to modify of change any previous information, and all information is

timestamped. This will allow ease and almost instant processing of data also oriented for claims and disputes solving processes.

13. **Improve the overhaul industry safety**

    Substantiation: Since data handling and managing will be evilly eased for organizations that uses the Earhart Solution Blockchain platform, both economic and human resources will be more available to be focused on Safety Management Systems and all sorts of compliance. Also, and since that the traceability and back-to-birth properties are the cornerstone of Earhart Solution Blockchain platform, all the end users will benefit from this data availability and accuracy. All this will increase locally and globally the aviation ecosystem safety.

14. **Blockchain Issuance of Certifications**

    Substantiation: The issuance of certifications, being them issued by authorities, Production or Design Organizations, can be used within the Earhart Solution Blockchain platform to keep track of the product life and to validate the processes within the used data. Future use cases can be enhanced with this, for example, remote 3D-Print of parts and respective certification.

COMPLIANCE

Earhart's solution complies with current US regulator, FAA, requirements outlined in CFR Part 11, Part 21, Part 25, Part 26, Part 43, Part 61, Part 91, Part 141, Part 145, Part 147, and Part 249.

Earhart Team has conducted several meetings with the European Regulator EASA. The current regulations are omitting the use of blockchain technology for aviation. EASA has confirmed that Blockchain complies with aviation regulations M.A.305, 145.A.55 and 21.A.55. They also confirmed that the proposed Earhart approach are reliable and consistent to the current aviation framework.

Following this and having into account the analysis made from FAA and EASA regulations, Earhart solution complies with all set of record keeping and transfer, making blockchain a valid choice for aviation records management.

Earhart Solution, Lda. is a private liability company incorporated in Portugal and governed under Portuguese law ("Earhart").

Earhart manages an electronic platform for data exchange based on blockchain technology and is the issuer of utility tokens ("EHT") that may be used by the users of the platform to access to encrypted data of other users. Although EHT may be qualified as virtual assets, Earhart is not subject to registration with Banco de Portugal, as it does not carry out any of the activities with virtual assets that are subject to said registration, set forth in article 2(1)(mm) of Law no. 83/2017, 18 August (Lei n.º 83/2017, de 18 de agosto), which lays down anti-money laundering and terrorism financing measures and transposes into the Portuguese legal order Directive (EU) 2018/849 of the European Parliament and of the Council of 30 May 2018, in relation to EHT or any other virtual assets. In addition, EHT should not be qualified as securities pursuant to article 1(1)(g) of the Portuguese Securities Code (Código dos Valores Mobiliários, approved by Decreto-Lei n.º 486/99, de 13 de novembro) as they are not functionally and legally comparable to securities (e.g., shares or bonds) or other financial instruments.

INTRODUCTION

The civil aeronautical industry is highly regulated, which demand very high airworthiness standards. One key point of the airworthiness standards required by the regulators is the records of all phases related to aircraft maintenance, operation, and airworthiness control. The aeronautical records are estimated to weigh up to 50% of an aged aircraft value [5], transforming the aviation records industry in a multi-million business. Is also important to refer that it is not appealing for nobody acquiring an aircraft with missing or poor records, which often devalues the aircraft by a huge factor.

The aviation industry still relies on paper and nonstandard software records, often called ERP's. Frequently, these records can be corrupted, damaged, missing data, wrong data, etc. When the logs of a certain aircraft work are missing, the aircraft loses its airworthy status and cannot fly until again perform that missing task. With Earhart blockchain powered solutions, all the records will be recorded forever, never lost, adulterated, or even corrupted. This solution will decrease by many factors the cost of recording, maintaining and issue airworthiness information for all aircraft, since the records will be cheaper and the needs for reworks are near zero because there is no loss of information, saving large USD millions in maintenance per year.

The daily management of aircraft fleets will be also highly facilitated since the key data will always be available and has a high degree of reliability, and as consequence, the administrative manpower to perform the aircraft airworthiness control will be reduced. It also allows to perform audits, aircraft modification status control and professionals working time in real time [3, 4, 6], since operation and maintenance can be followed as it happens. A good example is following the maintenance shop actions while they happen.

Earhart solution will ease aircraft re-deliveries since everything can easily be monitored, controlled, and automatized. An aircraft redelivery using this technology will reduce the ground time from months to weeks. The cost to do it will be decreased minimum 10x since no reworks or missing data need to be performed [5]. The need to tear down an aircraft to perform missing or unreliable maintenance actions will no longer be necessary.

Earhart's solution will help the aeronautical industry to optimize and achieve the next level of automation, computerization and digitization of aircraft airworthiness data, information, and records. Adopting this solution will save the airlines industry large thousands of aircraft ground time

per year mainly in the administrative tasks. This will increase the airline's liquidity and profits directly because the aircraft will fly more, and indirectly because since the re-works are reduced, the maintenance costs are also reduced.

This technology will also enhance the capabilities and highly benefit the several players in the aeronautical industry. CAMO's can benefit from real time airworthiness overview; on-chain and reliable data; reliable records; real time airworthiness impact. Service Centres can have access from OEM's and CAMO data in real time, with reliable data and correct configurations; engineering working time and certifications can be recorded and monitored in real time [1,3,4,6]. Operations can benefit from controlling the cockpit and cabin crew working times and certifications as well record all the relevant airworthiness data. Authorities and regulators, when grated access, can monitor or audit in real time and as well monitor in real time the airworthiness data. Can also perceive the degree of implementation of the airworthiness requirements. Training and certifications tracking can also benefit from Earhart Solution, both can be registered and easily accessed to verify the individual and organization certifications, training, and recurrent training needs. In the end, Earhart will allow to control who is working or operating the aircraft and detect who has not the initial certified training or recurrent training maintain or operate the aircraft.

The key feature of Earhart is the design a specific framework process which facilitate the interface between the centralized ledgers, blockchain and the aeronautical organizations. Earhart uses a hybrid approach, using a public blockchain to increase the networks security but controls who is using the Earhart services, granting access to Earhart platform only authorizes aeronautical stakeholders. Also, and in order to increase the data security, all the data that each stakeholder places in Earhart platform will be encrypted NFT, so, no other stakeholder, including Earhart, will be able to see what the content of that data is. Only if the owner of the data decides too, it is possible to send or share that data to other stakeholder, then, only those will be able to see the data content. To use Earhart Solution Blockchain service there is no need to change any software, there is no need to acquire state of the art hardware, or even have a high degree of IT proficiency. Earhart has built a very easy and clean tool that even users with low IT proficiency can use. Regarding the data, Earhart does not change, modify, or even catalogue it, since it is encrypted. The data content is full responsibility of the user. Nevertheless, Earhart provides a set of tools to all aviation stakeholders to be able to take all the advantages from the blockchain technology. An integrated Blockchain platform, based on common regulated principles, can be used to register, and assert the historic data of aircraft, aircraft components, aircraft parts, airport activities, aircraft flight personnel

activity, aircraft maintenance personnel activity and others (Bonomo et al., 2018; Mandolla et al., 2019; Liu et al., 2020).

The industry is demanding decentralized solutions, since every aeronautical management organization tends to use their own ERP's, developed sometimes internally, given no or few changes for external entities to manage and use that information. When a service is hired externally, the linkage between the platforms is different, arising then difficulties to use all the huge amounts of information, this gives origin to a huge administrative manpower, usually copy/paste information of hundreds (sometimes thousands) of data entries. Earhart besides eliminating the need of most these manpower, increases the overhaul process safety since the human errors of the copy/paste process will be eliminated. Earhart Solution Blockchain service arise here as a decentralized universal mean of airworthiness data storage and exchange with tailored features that allows the presented use cases. Additionally, and if the stakeholders decide to, any piece of data can be monetized, i.e., can be sold to other stakeholder. In Earhart vision, airworthiness data can be monetized since some of the information that one stakeholder has can be used by other.

HIGH LEVEL FUNCTIONS

Following it is represented and explained the function of the proposed model. To be simpler, it will be divided in several modules of explanation, every single module represents a part of the process or an aeronautical stakeholder. For last, all the process will be explained, with the interaction between all the participants.

It is convenient to introduce the definition of all the proposed processes. In the base are the proposed modules illustrated in figure 1.

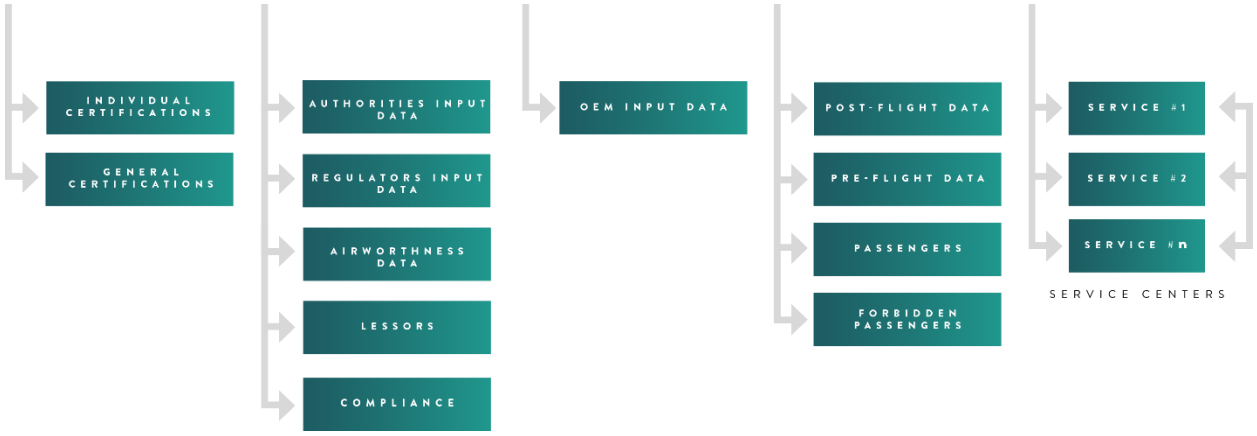

Figure 1 – Earhart working modules.

