Blockchain Solution for Efficient Aircraft Lease Phase-In Management

Autor:

Catarina Madureira

Student Nº 202230022

Dissertation presenting as partial fulfillment of the requirements necessary to obtain the degree of Master in Aeronautical Maintenance Engineering and Management

Barcarena, September 2024

This page is purposely blank

Blockchain Solution for Efficient Aircraft Lease Phase-In Management

Autor:

Catarina Madureira

Student Nº 202230022

Supervisors:

Professora Doutora Virgínia Araújo
Professor Doutor João Caldeira

Dissertation presenting as partial fulfillment of the requirements necessary to obtain the degree of Master in Aeronautical Maintenance Engineering and Management

Barcarena, September 2024

This page is purposely blank

ACKNOWLEDGEMENTS

I sincerely thank all my HiFly colleagues, especially João Abrunhosa and Yazan Khalayleh, for their invaluable support and assistance.

My heartfelt gratitude to my master's colleagues, whose support and helpfulness over the past two years have been remarkable.

My heartfelt thanks to my parents, sister, and dog, as well as my godmother Olivia and her husband Agostinho, who have been a constant source of inspiration and unwavering support.

To Professors João Caldeira and Virginia Araújo, for their interest, availability, and support, as well as for their scientific rigor, constructive criticism, and invaluable suggestions, which were essential to the coherence and success of this work.

This page is purposely blank

RESUMO

A indústria de *leasing* de aeronaves enfrenta desafios significativos durante o processo de *phase-in*, especialmente na gestão de registos de manutenção incompletos ou imprecisos, na garantia da rastreabilidade das Peças com Vida Limitada (LLPs) e na verificação de reparações não documentadas. Estes problemas complicam o cumprimento da regulamentação, aumentam os custos operacionais e representam riscos para a segurança. Esta dissertação apresenta o desenvolvimento de uma solução baseada na tecnologia Blockchain para otimizar e aumentar a segurança do processo de *phase-in* de aeronaves. O trabalho propõe uma arquitetura robusta que integra contratos inteligentes (Smart Contracts) baseados em Ethereum com o InterPlanetary File System (IPFS) - um sistema de armazenamento descentralizado de dados - estabelecendo assim um registo imutável e confiável. Utilizando uma metodologia baseada no método Design Science Research (DSR), o trabalho combina a fundamentação teórica com simulações práticas para avaliar a aplicabilidade de Blockchain no contexto da aviação.

Com base numa análise detalhada das práticas do sector e da aplicação de Blockchain na aviação, o trabalho demonstra como esta tecnologia pode melhorar a segurança e eficiência operacional, otimizar recursos humanos e reforçar a confiança entre os intervenientes no processo. O trabalho apresenta um protótipo de Smart Contract que simula uma solução de Blockchain para *leasing* de aeronaves, evidenciando o potencial da automatização de processos para uma maior transparência na gestão da documentação crítica nos processos de manutenção. Os resultados indicam que a tecnologia Blockchain representa uma alternativa viável para modernizar o processo de *leasing* de aeronaves, proporcionando redução significativa dos riscos operacionais e de conformidade, além de maior transparência e segurança na indústria de *leasing* aeronáutico.

Palavras-Chave: Blockchain, processo phase-in, leasing de aeronaves, smart contract, rastreabilidade, indústria aeronautica

ABSTRACT

The aircraft leasing industry faces significant challenges during the phase-in process, particularly in managing incomplete or inaccurate maintenance records, ensuring the traceability of Limited Life Parts (LLPs), and verifying undocumented repairs. These issues complicate regulatory compliance, increase operational costs, and pose safety risks. This dissertation presents the development of a Blockchain-based solution to optimize and enhance the security of the aircraft phase-in process. The work proposes a robust architecture that integrates Ethereum-based smart contracts with the InterPlanetary File System (IPFS) — a decentralized data storage system — thereby establishing an immutable and reliable record. Using a methodology based on the Design Science Research (DSR) method, the study combines theoretical foundations with practical simulations to assess the applicability of Blockchain in the aviation context.

Based on a detailed analysis of sector practices and the application of Blockchain in aviation, the study demonstrates how this technology can improve safety and operational efficiency, optimize human resources, and strengthen trust among stakeholders in the process. The work presents a prototype of a Smart Contract simulating a Blockchain solution for aircraft leasing, highlighting the potential of process automation for greater transparency in the management of critical documentation in maintenance processes. The results indicate that Blockchain technology represents a viable alternative to modernize the aircraft leasing process, providing significant reductions in operational and compliance risks, as well as increased transparency and security in the aircraft leasing industry.

KEYWORDS: Blockchain, phase-in process, aircraft leasing, smart contracts, traceability, aviation industry

Contents

List of Figures

List of Tables

This page is purposely blank.

Acronymous and Abbreviations

ACMI - Aircraft, Crew, Maintenance and Insurance

AD - Airworthiness Directive

AOC - Air Operator Certificate

ARINC - Aeronautical Radio, Incorporated

BC4A - Blockchain for Aviation

BH - Block Hour

BtB - Back-to-Birth Traceability

CAMO - Continuous Airworthiness Maintenance Organization

CIDs - Content Identifiers

CofA - Certificate of Airworthiness

DFP - Digital Fingerprint

DLT - Distributed Ledger Technology

DSR - Design Science Research

EASA - European Union Aviation Safety Agency

EU - European Union

EUROCONTROL - European Organisation for the Safety of Air Navigation

EVM - Ethereum Virtual Machine

FAA - Federal Aviation Administration

FH - Flight Hours

FC - Flight Cycles

GE - General Electrics

HPT - High-Pressure Turbine

IATA - International Air Transport Association

IFPS - Interplanetary File System

IoT - Internet of Things

LLP - Life Limited Parts

MSN - Manufacturer's Serial Number

MPD - Maintenance Planning and Data

MRO - Maintenance Repair and Overhaul

UK - United Kingdom

ULD - Unit Load Devices

OEM - Manufacturer

OVH - Overhaul

SAMR - Secure Aircraft Maintenance Record

SIAN - Safety Management Safety Information Advisory Notices

SUP - Suspected Un-Approved Parts

PoA - Proof of Authority

PoW - Proof-of-Work

1 Introduction

1.1 Problems and Motivation

Lockdowns and border closures devasted the airline industry, forcing major changes including the early phase-out of iconic planes like the well-known Airbus A380/A340 and the queen of the skies Boeing 747.[1][2]

But now that air travel is recovering from the COVID-19 pandemic and already reaching the values of 2019, the operators need to find airplanes very fast, speeding up the phase-in process. Referring to EUROCONTROL the European Union (EU) traffic in 2023 was 92% of 2019 with an average of 23,841 daily flights(Eurocontrol, 2024) and operating profits are expected to reach $59.9 billion in 2024, up from an estimated $52.2 billion in 2023[3].

When bringing a new aircraft to a fleet it is important to have a clear view of the history of critical components such as engines. An engine goes through repairs, shop visits, incidents, etc and every lost document makes the engine less valuable.

In the summer of 2023 during routine engine works TAP Air Portugal Maintenance and Engineering Engine Shop department found that some parts, namely bushings, of the CFM56 engine were worn out despite the completely new Federal Aviation Administration (FAA) / European Union Aviation Safety Agency (EASA) certificate from the manufacturer (OEM)[4]. This situation launched all the alarms with the parts supplied by United Kingdom (UK) shop AOG Technics and a major scandal in aviation maintenance started with national authorities issuing safety information and Safety Management Safety Information Advisory Notices (SIAN) (annex II) from the EASA[5].

[1] https://www.qantasnewsroom.com.au/media-releases/qantas-farewells-queen-of-the-skies/
[2] https://www.airfranceklm.com/en/phase-out-air-france-entire-airbus-a380-fleet
[3] https://www.iata.org/en/pressroom/2024-releases/2024-06-03-01/
[4] https://aviasg.com/en/media/our-news/locatory/unveiling-the-aog-technics-scandal-implications-for-the-aircraft-mro-industry
[5] https://www.easa.europa.eu/en/domains/aircraft-products/suspected-unapproved-parts/aircraft-parts-distributed-aog-technics

In this case, it is important to understand whether the certificates are genuine and how to revoke them when defects are identified or when cases of 'suspected unapproved parts' (SUP) are detected. Security and trust certificates of parts get very important and Blockchain can save time and money for operators and Maintenance Repair and Overhaul organizations (MROs).

Another challenge the aviation industry faces is the growth of aircraft leasing moving planes from one company to another (phase-in). Many important documents can be lost, damaged, etc., reducing the value of the aircraft and critical components such as engines and landing gears.

Even in a part-out process, having good records of all rotable units is important to sell them at the highest price possible.

1.2 Context

Aircraft phase-in refers to the process of integrating a new or used aircraft into an airline's operational fleet. This involves a series of technical, regulatory, and logistical steps to ensure the aircraft meets safety, airworthiness, and performance standards before entering service. Key activities include detailed inspections, necessary modifications, registration with aviation authorities, crew training, and updating maintenance records. The phase-in process ensures the aircraft is fully compliant with both airline and regulatory requirements, allowing for a seamless transition into commercial operations, for more details check section 2.1.

Blockchain is a decentralized and secure digital ledger that records transactions across multiple computers, ensuring transparency, immutability, and resistance to tampering. It operates without central authority, relying on cryptographic techniques and consensus mechanisms to validate transactions. Originally designed for Bitcoin, blockchain technology is now used in various fields such as finance, supply chain management, and smart contracts, offering a reliable way to verify and store data and in chapter 2.2 you will find more information.

1.3 Research Drivers

The engineers and the International Air Transport Association (IATA) identified significant challenges in the phase-in process for used aircraft due to incomplete or missing historical documentation. Specifically, there are difficulties in performing Back to Birth Traceability (BtB) for Life-Limited Parts (LLP) due to undocumented Flight Hours (FH) and Flight Cycles (FC), the absence of maintenance records for base//line inspections, modifications, Airworthiness Directives (AD), and SUP, as well as unidentified previous repairs on the fuselage performed by former operators. These gaps in documentation increase the complexity of ensuring regulatory compliance, safety, and operational readiness during the phase-in process.

Main Research Problem:

Inability to maintain records and guarantee their security without tampering, making the phase-in process complex and non-reliable.