Each player and respective module have his own functions and responsibilities, but all are interconnected and dependent from each other. Currently is foreseen 15 working modules:

- Individual Certifications
- General Certifications
- Authorities
- Regulators
- Airworthiness
- Lessors
- Maintenance
- Compliance
- OEM
- Post-Flight
- Pre-Flight

- Passengers
- Blacklisted Passengers
- Services (Maintenance)
- Airports

After the modules is the approval routines.

Figure 2 – Approval Routines.

The purpose of the approval routines is the act of approving some request, document, service, etc. The approval routines can be delegated to other players, for example a pilot license issued by a school and approved by the authority. It can be internal approval procedures such as approval of an airworthiness instruction by the authority, or even by AI or pre-programmed conditions.

Following is the gateway. The gateway verifies and transforms the content from a UI or ledger to the requirements of the blockchain and vice-versa.

Figure 3 – Gateway.

After the gateway comes the blockchains. Here is where it is stored and time-stamped all the data that needs to be immutable. It can be used several types of blockchain, depending on the content or purpose of the data. It can create a mechanism where several blockchains interact by exchanging data.

Figure 4 – Blockchains.

Following the process, it is found the databases, aka ledgers. The access to interchanging data between the ledgers can be given by authentication or by smart contracts. Ledgers can be centralized or decentralized.

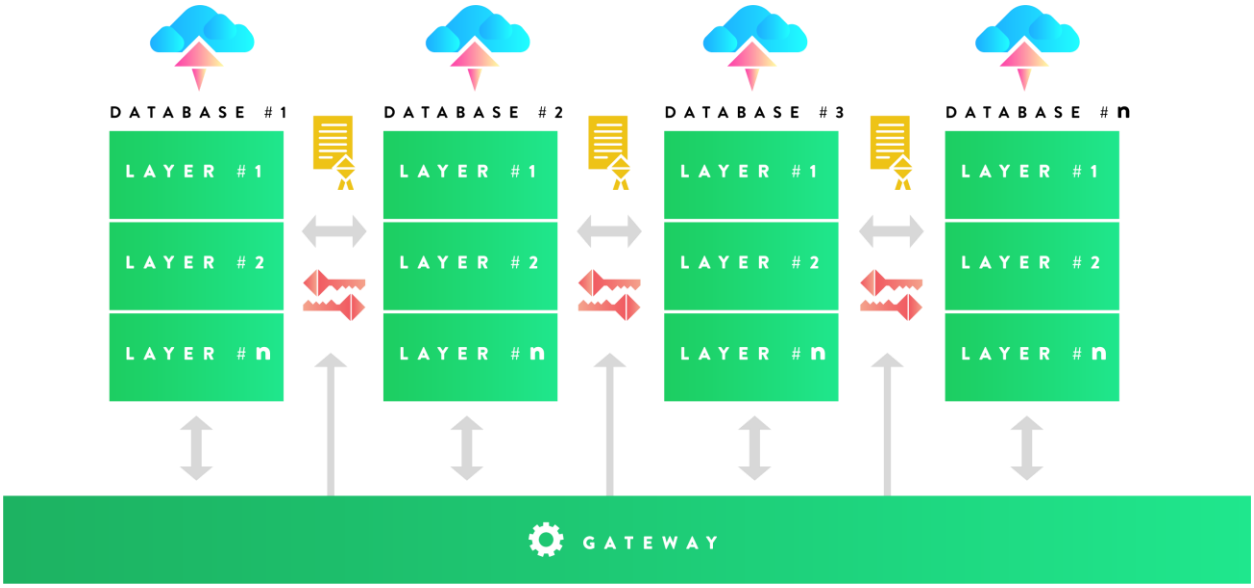

Figure 5 – Databases/ledgers.

On the top of the process is the hyper view, which is where users will browse, check, and verify all the data. The access can be granted by module, by a specific component, a specific instruction, a specific data or by specific aircraft or an entire fleet. This access can be granted by authentication or by smart contract.

Figure 6 – HyperView.

MODULES

Following is mentioned the workflow of the several modules. Is given in detail the role and the competences of each working module.

CERTIFICATIONS MODULES

In Figure 7 it is represented by the individual and general certifications. In this module, the initial and recurrent training, certifications, and type rating of all individuals will be recorded. It is also recorded the certifications of aircraft and organizations. The components certifications are not part of this module.

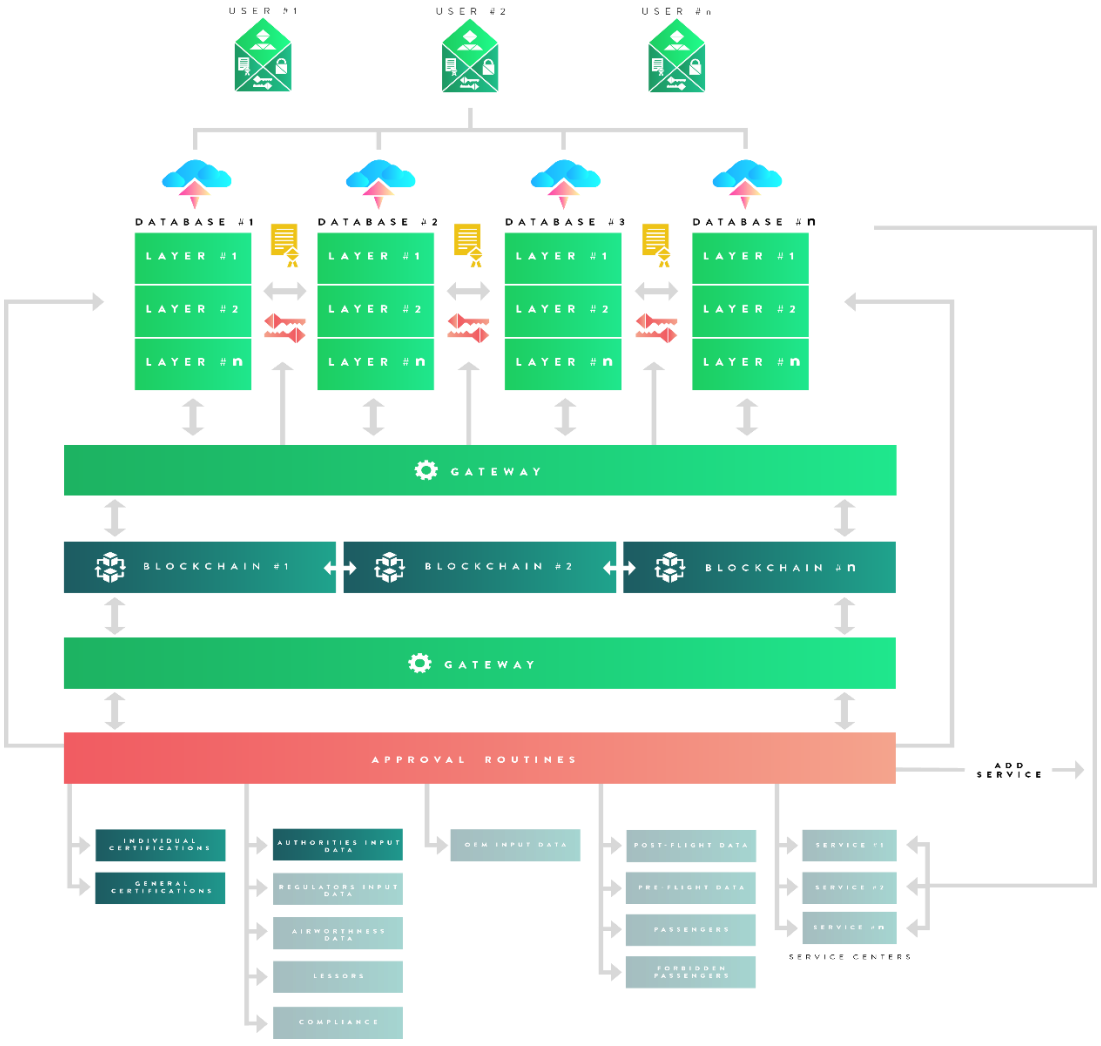

Figure 7 – Training and Certifications Process.

For individual certifications it can be recorded, for example, pilots, maintenance technicians, engineers, cabin crew, etc. Can be recorded as the pilot license and specific aircraft type rating, the aircraft maintenance license per issued authority; medical, technical, and physiological qualifications; the recurrent required training. For aircraft and organizations, it can record to which part is an organization compliant; for aircraft can record the noise certification, airworthiness certification, insurance, etc. At the end, this module will act like a digital ID for aircraft, individuals and organizations that interacts with the aircraft or its components.

Example 1:

An individual finishes the pilot license training, the pilot school and/or authority can issue the request for the license. After it goes to approval routines, which is made by the authority or AI in the Authorities module. If the submission accomplishes all the requirements such as flight hours, class modules, exams approval, physical, medical, and psychological fitness, etc. given in the Regulators module, the approval is granted. Then individual data is recorded on the blockchain whose interface is made by a gateway that verifies if all the blockchain requirements are fulfilled. In the blockchain is then recorded the name, license number, type rating, timestamp, operational data (flight hours and flight cycles). In the database/ledger it will record more operational data, such as which flights a pilot has made, its dates, flight duration, etc. If a pilot goes into refresh or simulated training, he follows the same path, i.e., approval routines and blockchain record. The access to the information is only possible through identification or smart contract.

Example 2:

An aircraft to be allowed to operate requires several certifications, one of those certifications is the noise certification[3,4,5]. The aircraft operator will present to the authority all the requirements for noise evaluation. The authority by individuals or any automation analyses and grant the approval in the Authorities module. This approval is going to the gateway which verifies if all the data and blockchain constraints are fulfilled, if yes then the certification is issued directly on the blockchain. Consulting information or records, only through identification or smart contract.

[3] EASA Requirements: 21.A.165, 21.A.201, 21.A.203, 21.A.204, 21.A.207, 21.A.209, 21.A.210, 21.A.211, M.A.901, CS-25.
[4]ICAO Requirements: Annex 16.
[5] FAA Requirements: CFR Part 21, CFR Part 25, CFR Part 33, CFR Part 36.