Below are the problems in detail and in the resume at Lean Figure 1:

- **P1 - Difficulty in performing Back to Birth Traceability of LLP because of Undocumented FH and FC**

  LLP means any Part that has a pre-determined life limit mandated by the Manufacturer or the Certificating Authority which requires any such Part to be discarded upon reaching such life limit that can be by FH or FC. Undocumented parts are especially important when we talk about an Engine, whose primary failure is likely to result in a catastrophic engine. And as everything in aviation is related to money, parts without vital master data are worthless.

- **P2 - Absence of Records concerning base/line maintenance inspection events, modifications, AD, and identification of SUP**

Aircraft documentation is inspected meticulously by the Continuous Airworthiness Maintenance Organization (CAMO) team during the delivery or redelivery process of an aircraft on lease, giving special attention to modifications, mandatory ADs from the manufacture and maintenance inspections events with the replacement of LLPs or hard time components that once reached the limit established by the OEM need to be removed for Overhaul (OVH) or bench testing. During this analysis, it can be identified SUP units with fake certificates and wrong accomplishment of tasks.

- **P3 - Unidentified Old Repairs on the Fuselage performed by previous operators of the aircraft**

During the phase-in, the documentation associated with the repairs performed on the aircraft must be analyzed as different repairs on the external fuselage were performed during the previous years of operation and some may be not correct or even with missing Digital Fingerprint (DFPs) for analysis.

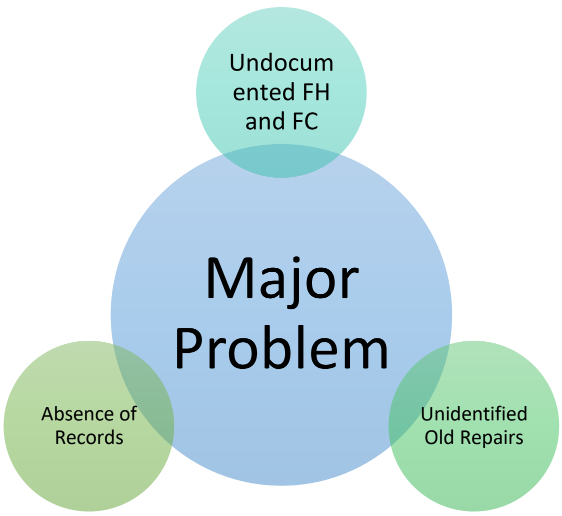


Figure 1 – Lean figure representing the problems

1.3.1 Research Questions

Given the problems previously identified, this dissertation proposes to answer the following major question:

Main Research Question:

How can the phase-in process of used aircraft be optimized to address challenges related to incomplete documentation, including Back to Birth Traceability, maintenance records, and the identification of prior repairs?

Based on this major question, the following specific research questions were identified:

- **RQ1:** How can airlines safely secure Back to Birth Traceability documentation for LLP during a phase-in process?
- **RQ2:** What strategies can be implemented to address the absence of maintenance records, including base/line inspections, modifications, AD, and SUP, during the phase-in process of used aircraft?
- **RQ3:** How can airlines identify and manage undocumented or unidentified old repairs on the fuselage performed by previous operators to ensure safety and compliance?

1.3.2 Research Objectives

To answer the research questions previously identified, the following objectives are proposed:

RO1: Identify a technological solution as an option to create a secure, trusted, and efficient solution to reduce the manpower and costs of the traditional phase-in process, with all the relevant documentation. With this technology, errors in tracking aircraft parts would be minimized.

The aim of this is to answer questions **RQ1** and **RQ2**.

RO3: Evaluate a technological solution to create a system with photos, videos, and documents of the aircraft's previous operators but also with the details of pre-delivery inspection.

The aim of this is to answer question **RQ3.**

1.3.3 Contributions

This subchapter presents the main contributions to the development of this dissertation:

C1 / C2: To address the incompleteness of documentation related to LLPs and records, it proposes the creation of blockchain software based on Ethereum and Smart Contracts. This proposal allows us to create a private blockchain network for the upload of files related to the most important components and contracts including the relevant information about an item (like localization on the engine, material, and maintenance logs). On the other hand, Smart Contracts can provide an automatic contract for the lease of the aircraft and can contain different allocations of money depending on findings during the Pre-Delivery of the aircraft. As both P1 and P2 are related to a lack of documentation, the proposal solution will be done together.

C3: To improve the analysis of old repairs, this study proposes evaluating the application of blockchain technology. The plan is to use a private blockchain and smart contracts, with migration capabilities, for an app that includes detailed reports such as DFP, manual references, damaged dimensions, and sizes, accompanied by photos and videos. This will allow users to take a virtual tour of all previous repairs.

1.4 Dissertation Structure

This Dissertation is divided into six chapters, outlined as follows:

Chapter 1 is dedicated to the introduction, where the problem is defined, and the objectives of this thesis are explained.

Chapter 2 describes in detail the concepts of aircraft phase-in lease and blockchain for an outside person to understand the problems of this work.

Chapter 3 contains the literature review and the state of the art of blockchain already implemented in the present aviation industry.

Chapter 4 presents all the methodologies utilized during the project.

Chapter 5 describes the framework as contributions to the problems identified in Chapter 1, namely the concept, methodology, and process of C1 and C3 and the limitations found in both studies.

Chapter 6 presents the conclusions and future work.

2 Background

2.1 Current Phase In Processes

The phase-in and phase-out processes in aircraft leasing refer to the procedures involved when an aircraft is introduced to or removed from an airline's fleet, typically during the start or end of a lease. During the phase-in, the lessee (airline) receives the aircraft, and this process includes inspections, documentation reviews, and regulatory compliance to ensure the aircraft meets operational and safety standards. The phase-out happens when the lease ends, requiring the aircraft to be returned in an agreed-upon condition.

2.1.1 Particularities of the Aviation Leasing Industry

Since the beginning of the Jet Age with the introduction of Boeing 707 to modern aviation in 1970 with the birth of Airbus manufacture, the industry has had many changes, one of which is Aircraft Leasing.

Aircraft leasing is a common practice in the aviation industry and provides airlines the flexibility to manage their fleet without committing to the full cost of purchasing an aircraft per example in 2018 the price of an Airbus A330-300 was 264.2 M USD (Annex III).

The Lease Agreement is a legal document outlining the terms under which one party agrees to rent property from another party and guarantees the Lessee (the renter) use of an asset and guarantees.

But for better understanding, it is important to know which aircraft receives a unique number or code called MSN, the Manufacturer's Serial Number when it's manufactured. This code/number will identify the plane during its life specially used for lease contracts, incidents/accidents.

In 1970 the leasing of aircraft only represented 0.1% and in 2021 it was already 52% of the total aircraft in use(Tozer-Pennington V, 2023) as shown in Figure 2.

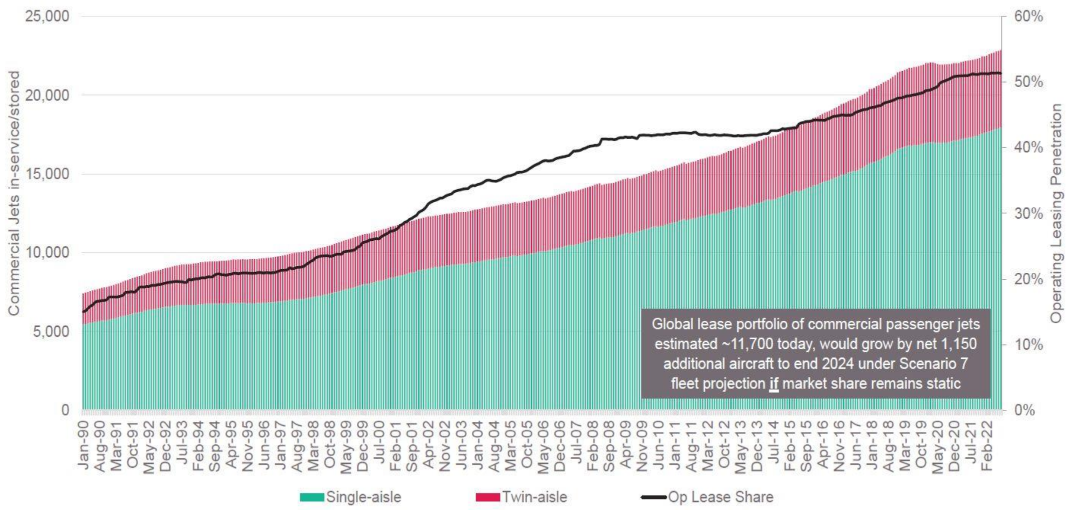
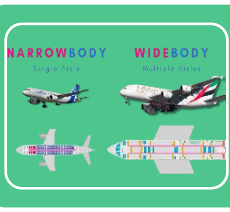


Figure 2 – Impact of the lease over the years (*Tozer-Pennington V, 2023*))

Table 1 shows how the leasing market is identified:

Table 1 – Leasing Market

By Aircraft Lease
- Operating or Dry Lease
- ACMI or Wet Lease



By Aircraft
- Wide Body
- Narrow Body

By Region
- North America
- Latin America
- Europe
- Middle East and Africa
- Asia

Below it's an explanation concerning the two types of leases[6]:

- The operating lease, also known as a dry lease, is a contract between an aircraft owner (or manager) and an operator. An operating lease is where the operator rents the aircraft from the owner for a defined lease term, typically between 6-12 years, and returns the aircraft to the owner at the end of the lease term. The lessee, who has operational responsibility and control of the aircraft, pays a monthly lease rental to the aircraft owner and is obligated to return the aircraft to the owner at the end of the lease term in a condition as defined in the lease agreement. Usually done by airlines like TAP or Lufthansa. ACMI leasing refers to the provision of Aircraft, Crew, Maintenance, and Insurance from one operator (an Air Operator Certificate (AOC holder)) to another for a defined period and utilization and is charged on an "all-in" hourly rate with a minimum guaranteed number of block hours each month or over the lease term. This type of lease is mainly used as a short-term solution for airlines that need periodic additional capacity during peak seasons like summer[7].

Figure 3 shows how the "normal" market of aircraft is divided into two groups, Wide and Narrow bodies.

Wide Body aircraft is known as a plane with a fuselage wide enough (diameter of 5 to 6 meters) to accommodate two passenger aisles like the Airbus A380, and Boeing 777. On the other hand, Narrow Bodies have a typical diameter of 3 to 4 meters with a single aisle being the most famous A320 and B737.

---

[6]https://www.accaviation.com/a-comparison-of-acmi-leasing-operating-leasing-and-aircraft-ownership-to-lease-or-to-own/

[7] https://www.acumen.aero/aircraft-lease-management

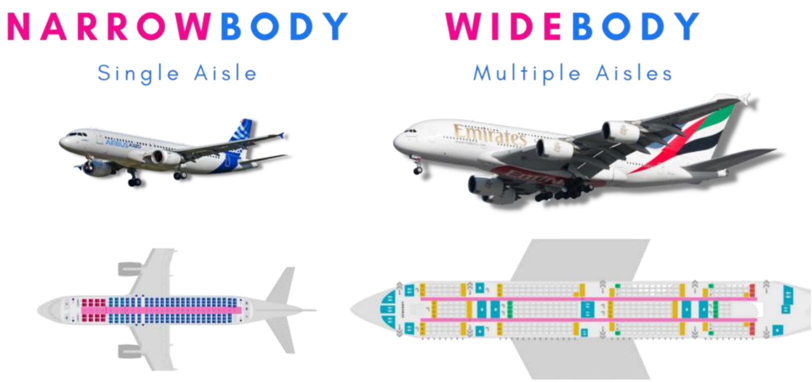


Figure 3 – Wide VS Narrow Body (By Pilot Institute[8])

At this moment, the most famous Leasing companies are AerCap, Avolon, Air Lease Corporation and DAE Capital (Tozer-Pennington V, 2023).

[8] https://pilotinstitute.com/narrowbody-vs-widebody-aircraft/

2.1.2 Detailed Process Description

In simple words, an aircraft phase-in entails transferring the responsibility for the continuous airworthiness of the aircraft from the previous operator to the next one.
To facilitate this process, IATA created guidance of best practices for aircraft lease (International Air Transport Association, 2017) where operators can find all steps from the Background to the Redelivery (Figure 4).

Figure 4 – Steps to perform a Phase-In (International Air Transport Association, 2017)

During the time of operation, it is important to keep all the records updated to continue the airworthiness of the aircraft but also to keep the value in case of a new redelivery to another customer.

Below we can find the key considerations for aircraft leasing[9]:

- Lease Terms: Duration, renew options, hourly rate penalties or conditions for early termination of the contract;
- Financial Terms: Lease rates, maintenance checks payments and reserves and security deposits;
- Regulatory Compliance: Compliance with aviation regulations including state of registration and operation;
- Maintenance: Responsibilities for all the maintenance (base and line);
- Return Conditions: Responsibilities for the condition of return and potential penalties for non-compliance;
- Insurance: Coverage requirements and responsibilities.

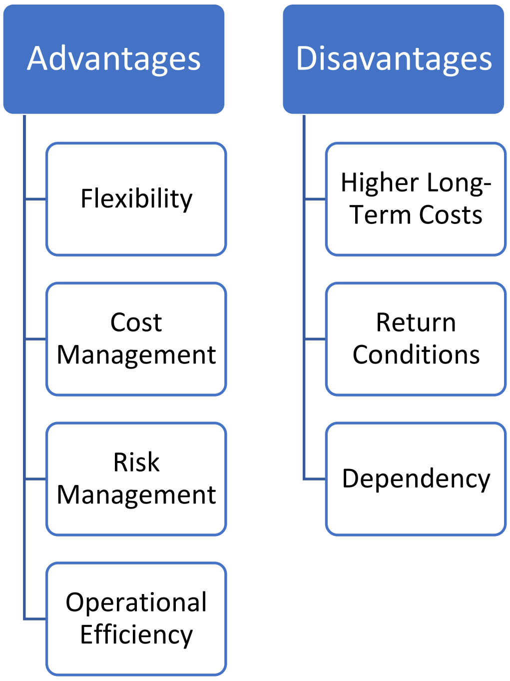
[9] https://www.acumen.aero/aircraft-lease-management

2.1.3 Challenges and Pain Points

If any of these documents are missing or lacking information, it can result in a loss of money.

For the aircraft leasing market itself, on table 2 we can find the list of advantages and disadvantages[10]:

Table 2 - Advantages and Disadvantages of Leasing Market



[10] https://www.accaviation.com/a-comparison-of-acmi-leasing-operating-leasing-and-aircraft-ownership-to-lease-or-to-own/

2.1.4 Financial Implications

The lease rent can be negotiated after phase-in inspections depending on the cabin, and engine status, currently offered in the market and may depend on the fly time hours.

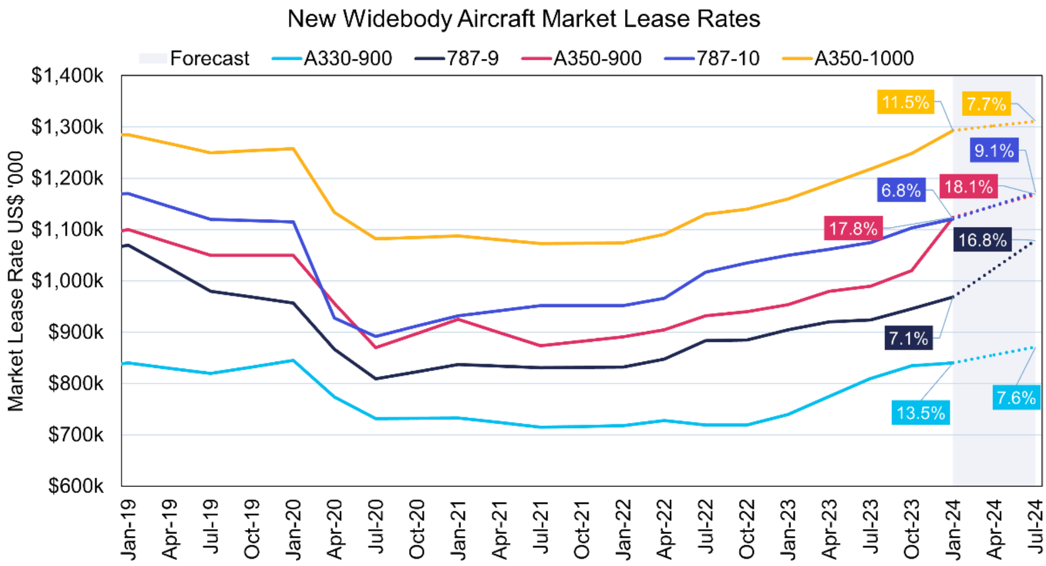


Figure 5 - New Widebody Aircraft Market Lease Rate (IBA Insight & IBA Research, 2024)

In Figure 5 is possible to see the evaluation of the rate lease during the COVID-19 pandemic.

A Block Hour (BH) is when the aircraft door closes at the departure of a revenue flight until the moment the aircraft door opens at the arrival gate following its landing and the average value for an A330-200 is around US$5.000.

As additional information, the average mensal lease of the same aircraft is between US$375.000 and US$400.000 but this number will depend on the contract, age of the plane, cabin, etc.

Concerning the engine CF6-80E, the normal lease rent varies between US$100.000 and US$120.000.

2.2 The Role of Blockchain in the Aviation Industry

Blockchain technology started gaining popularity when Bitcoin was launched and now a days is used in all areas from grocery stores to the maritime industry. EASA – European Union Aviation Safety Agency describe it as *"A decentralized and distributed digital ledger consisting of records called blocks that are used to record actions across many computers so that any involved block cannot be altered retroactively, without the alteration of all subsequent blocks. This allows the participants to verify and audit transactions independently and relatively inexpensively."*(European Union Aviation Safety Agency, 2023).

2.2.1 Basics of Blockchain Technology and How it Works

Distributed Ledger Technology (DLT) is a decentralized database (Figure 6) system where data is recorded, shared, and synchronized across multiple locations, or nodes, without needing central authority. Each participant in the network has access to an identical copy of the ledger, and any changes or transactions are validated through consensus mechanisms, ensuring security and transparency. DLT reduces the risks of data tampering and fraud because records are immutable once added and can be independently verified and blockchain is the most well-known example of DLT. (Government Accountability Office, 2019)

A blockchain is a digital database that keeps bits of information on a (public or private) peer-to-peer network. It offers transactions without the need for a middleman. (Tapscott & Tapscott, 2016)

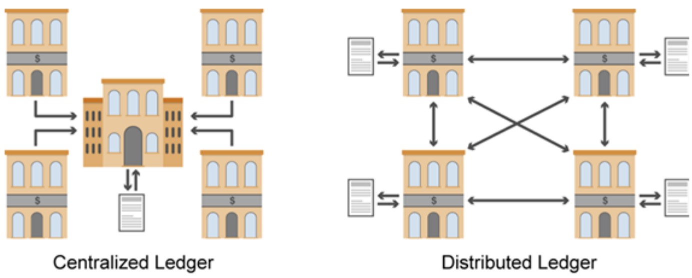


Figure 6 – Ledger Types (Government Accountability Office, 2019)

But for us to better understand Blockchain, we need to go back to money, crypto coins, and BitCoin.

Money started to be used in the transaction of goods and services with stones, whale's teeth, feathers, and in the Greek era metal coins with precious metals. On 1 January 1999, eleven countries agreed on the Euro Zone, having the same currency controlled by the European Central Bank facilitating business, encouraging the growth of the economy with the same base as the Roman times – Trust.

Nowadays we make payments on smartphones using Apps like Uber, Revolut, or even Apple Pay without physical money, just bits and bytes on a network.

Bitcoin is a digital payment system/network and a cryptocurrency that was described in a white paper in 2008 written using the pseudonym of Satoshi Nakamoto and launched as open-source software in 2009. As blockchain, Bitcoin uses a decentralized peer-to-peer protocol for tracking and verifying transactions (does not rely on a central server) (Nakamoto, n.d.).

Now getting back to the Blockchain and as shown in Figure 7, each group of transactions/information "the block" is encrypted and combined chronologically across a network "chain" so thieves can't steal that information without "accessing" the hundreds of thousands or even millions of nodes on the network[11]. But, if you have the key, you can unlock that information.