AUTHORITIES MODULE

Authorities play a crucial role in the aeronautical process and overall safety. Through the authority's module is possible to make all the approvals regarding their scope of work.

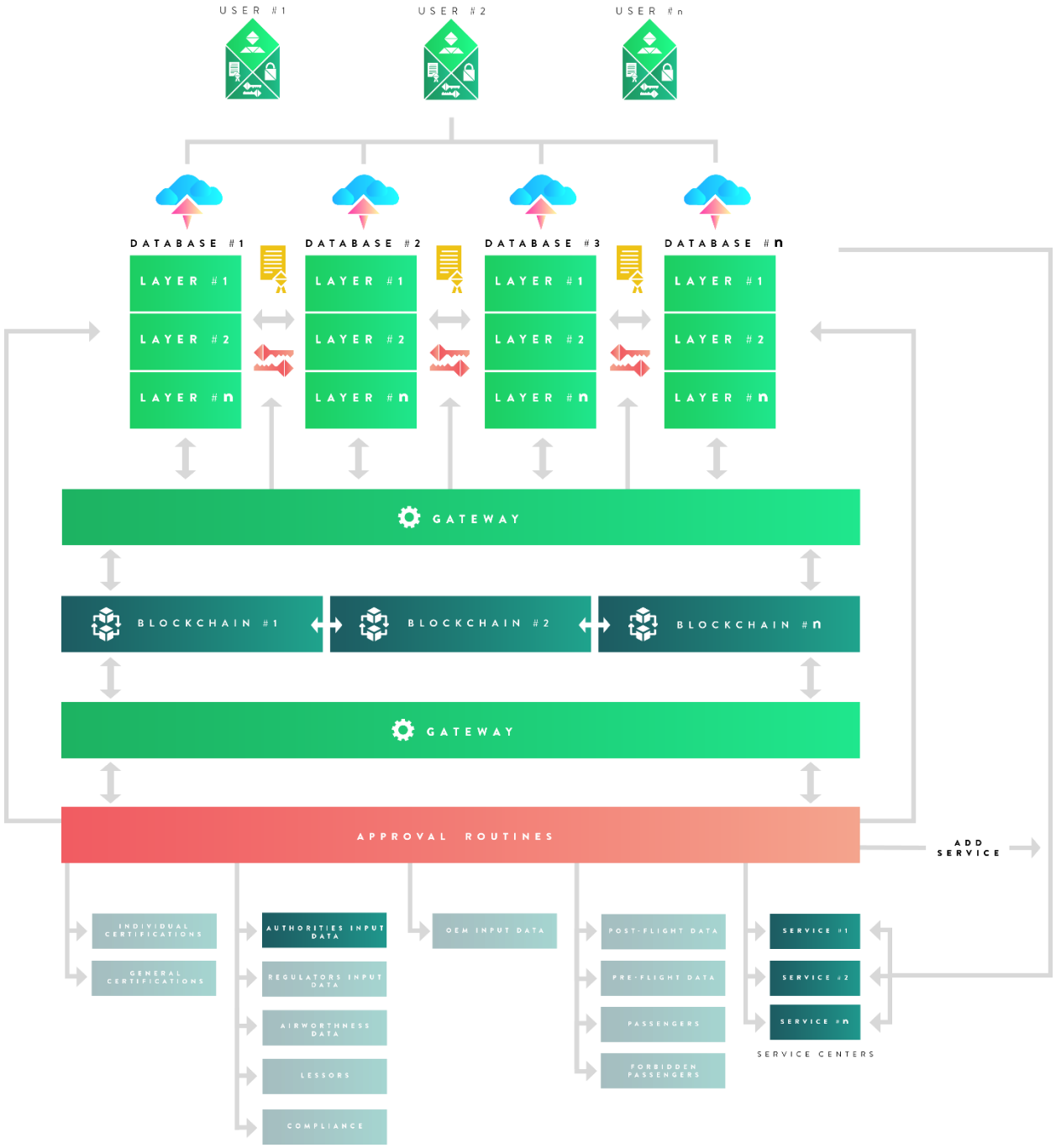

Figure 8 – Authorities Process.

Example 3:

Approve or reject certifications from example 1 and example 2.

Example 4:

Authority issued an airworthiness directive to replace wing structural fitting which is applicable to all Boeing 747-400 which has more than 24000 flight hours and have embodied wing fitting part number “ABC-123” installed. Currently, the time between the issuance of the airworthiness instructions, the analysis by the CAMO’s and the accomplishment by the maintenance service centres is not instant. In some cases, several years can pass between the airworthiness instructions issuance and accomplishment in the aircraft. Also, the authority does not know the full impact and the number of affected aircraft.

REGULATORS MODULE

Regulators also play a very important role in this industry. Regulations can be programmed in order to be verified by the applicable intervention. Currently this process is fully manmade and a time-consuming process. With Earhart solution, regulations can be easily programmed on the approval and requirement routines.

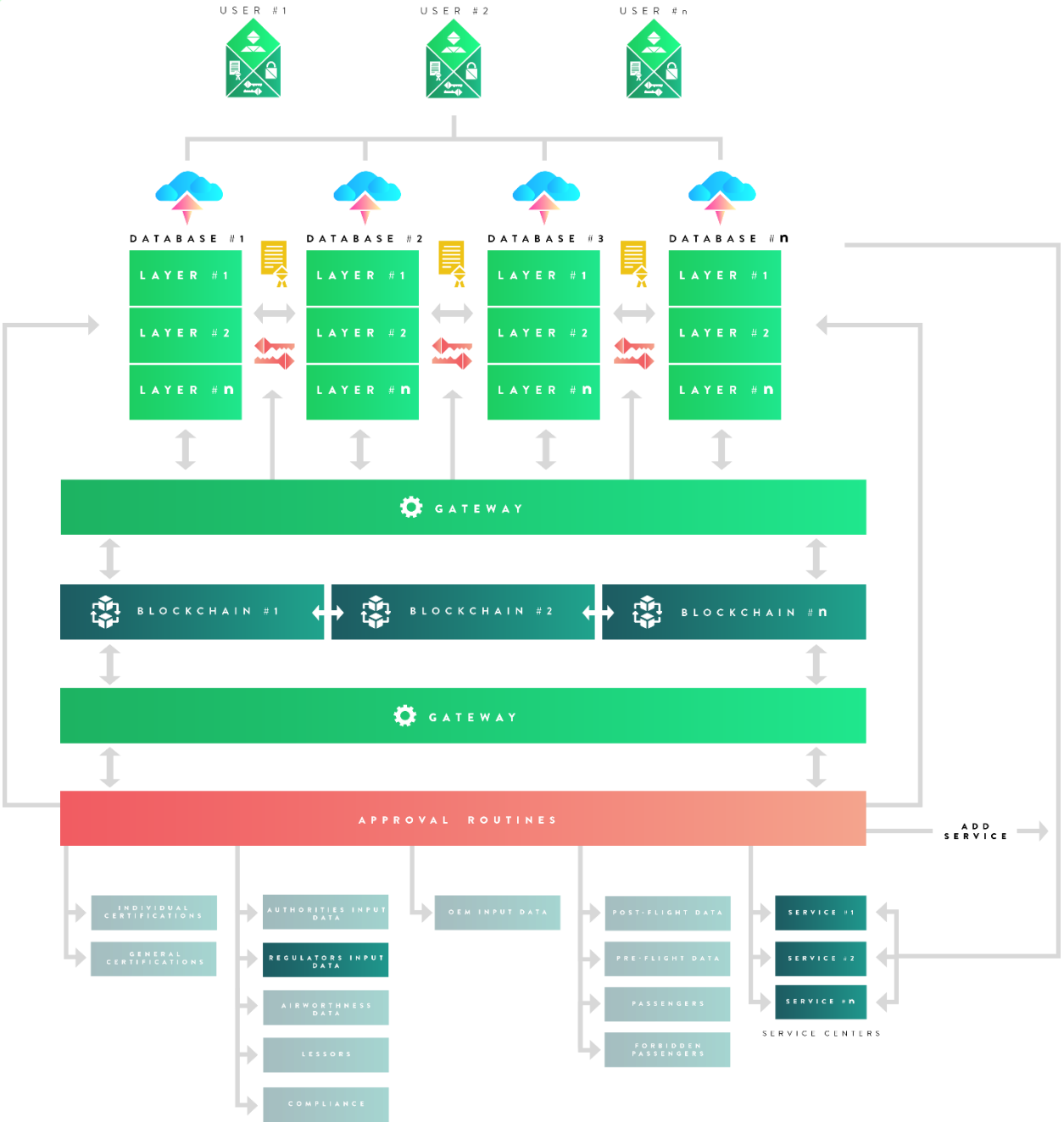

Figure 9 – Regulators.

Example 5:

Regulation: An aircraft pilot must be at least 18 years old and completed the course of airline pilot.

From Example 1, a pilot applies for certification, this approval routine will immediately verify his age and classification from airline pilot's degree from the Certifications module. If everything is successfully verified, then the certification is approved by the authority. An airline which will want to hire a pilot can verify if their skills and certifications match with his resume or internal requirements.

AIRWORTHINESS MODULE

CAMOs are one of the key players in the aircraft airworthiness management. It's their responsibility to make sure that all the maintenance and operation requirements are fulfilled[6,7]. It's their responsibility to build an aircraft maintenance plan and issue instructions to keep the aircraft in an airworthy condition. Nowadays this process requires large teams working around the clock to keep up with all the requirements. Especially when it's necessary to accomplish actions in third parties, who use different ledgers and methods. This happens because matches between two different systems need to be made. One area where Earhart Solution can help is when CAMO teams with the aircraft maintenance plan. The maintenance plan needs to be approved by an authority[8,9] as explained in Authorities module and need to constantly be studied and adapted. Anybody who was granted access can check the status of a specific aircraft regarding its maintenance plan. This is useful for CAMO teams, lessors, auditors, or authorities.

Another feature of Earhart is the capability to grant access to third party (lessor for example) to monitor all the parts installed in the aircraft and engines together with their certificates. Reliability is also one role of the CAMO's teams[10,11]. Using this solution, reliability reports can be placed in the platform for auditing, compliance, sharing or monetization purposes.