[11] https://www.forbes.com/advisor/investing/cryptocurrency/what-is-blockchain/

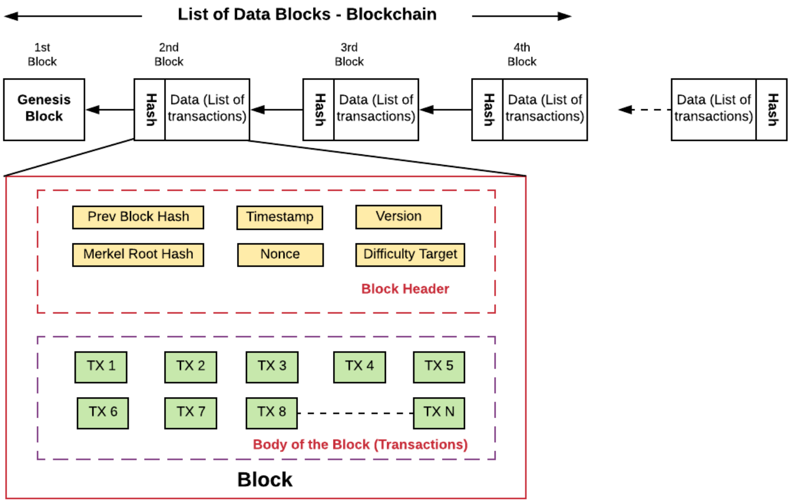


Figure 7 – Block and Hash[12]

Each block contains a unique cryptographic *hash*, which is a digital signature that ensures the integrity of the data within the block and converts an input of letters and numbers into an encrypted output of a fixed length. Figures 7 and 8 show how the *hash* of the previous block in the chain is also included in the current block, creating a link between the two. This linking mechanism ensures that the blockchain is a continuous, unbroken chain of blocks that cannot be altered without detection[13].

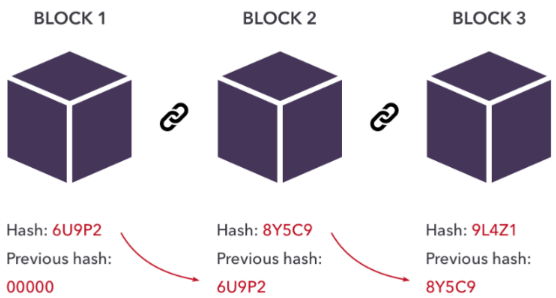


Figure 8 - Hashing Algorithm [14]

The complex process is the creation of blocks called mining, and it involves solving a complex mathematical puzzle that requires significant computational power. Miners will

[12] https://www.omni-academy.com/top-29-advanced-blockchain-interview-questions-answered/?print=print
[13] https://medium.com/@esthon/blocks-chains-and-hashes-b3bc323b978e
[14] https://www.ig.com/en-ch/trading-strategies/what-is-blockchain-technology--200710

compete to complete the puzzle first and with this, add a new block to the blockchain using a proof-of-work (PoW) consensus mechanism (Welfare, 2019).

Blockchain reduces vulnerability and increases transparency in all business sectors as information is stored digitally and it does not have a centralized point or an intermediary to carry out the transactions.

Antony Welfare, the father of this technology defines Blockchain in nine words as *"Thrusted and efficient way of sharing data and transaction*" (Welfare, 2019).

Blockchain technology is primarily categorized into public and private, each type has distinct characteristics, advantages, and disadvantages. Here is an in-depth look at both[15] in Table 3:

Table 3 - Public VS Private Blockchain

Public	Private
• Open Sourche, anyone can participate • Hight Decentralization • Low Speed • Low Efficiency • Per example Bitcoin, Polygon	• Participants are pre-selected • Low Decentralization • Fast Speed • High Efficiency • Per example Hyperledger, Corda

[15] https://www.investax.io/blog/public-vs-private-blockchain

Concerning the Public Blockchain, the main advantages and disadvantages are listed below:

Advantages:

- Transparency and Trust, offering transparency and building trust among users;
- Security, the decentralized and consensus mechanisms provide robust security against attacks and fraud.

Disadvantages:

- Speed, transactions can be slower and more expensive compared to private blockchains;
- Energy Consumption, PoW can be very energy intense.

For the Private Blockchain, the main advantages and disadvantages are listed below:

Advantages:

- Privacy and Confidentiality, data and transactions are only accessible to authorized persons ensuring confidentiality;
- Scalability, more scalable than public blockchain due to controlled participation and more efficient mechanisms;
- Speed, transactions are processed faster due to fewer participants.

Disadvantages:

- Trust, required trust in the central authority or company managing the blockchain;
- Security, might me more vulnerable to internal attacks;
- Innovation, restricted access can limit the pace of innovation compared to the public blockchain.

2.2.2 Ethereum and Smart Contracts

Ethereum was proposed by Vitalik Buterin in 2013 and launched in 2015 (Buterin, n.d.) and is a decentralized blockchain and development platform that establishes a peer-to-peer network (Figure 9) that securely executes and verifies application code, called smart contracts.

Smart contracts are like contracts in the real world, but this one is digital and "automating transactions" (Welfare, 2019). It's a self-executing contract where the terms of the agreement are directly written into lines of code and operated using the Ethereum Virtual Machine (EVM) without intermediaries.

The main advantages are:

- Automation and Efficiency: Reduce the need for manual intervention, thus lowering costs and increasing speed;
- Security and Trust: Immutable and transparent nature ensures that contract terms are tamper-proof;
- Decentralization: Eliminates the need for a central authority, providing more equitable access.

Both Bitcoin and Ethereum use Blockchain as a distributed database. However, bitcoin uses Blockchain to store transaction data while Ethereum uses Blockchain to execute code on it.

One important concept we need to understand is Proof of Authority (PoA). PoA is a consensus mechanism used in blockchain networks that relies on a small number of pre-approved authorities, to validate transactions and create new blocks. Unlike PoW, where computational power or token holdings are used to secure the network, PoA leverages the reputation of validators, who must be known and trusted entities.

This makes PoA highly efficient, as it reduces the computational requirements. Still, it centralizes control to a few trusted nodes, limiting decentralization and potentially compromising security if the authorities are compromised. (Zhang et al., 2019)

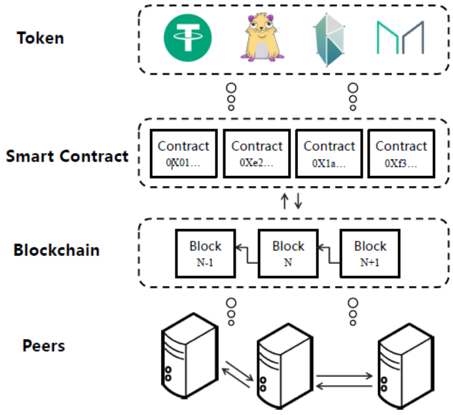


Figure 9 – Ethereum (Zheng et al., 2019)

Another important notion to keep in mind is the Interplanetary File System (IPFS). This system is a decentralized, peer-to-peer network designed for storing and sharing files in a distributed manner.

Unlike traditional centralized systems, IPFS breaks files into smaller pieces and distributes them across multiple nodes in the network, ensuring redundancy and improving access speed. Each file and its contents are uniquely identified by a cryptographic hash, making the system highly secure and resilient to censorship, basically being the hard drive of Blockchain. (Su et al., 2024)

By integrating with Ethereum's smart contracts, IPFS can provide secure and cost-effective storage capabilities within the crypto ecosystem to enhance Ethereum's overall performance.

The simplest example of a smart contract is a transaction between a consumer and a business, where a sale is made, for example, an Amazon subscription to a product.

2.2.3 Application of Blockchain in Various Industries

Figure 10 shows how Blockchain technology is currently used worldwide (International Air Transport Association, 2018) for money transfers, contracts, the Internet of Things (IoT), personal identification security, logistics, healthcare systems, tokens, aviation, and even at governments.

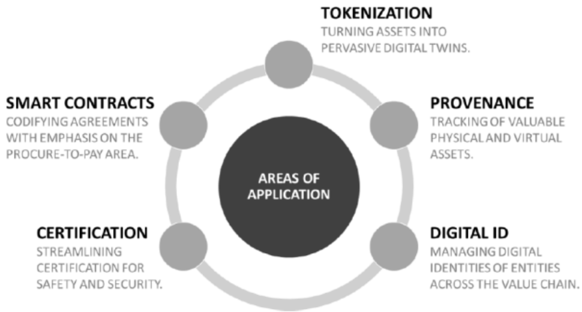


Figure 10 - Applications of Blockchain

For example, the United States Department of Homeland Security has been using blockchain to record and safely store data captured from its safety cameras. On the other hand, the De Beers Group is using this technology to track the importation and sale of diamonds, and DHL, is at the forefront of blockchain-backed logistics, using it to keep a digital ledger of shipments and maintain the integrity of transactions[16].

[16]https://medium.com/@Matzago/50-examples-of-how-blockchains-are-taking-over-the-world-4276bf488a4b

2.2.4 Application of Blockchain in Aviation

Blockchain technology is currently used in the all-aviation industry, from ticket reservation and loyalty programs to boarding or hold bag tracking and most importantly maintenance (International Air Transport Association, 2018; Vevera & Georgescu, 2024).

In this section, we will resume several projects initiated by well-known organizations related to the implementation of blockchain in the aviation industry:

1) *EASA Webinar Project*

EASA, for example, is currently a project Webinar to encourage companies to adopt Blockchain to their reality and create real-time certification, immutable and secure records/certificates of aircraft parts, maintenance history, approved/fake parts, and many other critical information[17].

Figure 11 – EASA Webinar [18]

[17] https://www.easa.europa.eu/en/newsroom-and-events/events/virtua-blockchain-airworthiness-aviation-introductory-webinar

[18] https://www.easa.europa.eu/en/newsroom-and-events/events/virtua-blockchain-airworthiness-aviation-developing-solutions-and

2) *BtB Traceability of Aircraft parts*

Air France – KLM group has announced last July a partnership with SkyThread and Parker Aerospace Group for the back-to-birth track and traceability of aircraft parts for the Boeing 787 fleet using blockchain technology[19].

"This is a significant milestone for the aviation industry. Never have an Operator and a Tier-1 OEM been able to share this depth of data. By leveraging Blockchain technology, we can establish a comprehensive aircraft parts track and trace solution that ensures complete transparency and traceability of our parts. The system will also provide our valued customers the assurance of part authenticity through access to full part history." Jeff Smith, Head of Digital Product Programs at Parker Aerospace Group

3) *Basic Training and Industry Solutions*

On the other hand, Lufthansa Industry Solutions[20] created an initiative called Blockchain for Aviation (BC4A) to bring together all fields of expertise like software developers, aircraft manufacturers, MRO service providers, logistics providers, lessors, and regulators to understand the potential of this technology.

4) *Softwares*

Even companies like PWC, Microsoft, Deloitte, Aeron or SkyThread launched services of blockchain for the aviation/aerospace industry (Figure 12).

---

[19] https://www.afiklmem.com/en/press-release/25072024_afiklmem-and-parker-aerospace-group-reach-major-milestone-in-deploying-skythread-s-blockchain-based-aircraft-parts-track-and-trace-platform-for-787-fleet

[20] https://www.lufthansa-industry-solutions.com/de-en/solutions-products/aviation/generating-more-transparency-in-aviation-with-blockchain-technology/

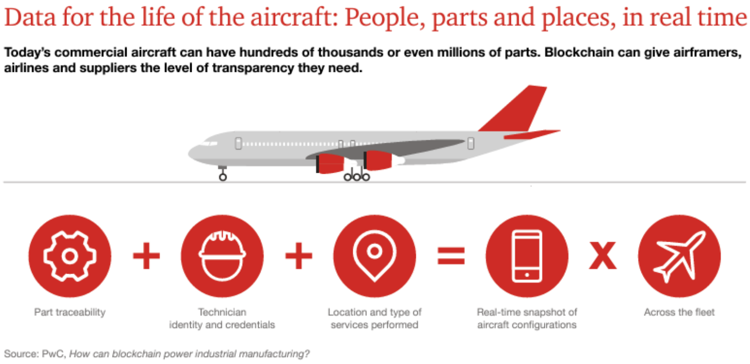


Figure 12 – Example of the use of Blockchain in the Aviation

5) *Cargo Handling ULDs*

On the operational side, in a recent study conducted at Heathrow Airport UK, airlines saved 7% in cargo handling due to the migration of Unit Load Devices (ULDs) to blockchain making supply chains more efficient and setting charges between parties easier[21].

2.2.5 Regulation and Security

Has mentioned by Antony Welfare in his book (Welfare, 2019), the Blockchain consists of Five important characteristics that are the main key for justifying its use in aviation:

- For Truth and Trust
- For Transparency
- For Security
- For Quality and Certainty
- For Efficiency

[21] https://www.aventus.io/success-stories/aventus-overhauls-operational-efficiency-of-airline-cargo-with-blockchain-at-heathrow-airport

2.3 Benefits of Blockchain Implementation in Aviation

Implementing blockchain technology in the aviation industry will bring several significant benefits and can enhance operational efficiency, improve safety and security, reduce costs, and provide a better experience for passengers.

Here are some key advantages:

- Enhanced Maintenance and Safety
- Efficient Supply Chain Management
- Passenger Experience
- Identity Verification
- Operational Efficiency
- Regulatory Compliance
- Cost Reduction
- Sustainable Practices
- Enhanced Security

3 Literature Review

3.1 State of the Art in Aviation Blockchain

Current research on Blockchain applications in the aviation industry is small and namely confined to a specific sector - passenger services - but during the last two years, a major investment in maintenance was made.

This literature review considers the research of articles and dissertations searched on ASM, IEEE, Webscience, Researcch Gate and Google Scholar, giving special focus to improvements in the effectiveness, and efficiency of this activity in various areas to highlight the importance of applying Blockchain in the future development of the aviation industry.

3.2 Analysis of Use Cases

3.2.1 Documentation Practices in Aviation

This topic corresponds to P2, as outlined in section 1.3.3, and several studies have explored the use of blockchain to address it.

The first one uses Hyperledger Fabric a different transaction flow and consensus mechanism that allows a higher performance in lower-scaled networks, and it can reach the finality of transactions, making them impossible to change or reverse. Since maintaining consensus between the ledger copies in Fabric does not require proof of work, no cryptocurrency is needed as an economic incentive for block creation. The analysis of the study model shows a considerable potential of the technology to increase the efficiency of an MRO network through credibility, traceability, and transparency of the data, with high reliability and system availability, especially for larger networks with a high complexity of process flows (Schyga et al., 2019).

In another study, the authors proposed the creation of Secure Aircraft Maintenance Record (SAMR) hosted by the Linux Hyperledger. The blockchain developed in this work uses a distributed ledger data structure to allow all participants and authorized parties to view the same information (Aleshi et al., 2019).

The third study uses Python programming as a modern way of storing and managing maintenance aviation records (Andrei et al., 2021).

3.2.2 Spare Parts

Spare parts are essential assets to maintain productivity and operations. A spare part is used for the repair or replacement of failed units. However, today's spare part inventory systems fall short of providing reliable tracing and tracking of spare parts ownership which poses serious threats to their authenticity. This problem would be solved using Blockchain IPFS Server and each spare part has its smart contract (Hasan et al., 2020).

Another article introduces an innovative framework utilizing Non-Fungible Tokens (NFTs) and digital twins to enhance aviation component lifecycle management. By linking NFTs with digital twins, the system ensures immutable, blockchain-based records for real-time tracking, compliance, and predictive maintenance. The proposed architecture integrates blockchain, smart contracts, and IoT for seamless data sharing and decision-making across stakeholders, improving safety, transparency, and efficiency in aviation operations (Kabashkin, 2024).

3.2.3 Loyalty Reward Program

A customer loyalty program, also known as frequent flyer miles, offers financial benefits to frequent flying passengers for using airline services. Since a loyalty reward program involves multiple parties including participating merchants, platform providers, and customers with each having competing needs, blockchain adds value to the ecosystem by providing an immutable and verifiable ledger of all the transactions. A common thread in all blockchain-based loyalty programs is tokens that are used as a reward and form a medium for transactions. Unlike traditional paper-based reward systems, tokens cannot expire, and this resolves the current major problem with traditional loyalty programs (Kumar et al., 2019).

3.2.4 Aviation Database

The AviChainDB project is a hybrid blockchain-based aviation database currently under development. AviChainDB is designed to save the data generated in the Aeronautical Radio, Incorporated (ARINC) standards also known as "Mark33 Digital Information Transfer System (DITS) "to a special blockchain network developed on the Ethereum platform (Takaoğlu Mustafa et al., 2021).

3.2.5 Airport Security

In this paper, the authors perform and investigate the impact of blockchain-based smart contracts to enhance the security, immutability, and transparent execution of the issuance process (Karamitsos et al., 2023).

3.2.6 Air Cargo

The study proposes using blockchain in combination with IoT and smart contracts to optimize logistics, improve data sharing, and automate processes like booking, compliance verification, and financial transactions. These innovations aim to reduce cargo handling times, increase transparency, and foster collaboration among air cargo stakeholders, ultimately making the sector more competitive and efficient(Poleshkina, 2021).

3.3 Research Gaps

While blockchain technology has demonstrated significant potential across various aspects of aviation, several research gaps remain that need to be addressed to fully harness its capabilities. One primary gap is the integration of blockchain with existing aviation systems, particularly legacy technologies. Many aviation organizations still rely on outdated software and hardware, making the transition to blockchain challenging. Future research should focus on developing solutions that enable seamless integration between blockchain and current systems, ensuring minimal disruption and cost-effective adoption.

Another gap lies in the scalability of blockchain solutions within the aviation sector. While several studies have focused on smaller-scale implementations, the aviation industry is vast and highly complex, with diverse stakeholders involved. More research is needed to explore how blockchain can scale efficiently across larger, more intricate networks, particularly when dealing with high volumes of data and transactions that must remain secure and transparent.

Lastly, user acceptance and practical implementation remain significant barriers to blockchain adoption. While blockchain offers promising benefits, its real-world usability in daily operations, especially for non-technical stakeholders such as pilots, maintenance personnel, and ground crews, requires further investigation. Research into user interfaces, ease of adoption, and training programs is essential to ensure that blockchain solutions are both user-friendly and effective in improving operational processes within the aviation industry.

3.4 Literature Synthesis

In conclusion, the seven articles showed that blockchain technology shows significant potential to improve efficiency, security, and transparency in the aviation industry. Hyperledger Fabric enhances MRO networks by ensuring credibility and reliability. Systems like SAMR and Python-based record management strengthen maintenance data integrity being a possible solution for our RQ2. While blockchain-based tracking of spare parts addresses authenticity concerns. Additionally, blockchain improves loyalty programs and aviation databases, such as AviChainDB, by ensuring transparency. Lastly, smart contracts enhance airport security, demonstrating blockchain's transformative impact on aviation operations.

With this and from the sample of articles analyzed, no solutions were identified that respond to problems P1 and P3.

4 Methodology

Design Science Research (DSR) is a methodology focused on solving real-world problems by creating and evaluating innovative artifacts, such as models, frameworks, processes, or systems. It bridges the gap between theoretical research and practical application by iteratively designing solutions and testing them in context. DSR emphasizes both the development of artifacts and the generation of new knowledge, using rigorous scientific methods to evaluate their effectiveness and impact. The goal is to produce useful and scientifically validated artifacts, contributing to academic theory and practical advancements in fields like information systems, engineering, and business. (Peffers et al., 2006) (Hevner & Park, 2004)

To answer the research questions identified in topic 1.3.1, DSR is the most suitable methodology for this work because it focuses on solving real-world problems through the creation and evaluation of innovative technological artifacts.

DSR allows the development of a blockchain-based framework tailored specifically for these industry issues. This approach is ideal because it bridges the gap between theoretical research and real-world application, enabling the creation of a secure, tamper-proof system that can be directly implemented in the aviation industry. The iterative nature of DSR ensures that the proposed solution is rigorously evaluated and refined based on expert feedback, making it adaptable and efficient in addressing the identified challenges.

4.1 Research Methodology

This methodology section provides a clear, structured approach to addressing the key challenges associated with aircraft phase-ins, combining framework analysis, technological innovation, and expert validation as shown in Figure 13.