[6] EASA Requirements: M.A.201, Part-M Subpart F, Part-M Subpart G, Part-CAMO, Part-OPS Subpart OPS.
[7] FAA Requirements: CFR Part 11, CFR Part 26, CFR Part 43, CFR Part 91, CFR Part 249.
[8] EASA Requirements: M.A.302(b).
[9] FAA Requirements: CFR Part 91.1109(3).
[10] EASA Requirements: M.A.302, M.A.708, M.A.711, CAMO.A.220, CAMO.A.315, CAMO.A.325.
[11] FAA Requirements: CFR Part 91.1415, CFR Part 121.374.

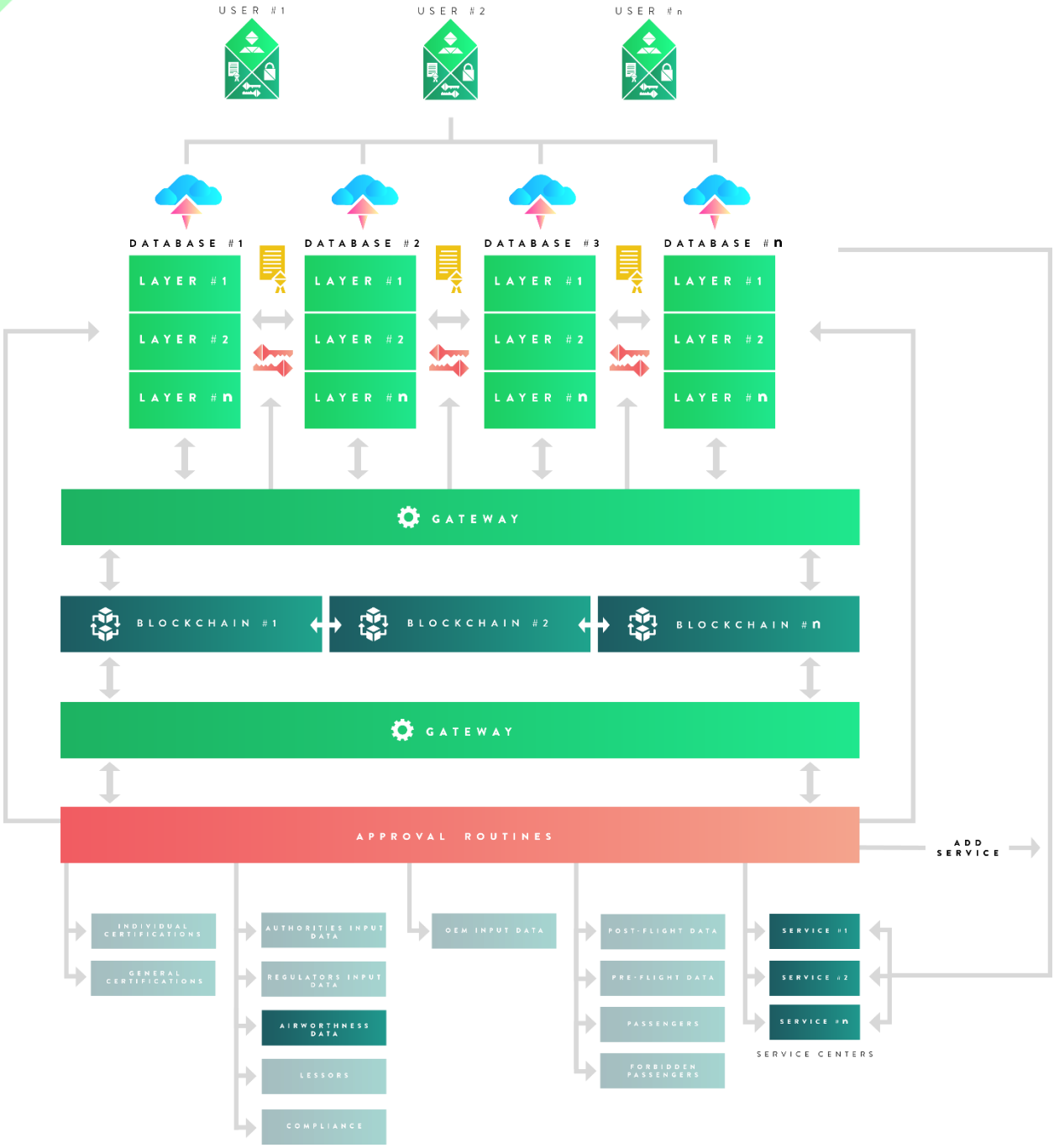

Figure 10 – Airworthiness.

Example 6:

The CAMO team prepares an aircraft maintenance plan[12,13]. Then the maintenance plan, composed of many hundreds of maintenance actions, can be reviewed by the authority in the Authorities module[14,15], and approved if it meets the Regulators requirements[16,17] module or be immediately implemented. Through the gateway is then stored in the blockchain the reference to who made the submission, who made the approval (if required), and the maintenance plan composed of tasks interval, applicability, task reference, etc.

LESSORS MODULE

The Lessors are usually big financial institutions that acquires aircraft and place them on rental to operators, i.e., the lessors are the aircraft owners. When the aircraft in on lease, the lessor has few or inexistent contact with the aircraft status. Only on some specific occasions or during the aircraft delivery, the lessor has contact with the aircraft and its records. This increases a lot the delivery time, and cut aircraft operation time, which translates it into loss of potential financial gains. Earhart can help lessors to be constantly informed about the aircraft status by introducing routines to the CAMO module. If both lessee and lessor agree, all or partial data transactions made and received by the CAMO will be immediately available for the lessor. This feature allows the lessor to be constantly informed about the aircraft status, cutting precious time in the redelivery of the aircraft.

Example 7:

CAMO sends a work package for a maintenance organization. In this work package is the accomplishment of several maintenance tasks regarding the maintenance plan, several Service Bulletins and Airworthiness Directives. When the maintenance ends, the CAMO receives the report from the maintenance organization with the detailed accomplished maintenance actions. Upon receiving this information, the CAMO will have in their user area both sent and received maintenance data. The lessor can have access to both these reports and be informed about what the CAMO sent for maintenance and what was the really accomplished tasks. He is also informed about possible cancelled work orders, and the new SB and AD status.

[12] EASA Requirements: M.A.302, CAMO.A.220, CAMO.A.315, CAMO.A.325.
[13] FAA Requirements: CFR Part 11, CFR Part 26, CFR Part 43, CFR Part 91, CFR Part 249.
[14] EASA Requirements: M.A.302(b).
[15] FAA Requirements: CFR Part 91.1109(3).
[16] EASA Requirements: Part-M, Part-CAMO, Part-145, Part-66, Part-147, Part-21.
[17] FAA Requirements: CFR Part 11, CFR Part 26, CFR Part 43, CFR Part 91, CFR Part 249.

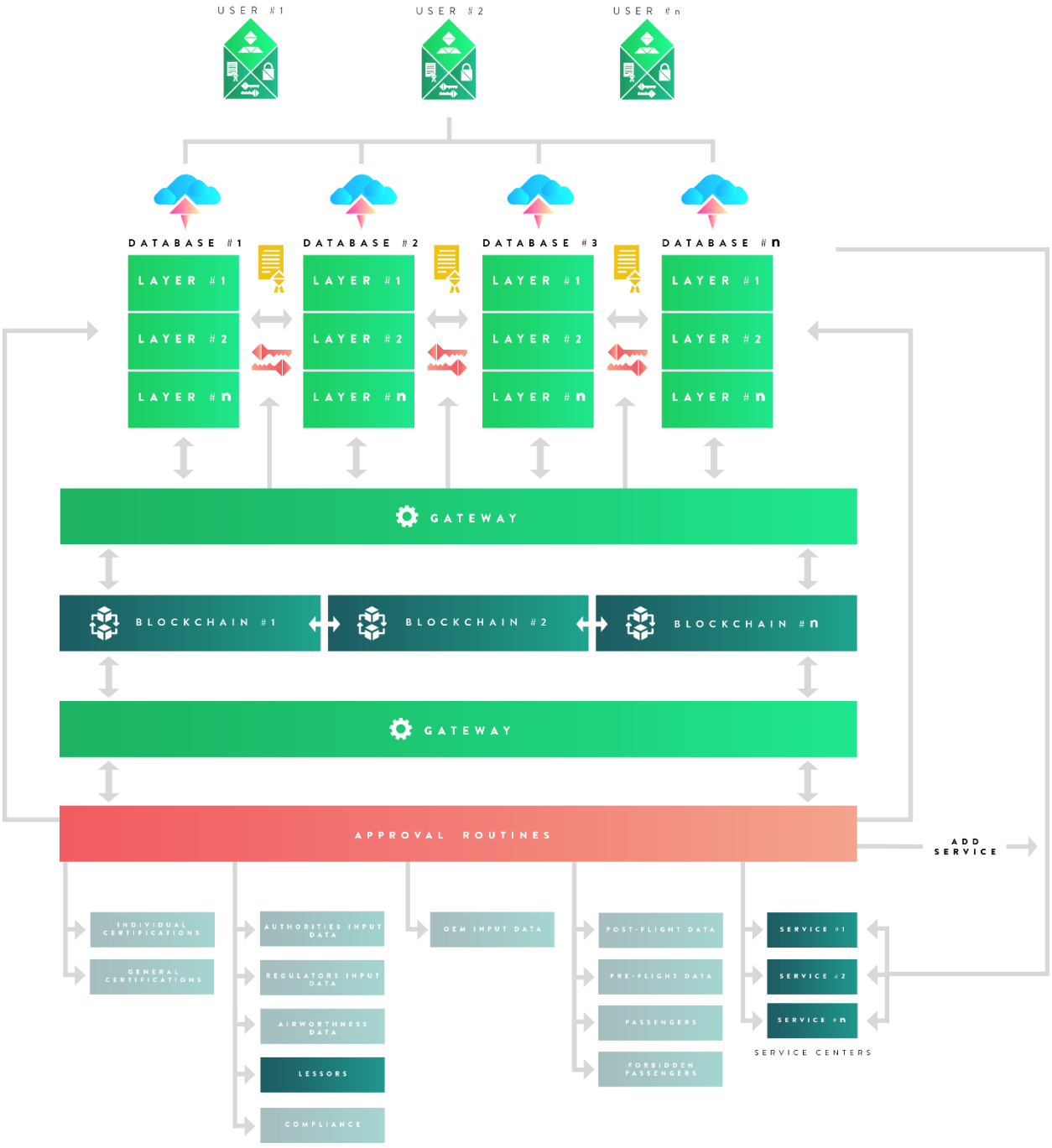

Figure 11 – Lessors.