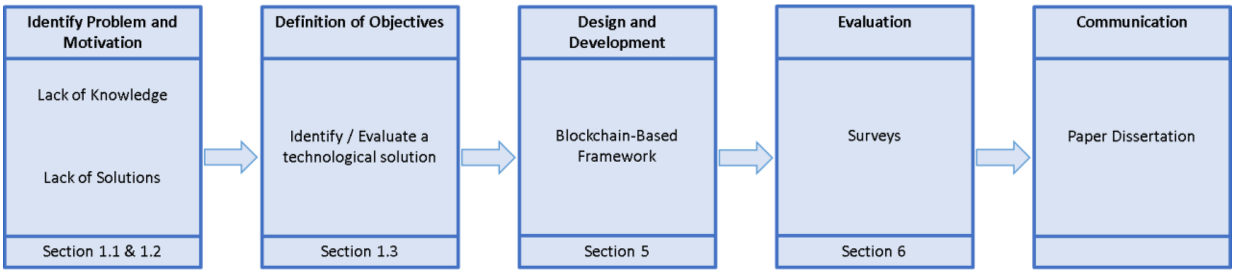


Figure 13 - DSR Model (Adapted of (vom Brocke et al., 2020)

<u>Identification of the Problem and Motivation</u>

For this dissertation, we will use Hifly, a Portuguese aviation company, as the primary focus. Hifly's expertise in managing used aircraft phase-ins provides a relevant context to address the key challenges of incomplete documentation, untraceable Life-Limited Parts (LLPs), and unidentified repairs. The case study will serve as the basis for developing a practical framework that addresses these issues.

<u>Objectives</u>

The research focuses on developing and evaluating technological solutions to improve the aircraft phase-in process. The first objective is to identify a secure and efficient system that reduces manpower and costs while ensuring accurate tracking of aircraft parts and minimizing documentation errors. The second objective is to evaluate a system that integrates photos, videos, and documents from previous operators, along with pre-delivery inspection details, to enhance transparency and reliability during the aircraft handover process. Together, these solutions aim to streamline operations and improve overall efficiency in aircraft management.

Blockchain-Based Framework Design and Development

The development of a blockchain-supported framework is detailed here, focusing on how this technology can enhance traceability, security, and transparency in aircraft maintenance records. Blockchain offers a decentralized and immutable record-keeping system, making it ideal for securely managing maintenance documentation across multiple stakeholders. This section will elaborate on how the blockchain framework can be integrated into existing aviation processes to ensure data accuracy and compliance.

Evaluation: Survey

To validate the proposed framework, a survey will be conducted using Microsoft Forms. These consultations will help ensure the practical applicability of the framework and its adaptability to different operational contexts. Feedback from experts will be used to refine the framework, ensuring it meets the needs of both regulatory bodies and aviation operators.

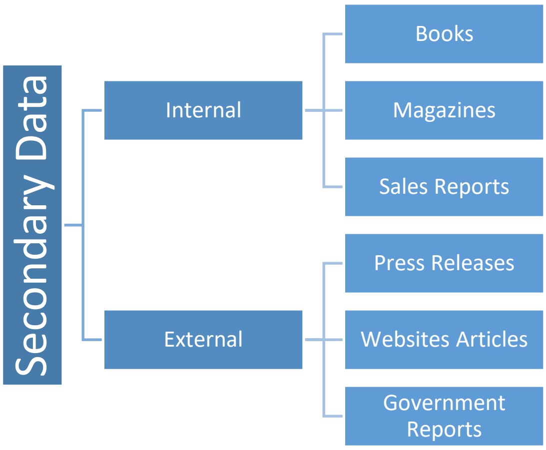
4.2 Data Collection Methods

To carry out this dissertation, an approach was taken to survey and frame the problem in a real environment with search and data collection from different sources. This final work was done with the collaboration of my colleagues at HiFly in the CAMO department.

I used a mix of primary and secondary data collection methods for this work (table 5). Concerning the primary data collection method, interviews were performed with the Kaleido Team and focus groups with the Hifly Team.

For the secondary data collection, I used internal and external sources as explained below:

Table 4 – Data Collection Methods



From the primary data collection, a framework chapter was created to explain how a real case lease phase-in occurs at HiFly.

5 Proposed Solution

5.1 Solution Architecture

This chapter presents the design of the technological solution to answer questions of section 1.3.2 and thus achieve the proposed objectives.

> **RQ1:** How can airlines safely secure Back to Birth Traceability documentation for Life-Limited Parts (LLP) during a phase-in?

> **RQ3:** How can airlines identify and manage undocumented or unidentified old repairs on the fuselage performed by previous operators to ensure safety and compliance?

In the future, the ideal scenario would be for the aircraft to leave the factory with all its most important documents encrypted in a blockchain-based cloud database, creating a unique digital key that would accompany the aircraft throughout its entire lifespan. For aircraft already in operation, the current operators or lessors shall be responsible for creating a blockchain for each aircraft, thereby minimizing the risk of tampering and missing documents.

To make it easier to respond to the above questions, it's intended that HiFly will perform a phase-in of an Airbus A330-200 with MSN XSP (for confidentiality the real MSN is not revealed) powered with General Electric's Engines CF6-80E1A4.

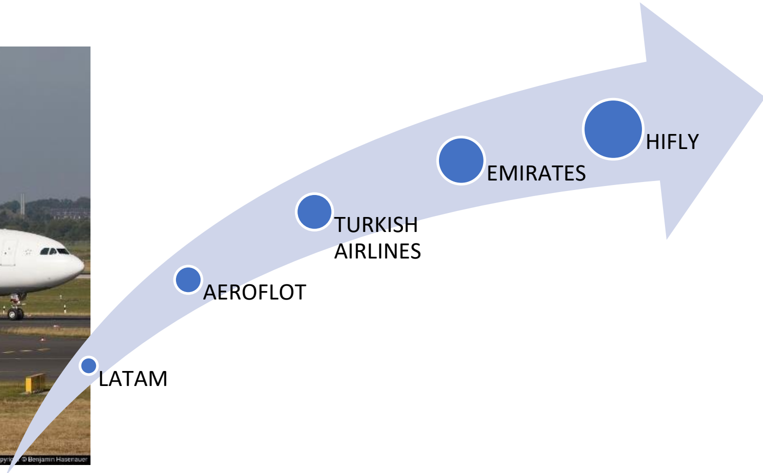


Figure 14 – Turkish Airlines Airbus A330 by Benjamin Hasenauer

This aircraft is 18 years old and passed through four operators before reaching HiFly. With this date, the average is to receive around 70 boxes full of papers for internal analysis, and a link with digital documents making it very manpower-consuming, so MSN XSP is the perfect example for Blockchain implementation.

Aircraft documentation is inspected meticulously during the phase-in process of an aircraft on lease, including documentation associated with engines and different kinds of repairs on the external fuselage performed by the previous operator on the aircraft.

5.2 Functional and Non-Functional Requirements

RQ1 – Engine LLPs

Starting with RQ1, a normal delivery condition on a phase-in is that each engine shall be serviceable and not "on watch" (which means that the engine has exhibited a concerning trend (prolonged period) or a concerning spike (short term)) or subject to an increased frequency of inspections compared to what is established in the relevant Manufacturer manuals for such Engine.

IATA on his guidance for aircraft leases refers to the below concerning the engines:

> "As engines are high-value components and individual maintenance events are extremely costly, special attention should be paid to the documentation associated with engines. During the review of the engine records, the Lessee should ensure that all documentation required to determine the engine's remaining life and expected operational limitations is available (shop visit reports, trend data, borescope reports, etc.). Subsequently, the BtB documentation for LLPs should be carefully reviewed."(International Air Transport Association, 2017)

All the documents required for the engine documentation checklist are in Annex I of this dissertation.

Before we reach the more practical part it's important to make a resume of the CF6-80E engine[22].

Figure 15 – CF6 Engine (Photo by GE)

[22] https://www.geaerospace.com/commercial/aircraft-engines/cf6

The CF6 (Figure 15) is a high-bypass turbofan engine produced by GE Aviation in 1969 and was first used on the McDonnell Douglas DC10. The CF6E1 is a derivative of the first variations and powers the Airbus A330.

Details and power specifications can be found in Table 5:

Table 5 - CF6 Engine Details (Data from GE)

Takeoff Thrust	300-320 kN
Bypass Ratio	5.3
Pressure Ratio	32,6
Fan Tip Diameter	244,3 cm
Length	417,3 cm
Blades	34

As mentioned in Chapter 1.3.1, Life Limited Part or "LLP" means any Part that has a pre-determined life limit mandated by the Manufacturer or the Certificating Authority which requires any such Part to be discarded upon reaching such life limit[23].

Engine LLPs are typically disks, shafts, rotors, bolts, and major static structural parts that cannot be replaced "on the wing", so the engine needs to be removed from the aircraft and sent to the shop. If this happened during an operation, would cause major disruptions with cancelations and loss of revenue.

[23] https://www.linkedin.com/pulse/lease-conditions-ht-components-occm-onur-hazar-altindag

RQ3 – Old Repairs

After the Structures team analyzes all the DFPs, it may be found that a repair lacks proper supporting documentation or is incomplete. If this occurs, the phase-in process could be delayed, leading to the need for a detailed inspection and/or re-inspection of the repairs. In the worst-case scenario, a completely new repair may be required by the approved manual.

It's planned to use a private blockchain and smart contracts, with migration capabilities, for an app that includes detailed reports such as DFP, manual references, damaged dimensions, and sizes, accompanied by photos and videos. This will allow users to take a virtual tour of all previous repairs as described in Figure 16.

The Smart Contract for this problem will have the same base as the one for RQ1.

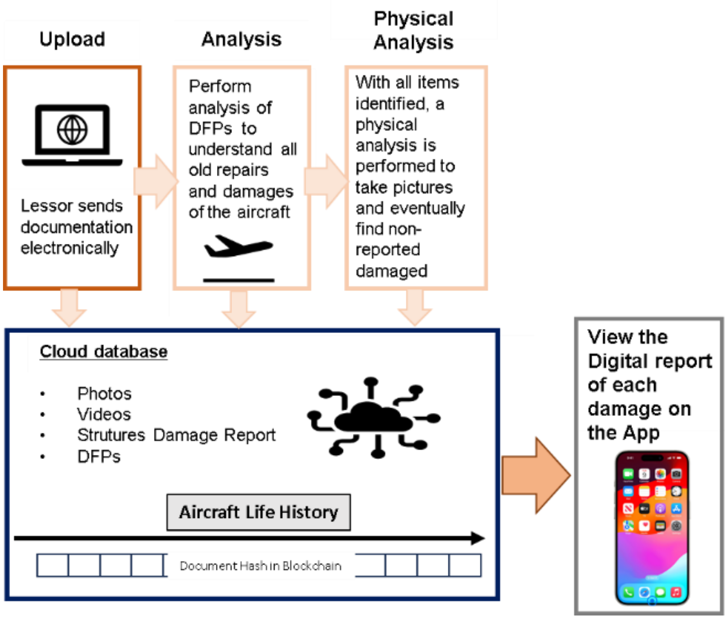


Figure 16 – Blockchain Implementation for Old Repairs

For both RQ1 and RQ3, part of the Smart Contract simulation architecture is found in the chapter below.

5.3 Implementation

To address RQ1/P1, it's proposed to implement a blockchain and smart contract solution to ensure the security and integrity of all documents, preventing any unauthorized alterations or tampering (Figure 17).

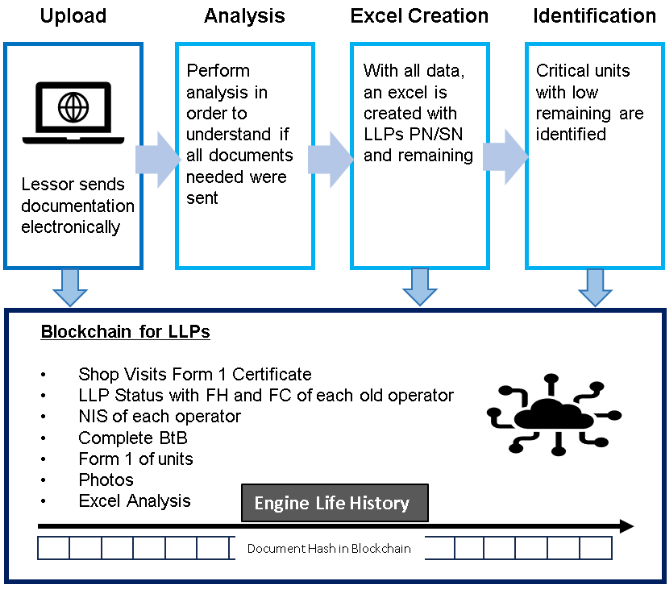


Figure 17 – Blockchain for RQ1

Following the creation of the blockchain, it's intended to implement a Smart Contract in which a critical LLP, High-Pressure Turbine (HPT) Stage 2 disk, is identified with only 100 FC of remaining. This finding will jeopardize the future operation of the aircraft, as it will have to perform an engine change before or during a revenue operation, causing money loss and cancelations. As shown at Figure 18, there will be two options:

- Suspension of all funds in case the Lessor doesn't provide a new engine for replacement;
- Or a 25% rent discount for 3 years and all costs (new engine, MRO contract, loss of revenue) will be supported by the Lessor.

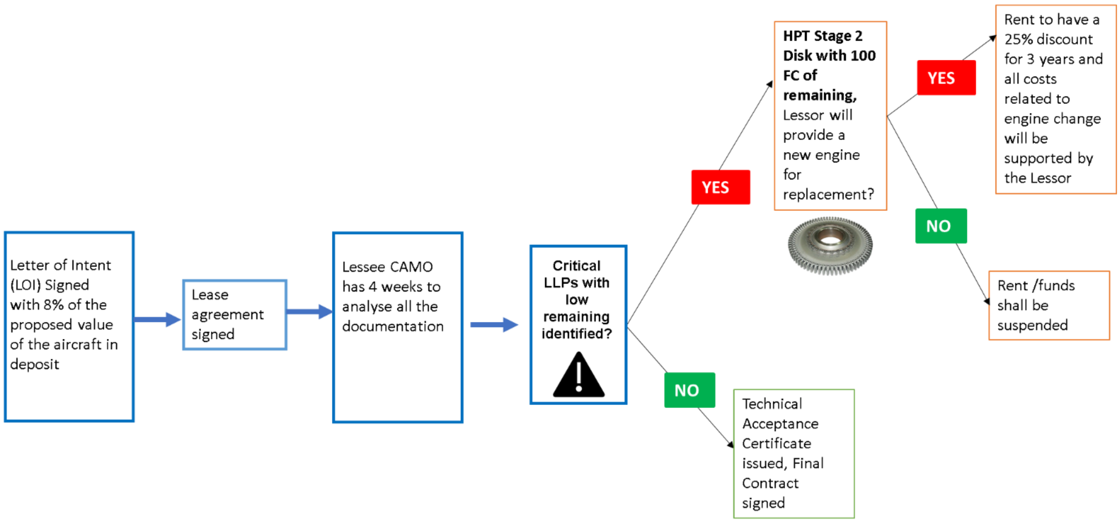


Figure 18 - Smart Contract conditions RQ1

5.4 Simulation Process

A proposal for a smart contract will include the following features:

- **Store multiple documents on IPFS**: This will allow the storage of certificates, maintenance records, and other relevant documents
- **Validate documents by external entities:** Trusted third parties, such as aviation authorities, will be able to validate the documents.
- **Update the price based on business agreements**: The price can be updated based on business agreements before finalizing the transfer.

The main entities are described in Figure 19 and described below:

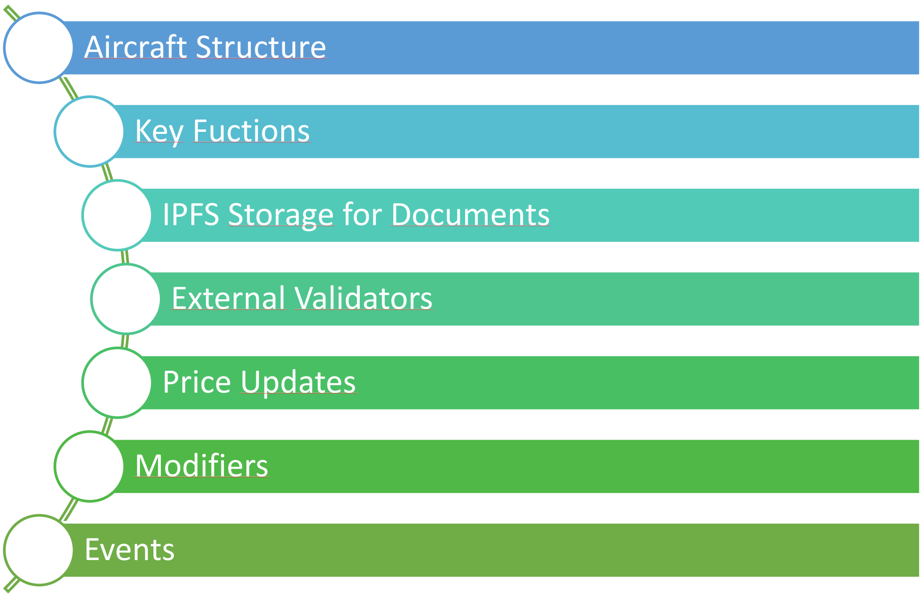


Figure 19 - Main Entities for the Creation of a Smart Contract

<u>Aircraft Structure:</u>

- **aircraftId:** A unique identifier for the aircraft (MSN XSP).
- **currentOwner:** The address of the current owner.
- **price:** The agreed-upon price for the transfer of the aircraft.
- **ipfsDocumentHashes:** An array of IPFS hashes pointing to documents (such as registration papers, maintenance logs, etc.). Documents will not be stored in the contract, only the hash of their location in the IPFS.
- **isDocumentValidated:** A Boolean flag indicating whether the documents have been validated.
- **externalValidators:** A list of addresses authorized to validate documents.
- **isOwnershipTransferred:** A Boolean flag indicating whether the ownership transfer has been completed.

Key Functions:

- **registerAircraft:** Registers the aircraft, associating it with IPFS document hashes and authorized validators.
- **validateDocuments:** Allows external validators to validate the documents (must be an authorized external entity).
- **updatePrice:** Allows the owner to update the price before ownership transfer, reflecting business agreements.
- **transferOwnership:** Transfers ownership of the aircraft after validation and price agreement.
- **getAircraftDocuments:** Retrieves the IPFS document hashes for a specific aircraft.
- **getAircraftDetails:** Retrieves aircraft details, including owner, price, validation status, validators, and transfer status.

IPFS Storage of Documents

- **Storing Documents:** Documents like airworthiness certificates, registration papers, and maintenance logs will be uploaded to IPFS. The system will generate Content Identifiers (CIDs) or IPFS hashes, which are stored in the smart contract's *ipfsDocumentHashes* array.
- **Retrieving Documents:** The IPFS hashes stored in the contract can be used to fetch documents via IPFS gateways https://ipfs.io/ipfs/{CID}.

External Validators:

- **Multiple Validators:** The contract supports multiple external validators, such as aviation authorities, maintenance agencies, or insurance companies, who must approve the documents before ownership transfer.
- **Validation Process:** Only pre-approved validators (whose addresses are stored in *externalValidators)* are allowed to call the *validateDocuments()* function.

Price Updates:

- **Business Agreement:** The owner can adjust the price via the *updatePrice()* function, reflecting negotiations or agreements between parties.
- **Ownership Transfer:** Ownership transfer requires that the price be agreed upon and documents validated before proceeding.

Modifiers:

- **onlyOwner:** Restricts actions like updating the price and initiating the transfer to the current owner of the aircraft.
- **notTransferred:** Ensures that certain functions can only be called if the ownership transfer has not yet occurred.
- **allDocumentsValidated:** Ensures that all documents must be validated by external validators before ownership transfer.

Events:

- **AircraftRegistered:** Emitted when an aircraft is registered with its details and IPFS document hashes.
- **DocumentValidated:** Emitted when an external validator approves document validation.
- **OwnershipTransferred:** Emitted when the aircraft's ownership is transferred to a new owner.

Using Figure 18, we have updated it with the main entities of the Smart Contract to improve clarity and understanding as seen in Figure 20.