COMPLIANCE MODULE

Dealing with the aviation ecosystem implies dealing with a highly regulated industry, in which Earhart Solution Blockchain solution works towards to provide tools for the industry to comply these regulations. When dealing with regulations, especially in the Safety Management Systems framework, it is often necessary to provide the information and the mitigating measures that organisations perform to the authorities. The evidence of this, together with the compliance measures are the cornerstone of the modern safety management systems[18,19,20]. In order to provide credible auditable evidence, these are required to be recorded in such a way that must be immutable and timestamped. These properties are provided by Earhart Solution Blockchain which also allows secure and encrypted data exchange, enhancing the way how the compliance records are managed and shared.

Example 8:

An aircraft operator has been involved in an incident, which after investigation, need to comply with certain actions. To record and report both the incident and the future mitigation actions, the operator need to provide to the authority both the notice of the incident, the investigation results and future mitigation actions. Using Earhart Solution Blockchain allows to record all the phases of this process, provide an easy and effortless way to follow the evolution of the events and results and to securely report to the authority using secure and decentralized tools.

[18] ICAO Annex 19
[19] EASA Part-CAMO
[20] EASA Part-OPS

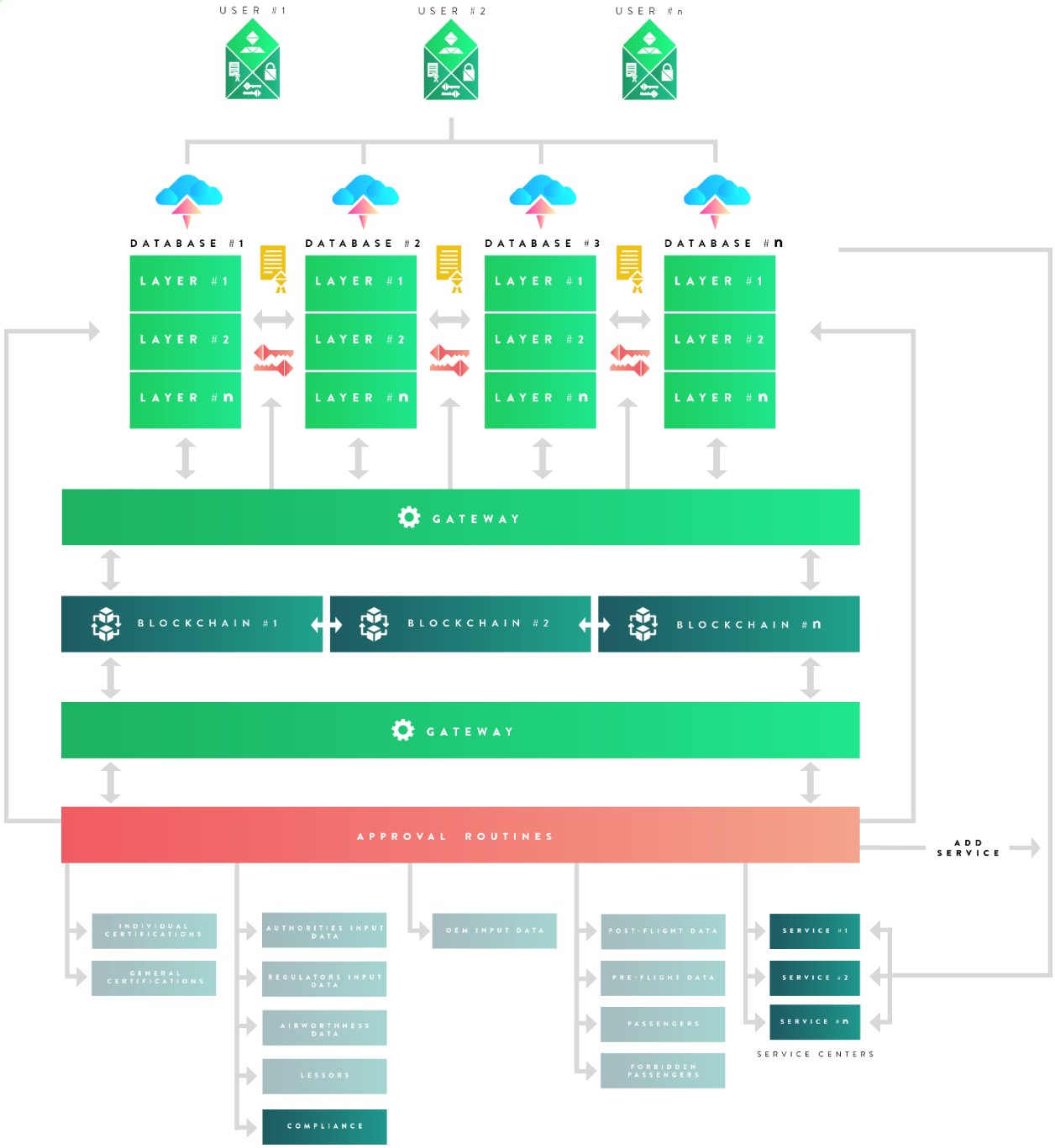

Figure 12 – Compliance.

OEM'S MODULE

OEMs are also one of the key players. They design and manufacture every component and part that are installed in aircraft. According to current regulations, they are required to keep record[21,22], ensure the serviceability and the performance of every installed part [23,24]. Therefore, they require ever more efficient systems that store and keep track of aircraft part's data, ensuring regulatory compliance. Earhart Blockchain Solution can boost current systems, with a more reliable platform. The databases can be initially filled with the information from the OEMs, can be filled by the operators with their service information or can be acquired by monetizing other data. Furthermore, OEMs by being able to access the parts or modification status in real time, can provide better services to industry players, namely helping in the troubleshooting or dispositions issuance.

Example 9:

During the manufacture of a Boeing 747-400 it is necessary to install the LH wing fitting PN ABC123-1 with SN 123 on aircraft SN 00321. Following the approval routines and recording in the blockchain the relevant data a service is generated. Then after service implementation the relevant data such as PN, SN and ID is recorded in the blockchain and databases.

During this process is issued the first parts certificates, also known as birth certificates, which will then be updated during their operating life.

Example 10:

During operation of a Boeing 747-400 SN 00321 a maintenance message is shown. After troubleshooting it is requested help from the OEM to solve the problem. Can be granted to OEM access to information of aircraft SN 00321. OEM can then verify all performed work, aircraft configuration, parts installed, etc. Time between asking and replying will vanish. Reducing the aircraft ground time several times.

[21] EASA Requirements: 21.A.55.
[22] FAA Requirements: CFR Part CFR Part 21.2, CFR Part 21.137, CFR Part 21.142.
[23] EASA Requirements: Certification Specifications, Part-21.
[24] FAA Requirements: CFR Part 21.

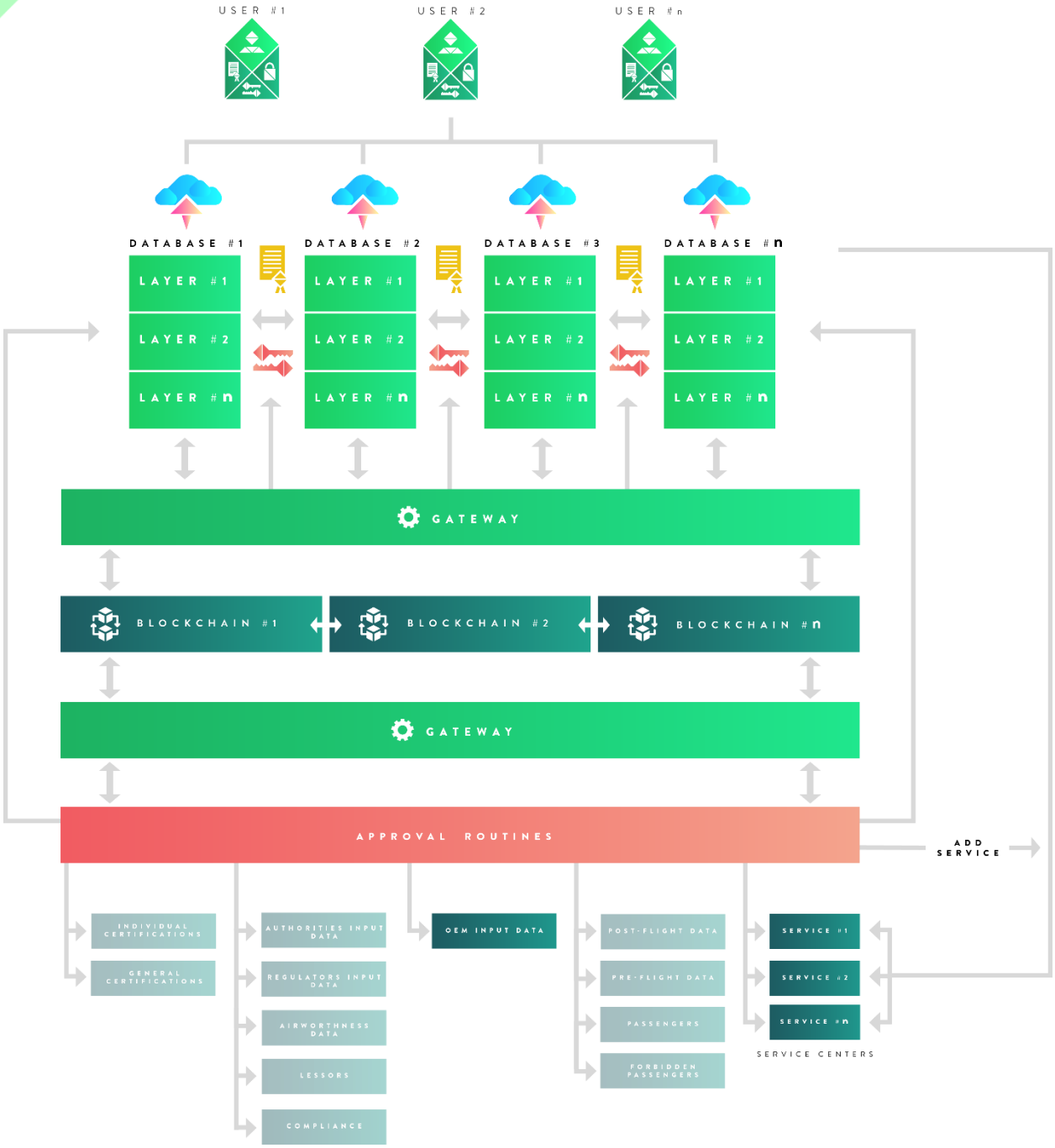

Figure 11 – OEM's.

OPERATIONS MODULE

Operations will give important inputs to the aircraft ledgers. Aircraft are controlled by calendar time, by aircraft flight hours or flight cycles. There are other forms of accounting operational data, namely engines flight hours and flight cycles, APU operating hours and landing gear cycles. Individual components life monitoring is mandatory[25,26] since components can be swapped between aircraft, and when this happens, this individual data must go with it. This module also allows to permanent record all the aircraft operation, this allows to build a permanent history of the aircraft life. The Passengers module will be able to permanent record the passengers of every flight, and the forbidden or blacklisted module will allow operators, airports and/or other organizations to be able to store and securely share among them the passengers that are not authorized to board aircrafts in a certain zone (or globally).

Example 11:

Aircraft registry N00001, a Boeing 747-400 has a programmed flight from New York to London with estimated Departure Time at 12:00 UTC and Arrival 17:00 UTC. This flight has a total of 5 aircraft and engine flight hours and 1 aircraft, engines, and landing gears flight cycles. The cockpit crew is Captain John and First Officer Mike. The cabin crew is Larissa, Joanne, Michael, Peter, Danielle, Abigail and Chloe. After aircraft flight, crew reported that the Departure Time was 12:01 UTC and Arrival 16:31 UTC, total 4,5 aircraft and engines flight hours and 1 aircraft, engines, and landing gears flight cycle. Will then be added 4,5 flight hours to the aircraft and engines and 1 aircraft, engines and landing gears cycles which will be then recorded in the blockchain. It will also be recorded who performed the flight[27,28], cockpit and cabin crew total flown hours and remaining or required rest/off duty time[29,30]. All passengers that will be crosschecked from the forbidden passengers' modules to verify if there are any passengers which are not allowed to board the airplane. Then, all passengers that will bord the aircraft will be recorded to maintain a permanent record of all the passengers.

[25] EASA Requirements: M.A.305, AMC M.A.305(e), M.A.306, M.A.503, M.A.801, M.A.901, CAMO.A.220, CAMO.A.315, CAMO.A.325, 145.A.55, 21.A.55.

[26] FAA Requirements: CFR Part 11, CFR 21.2, CFR 21.137, CFR 21.142, CFR 21.2, CFR Part 25, CFR 43.2, CFR 43.9, CFR 43.11, CFR 43.17, CFR 91.417, CFR 91.419, CFR 91.421, CFR 91.1027, CFR 91.1113, CFR 91.1427, CFR 91.1439, CFR 91.1441, CFR 91.1443, CFR 145.12, CFR 91.161, CFR 91.219, CFR Part 249.

[27] EASA Requirements: M.A.306, CAMO.A.220, CAMO.A.315, CAMO.A.325.

[28] FAA Requirements: CFR Part 249.

[29] EASA Requirements: ORO.FTL.210.

[30] FAA Requirements: CFR Part 117, CFR Part 61.13, CFR Part 61.5, CFR Part 61.189, CFR Part 61.423.

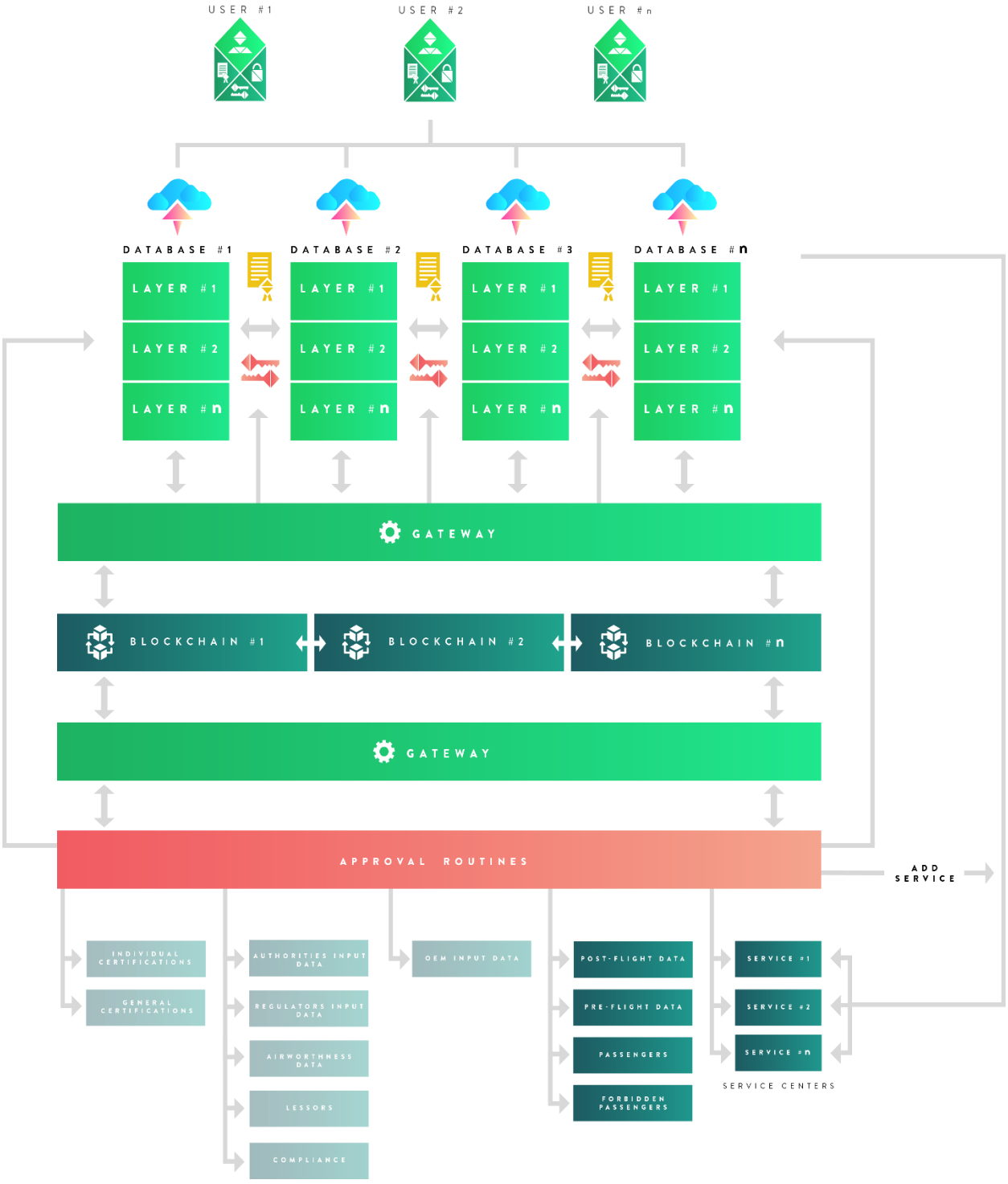

Figure 12 – Flight Operations.

SERVICE CENTRES MODULE

Service Centres are usually defined as maintenance centres and are where the maintenance technicians work for. Service Centres are to accomplish the line, base, and shop maintenance tasks, defined by the CAMO's and/or engineering. During the accomplishment of these maintenance tasks, can arise a non-routine work, or not predicted, aka "Added Service". These added services work need to be carried out to preserve the airworthiness[31,32] of the aeronautical products.

Example 12:

Starting to accomplish a maintenance plan, submitted in the Airworthiness module, technicians start to remove, inspect, test, etc. aircraft equipment's. All these accomplishments are blockchain recorded and controlled. When a defect arises from this, an Added Service is generated and recorded in the blockchain. After, a customer or a routine will approve or reject this added work. All this will be recorded in the blockchain to maintain the accountability, traceability, and records.

[31] EASA Requirements: M.A.301, M.A.401, M.A.403.
[32] FAA Requirements: CFR part 26, CFR Part 43.

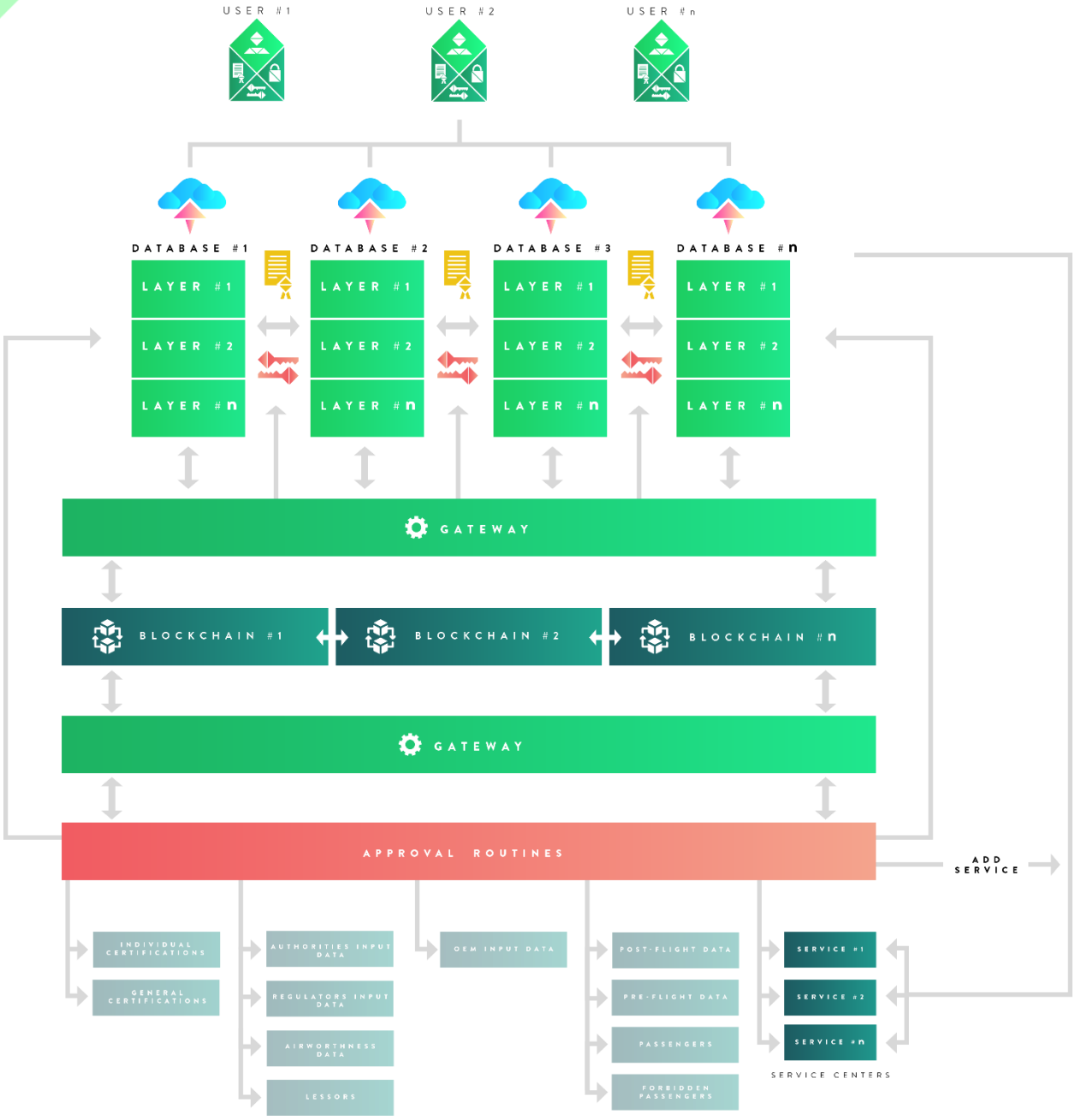

Figure 13 – Service Centres.

EARHART SOLUTION

In aviation every role relates to others. Analysing every single module is important to understand the individual role but understand the interactions is the key to recognize the true potential of Earhart project.

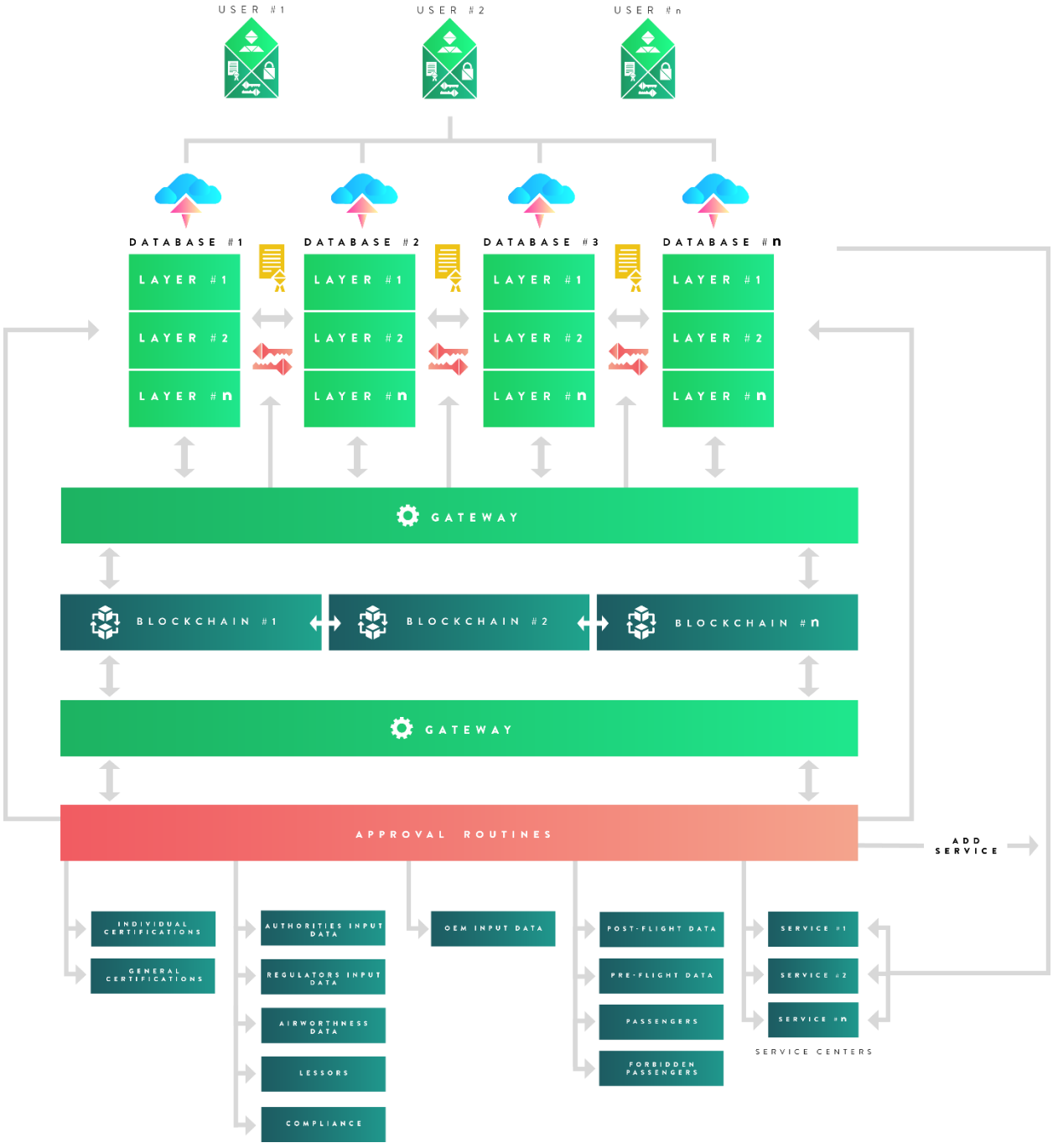

Figure 14 – Earhart.

To understand how Earhart can be deployed, is detailed below the case scenario of an airline that uses Earhart solution. Explained step by step, as the scenario unfolds, what would be requirements, as well as how other players could be involved.

Example 13:

Pre-Requirements: Database/ledger be loaded with at least one aircraft technical information, regarding parts identification.

An airline decides to acquire a used aircraft to one lessor company. The airline CAMO then must develop an aircraft maintenance plan[33,34] aka the module of airworthiness data. From this point there are three options, 1. have manpower to develop one, 2. subcontract an external CAMO to perform this work or 3. use the monetization function to instant acquire one. This will not exclude CAMO from studying, evaluating and periodic reviews per requirements[35,36]. This maintenance plan, with requirements given by the regulator's module, is submitted to the approval routines for the authority to approve[37,38]. Once approved, record of submission and the approval is recorded in the blockchain.

At the same time the airline needs to acquire the aircraft and company certifications, aka general certifications module with requirements given by the regulator's module. After submission to the approval routines, the authority will then review it and if the case, approve the certifications. After the approval, information will be recorded in the blockchain.

At this stage, with aircraft and company certifications validated, the next step is to start the operation. For that is required cockpit and cabin crew. After a candidate's appliance, the airline will validate their licenses, type ratings, and training of the crew which were issued previously in the blockchain.

Then the aircraft will start to operate, in the module of flight data, operations will update after every single flight the operational data. The flight hours and cycles will also be added to the crew curriculum, and also their duty time. Also, the passenger's information is recorded.

[33] EASA Requirements: M.A.302, CAMO.A.220, CAMO.A.315, CAMO.A.325.
[34] FAA Requirements: CFR Part 11, CFR Part 26, CFR Part 43, CFR Part 91, CFR Part 249.
[35] EASA Requirements: M.A.302(h).
[36] FAA Requirements: CFR Part 121, CFR 135.411, CFR Part 91 Subpart K, CFR Part 119.
[37] EASA Requirements: M.A.302(b).
[38] FAA Requirements: CFR Part 91.1109(3).

With the aircraft operation, i.e., the increase in the flight hours and cycles, the continuing airworthiness instructions will start to become active and life limit parts remaining time decreasing its potential[39,40]. Then, the maintenance technicians, which has his license and training validated through the individual certifications' module accomplish the maintenance. After maintenance accomplishment, the service records in the blockchain the relevant information, and depending on the level of agreement with the lessor, this one will be informed about aircraft operation and maintenance.

If during operation is required assistance from any OEM, it can then be granted to help in any required assistance. This is done under the OEM module. Here the OEM can verify and check the relevant data for the analysis and can also issue services to perform. These services are instructions to solve the requested assistance.

[39] EASA Requirements: M.A.503.
[40] FAA Requirements: CFR Part 33.70.

COST SAVINGS ESTIMATION

Maintaining an airworthy fleet is costly. Many man hours of work are carried out by all aeronautical players. Trying to quantify how much is the savings is no easy task. Several approaches need to be made only from the operator point of view.

The total amount of saved man hours is defined as:

$$\sum_{Total_{MH}} = \sum_{All\ Modules_{MH}} \quad (1)$$

The total amount of savings is defined by the sum of all the direct savings plus all the indirect savings. This relation is defined in (2).

$$\sum_{Total\ Savings} = \sum_{Direct\ Savings} + \sum_{Indirect\ Savings} \quad (2)$$

The Direct Savings are easily described as the total man hours saved using Earhart solution plus costs of reworks plus the costs of all traceability. This is defined in (3).

$$\sum_{Direct\ Savings} = \sum_{Total\ MH} + \sum_{Reworks} + \sum_{Traceability} \quad (3)$$

The Indirect Savings is the return of aircraft availability plus the second-hand aircraft market value. This is defined in (4).

$$\sum_{Indirect\ Savings} = \sum_{Aircraft\ Availability} + \sum_{Aircraft\ Market\ Value} \quad (4)$$

Since this process is highly complex, no precise values can be obtained. Nevertheless, and taking only the aircraft CAMO management and Service Centres, a fair approximation can be given when applying equations (2), (3) and (4).

As a keynote the Authorities, Regulators, Lessors, Airports, Certifications, OEMs, Operations and Airports savings will not go into account in this approximation but can be estimated as 1 to 5 % of the savings of the combined CAMO and Service Centres. CAMO management needs a fair average of 3 MH per aircraft of Engineering, Quality, Planning and Service Centres Line Maintenance. Total per aircraft is 15 MH per day in this estimation.
The amount of MH from the Service Centres is difficult to eliminate since it involves physical work on aircraft. Nevertheless, and having into account the above referred 15 MH average per day per

aircraft (from several departments), a low estimation of 2 MH can be saved mainly in traceability and verification tasks, since Earhart Blockchain Solution will be able to verify and trace all aircraft airworthiness information in a simple, easy and with a very high degree of data confidence.
Regarding base maintenance checks, light and heavy, the amount of man hours is exponentially higher. For a 1000 MH base maintenance check, a 4000 MH is easily achieved with defect rectification. From those 3000 MH, a fair 50 MH of reworks are done due to poor records, loss of certificates or Part Numbers confirmation. The cost of parts exchange or recertification due also to poor maintenance records can also be estimated, but in these calculations, it is left aside assuming an optimistic approach. Having this and estimating an average cost of 40 USD per MH, equation (3) can be completed as:

$$\sum_{Direct\ Savings} = (2 \times 365 \times 40) + (50 \times 40) + (0) = 31200 \text{ USD per aircraft per year}$$

Regarding the Indirect Savings calculation, equation (4), the revenue per aircraft availability model is developed by IATA in [11]. The saved amount depends on the aircraft type, for an approximation, can be averaged to an amount of 12k per aircraft per day. Per year it can be estimated an average of 4 to 10 days of aircraft unavailability mainly due to reworks, overhaul interactions between the several aeronautical players, or maintaining the lessor informed. Earhart Blockchain solution can help to cut the aircraft ground time, since all the data evolution have a high degree of trust, all records are never lost or adulterated and because lessors can be always informed about the airworthiness status of the aircraft. Doing again a low estimation of an average 4 grounded aircraft days per year, with Earhart Blockchain solution implemented, it is estimated that is saved one day from these 4 grounded days.
For the Aircraft Market Value and having in consideration a modest second-hand aircraft valued in 40 million USD (values can be much higher considering newer or bigger aircraft), when time of doing the redelivery, authors in [5] estimated that the records value proximally 50% of the aircraft value. Poor records devalue the aircraft since recertifications need to be performed, which corresponds to reworks and traceability in equation (3). Having this into consideration, and again assuming a very optimistic approach with 1% savings, equation (4) can now be computed.

$$\sum_{Indirect\ Savings} = (1 \times 12000) + \frac{(1\% \times 40000000)}{10} = 52000 \text{ USD per aircraft per year}$$

The above equation reflects a savings of 1 downtime day per year, costing 12k per day, and 1% of the aircraft 40 million market value diluted for example with 10 years' operation time. The result is approximately 52 000 USD per aircraft per year of Indirect Savings that Earhart Blockchain Solution can bring.

Now, equation (2) can be calculated, giving the total savings per aircraft per year.

$\sum_{Total\ Savings} = 31200 + 52000 = 83200$ USD per aircraft per year

An average operator with 50 aircraft, can catch up savings of more than 4 million USD per year.

This estimation is not straight forward nor a rule, and obviously depends on the degree of assertiveness of each aviation stakeholder. But can easily demonstrate the loss potential that the airline business faces within this scope. In this estimation, it was not considered the digital twin savings. The number of cyber-attacks towards aviation is increasing by many factors a year, mainly because the attackers know the value of the aviation records. With Earhart Blockchain Solution all airworthiness records are safe in the blockchain, never loss or adulterated. And those records in the event of an attack, can be recovered in a very easy and effortless way. The true value of Earhart Blockchain Solution can be measured in the worth of the stakeholder's aviation records value, much higher than the result of the previous equation.

MONETIZATION AND TOKENOMICS

The work behind construction of an aircraft database can be quite laborious. By monetizing it, incentives to their construction can be made.

The airworthiness data can be monetized. Currently if new airworthiness data needs to be constructed, the solution is to hire a CAMO or specialized and experienced personnel to build this plan. Both these options required a lot of monetary and man-power efforts. An already existing maintenance plan can be tokenized and sold to a third party within minutes. This will not exclude CAMO from studying, evaluating and periodic reviews per requirements[41,42]. The expenses would then be astronomically decreased, the aircraft down time will also be reduced.

The reliability data can also be tokenized. The reliability is quite important in the development and improving components and maintenance plans. Nevertheless, the OEM's only have access to a small part of the data since the operators are not impelled to provide the required data. Monetizing the reliability data will impel the operators and maintenance providers to sell their data to the OEMs to improve their design and for the authority's supervision.

The defects found from the inspections and/or tests, represented by the added services can also be monetized. This data is relevant for the OEM's and authorities to know the degree of findings from which programmed task. From this can arise the necessity to change the intervals to adapt to the levels and number of findings. This can optimize the maintenance plans becoming less expensive[43,44]. And so, this data can also be tokenized to be sold to the interested parts.

The logistics behind the aircraft operation or Service Centres are a huge problem. Aircraft readiness can be sacrificed to reduce the available stocked material, or a considerable investment is made in SKU's to increase the material stock. Operators and Service Centres with a considerable backlog can tokenize the approximated required material per aircraft per its stage of life. This will reduce the aircraft ground time and decrease the stoked material.

[41] EASA Requirements: M.A.302(h).
[42] FAA Requirements: CFR Part 121, CFR 135.411 CFR Part 91 Subpart K, CFR Part 119.
[43] EASA Requirements: M.A.302(h).
[44] FAA Requirements: CFR Part 121, CFR 135.411 CFR Part 91 Subpart K, CFR Part 119.

TOKENOMICS:

Name: EHT (Earhart Token)
Total tokens: 1 000 000 000 EHT

1) Early development: 100 M (10%)
It is used in the early stage for Earhart Solution initial development, community construction and promotion.

2) Cornerstone Investment: 200 M (20%)
It is used for the certification of Earhart Solution within all regulatory and financial institutions.

3) Earhart Lda.: 110 M (11%)
It is used for the team development and R&D, as well as the long-term development fund support of and sustainable development of the Earhart project.

4) Marketing: 200 M (20%)
Destined for marketing purposes, used principally, but not limited to customers in site presentations, conferences, publications, etc.

5) SCO: 40 M (4%)
For early distribution for the NULS community using the SCO process. This will allow to build up a community organically from the ground up.

6) NULS foundation: 50 M (5%)
Destined for cross promotion activities to help build up both communities organically. Core team direct support, and other activities.

7) Early Industry Adopters Incentives: 100 M (10%)
To be used as incentives to industry early adopters in the use of EHT and Earhart Solution.

8) Exchanges Listing Activities and Promotion: 200 M (20%)
To be used for exchanges listing and promotion activities of EHT.

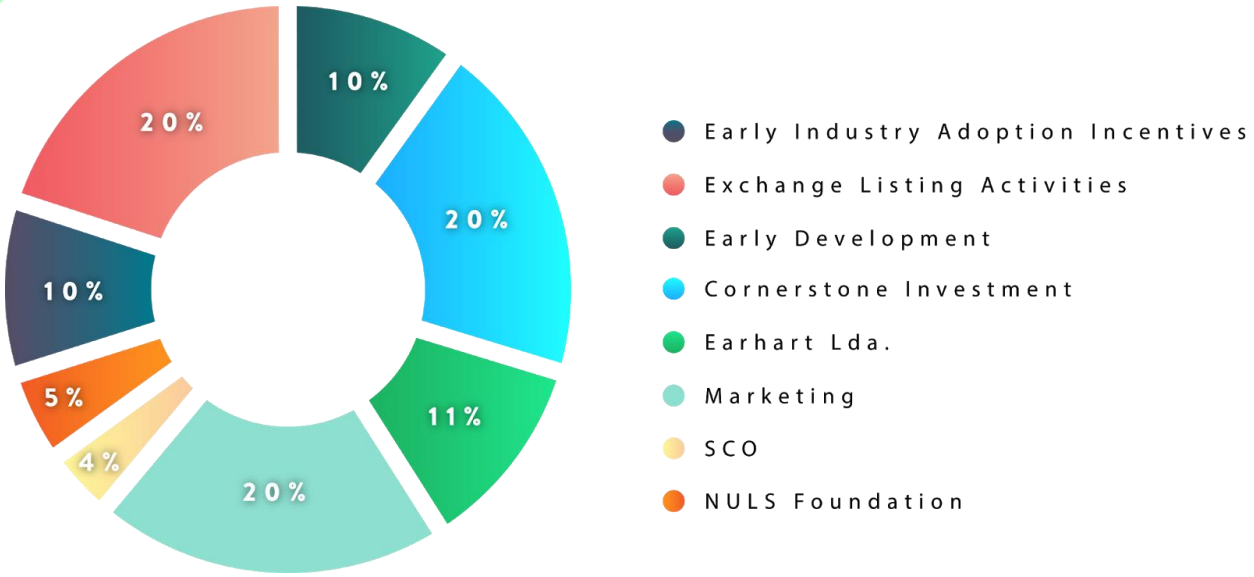

Figure 15 – Token Distribution.

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