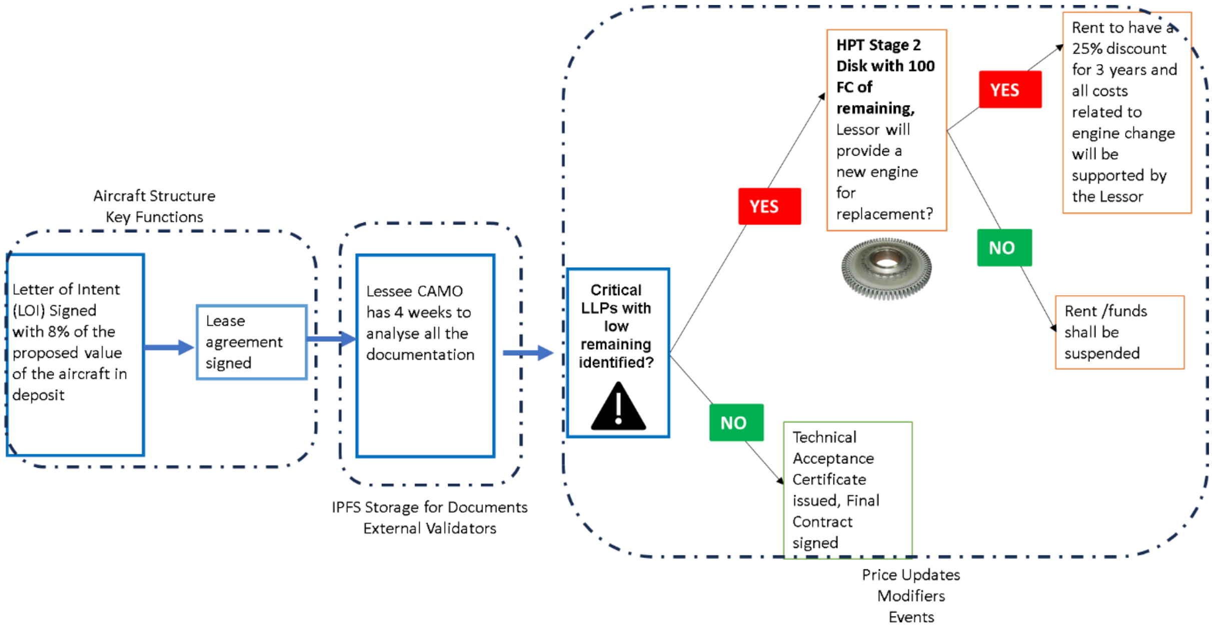


Figure 20 – Explained Main Entities of Smart Contract

<u>Consensus Algorithm</u>

Since this use case involves aircraft ownership transfers and document validation by trusted external entities (aviation authorities, regulators, etc.), the consensus algorithm should:

1. Ensure trust between parties, as validators are pre-approved.
2. Provide fast transaction speeds.
3. Keep transaction costs low for participants.
4. Allow for permission or semi-permission access, as only specific validators are authorized to validate documents.

Balancing decentralization, security, speed, cost efficiency, and trust is crucial for selecting the appropriate consensus algorithm for managing aircraft ownership transfers via a smart contract. Given these requirements, **Proof of Authority (PoA)** is the most viable option.

- PoA relies on validator identity, not computational work or stake, making it ideal for systems where trusted, pre-approved authorities (e.g., aviation regulators) validate transactions.

- PoA is highly efficient with fast transaction speeds, low energy consumption, and minimal costs.

- PoA supports public or private networks, which are suitable for consortium blockchains where only authorized entities (aviation authorities, regulators) participate in validation.

- PoA networks provide a clear governance model, which fits well with industry-specific blockchains, particularly in aviation, legal, or regulatory ecosystems.

The proposed Smart Contract template can be found in Annex IV of this dissertation.

6 Solution Evaluation

6.1 Evaluation Methodology

To validate the proposed solution, a survey with seven questions was created using Microsoft Forms (Annex V and VI). The form was shared online via LinkedIn and sent to several colleagues in the aviation industry, gathering a total of **50 responses**.

Figure 21 – Survey Cover

6.2 Results

The survey conducted as part of this research gathered feedback from experienced aviation professionals to evaluate the proposed blockchain-based framework for aircraft lease phase-ins. Respondents, predominantly from engineering backgrounds and with significant industry expertise, provided insights into the framework's clarity, usability, and relevance. The results reveal a positive reception to the framework's design and its potential to address critical challenges in documentation accuracy, traceability, and operational efficiency. These findings highlight the framework's practicality and align it with the industry's needs, offering a foundation for refinement and broader application.

Below are the questions and results in percentage.

1. What is your role in the organization?

For this question, it can be observed that 64% of the respondents are from the engineering field.

Figure 22 – Question 1 Results

2. <u>What is your academic degree?</u>

For question number 2, it is clear that the majority of respondents hold a master's degree (49%), followed by a bachelor's degree at 31%. Both a PhD and other qualifications are at the bottom, each accounting for 10%.

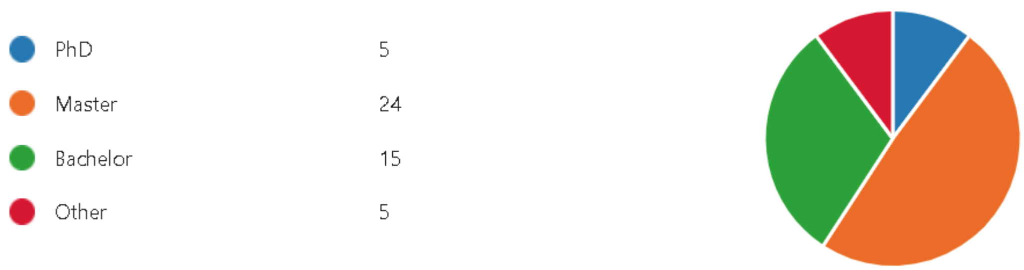


Figure 23 – Question 2 Results

3. <u>What is your experience in your area?</u>

Fifty-six percent of the respondents have over five years of experience in their field, and notably, none of the 50 individuals have less than one year of experience.

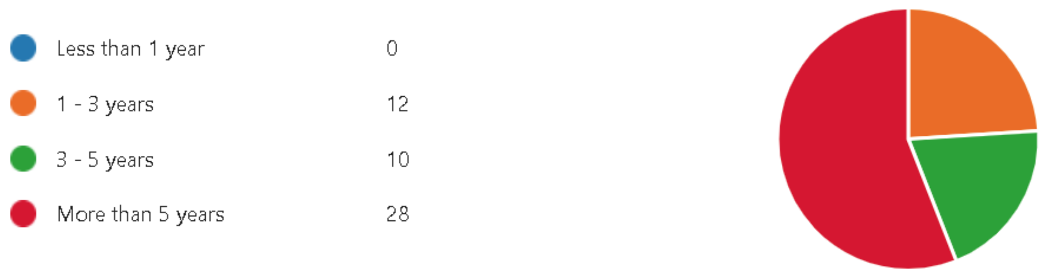


Figure 24 – Question 3 Results

4. <u>How clear was the purpose of the product to you?</u>

For question 4, the responses were almost evenly divided between "Very Clear" at 54% and "Clear" at 40%, with no respondents selecting "Not Clear at All."

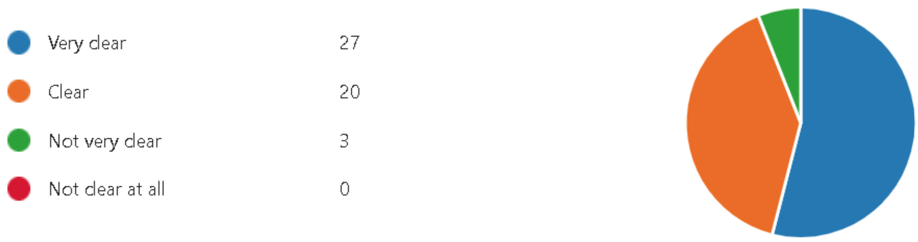


Figure 25 – Question 4 Results

5. <u>What is your perception of the usability of the product?</u>

For this question, the Net Promoter Score (NPS) was used, resulting in a score of 22 (NPS = %Promoters - %Detractors), indicating a good usability of the product.

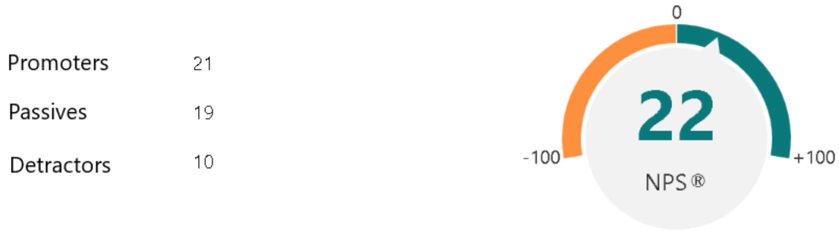


Figure 26 – Question 5 Results

6. <u>How relevant do you find this product to your field of work or daily activities?</u>

In this question, two responses together accounted for 80% of the total responses, with 44% considering "Very Relevant" and 36% considering "Relevant."

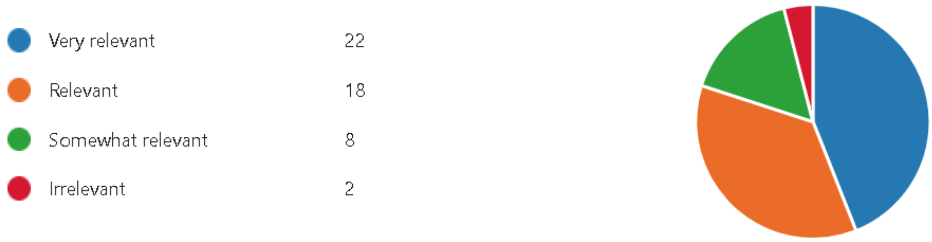


Figure 27 – Question 6 Results

7. <u>Are there any additional features you would like to see in future versions?</u>

As an open-ended question, the responses underwent filtering to consider only what is truly important, as detailed in the list below:

- On how this information can also be integrated to be available for pilots as well.
- To be able to interconnect all the features/jobs and responsibilities of the entire Organization under the scope of an aircraft transaction!
- The life cycle data can be easily traced with Traxxall or Camp, newer aircraft like the Global 7500 have already an AHMU (Aircraft Health Monitoring Unit) which collects all parameters (over 15.000 I believe to

remember) and sends faults live via Satcom to the ground, a full download can be sent from the hangar via Wifi automatic or downloaded on a USB. So really the new thing about this is that all would be together and payment via some kind of blockchain technology where you have to buy some kind of virtual currency.

- Synchronization of current documentation with old, to obtain an associated history
- The introduction of the OIL as a live platform between the lessor and future client, with direct upload of each physical finding or related correction
- Some features to track Maintenance Planning and Data (MPD) tasks performed and the remaining time

6.3 Discussion

The survey results validate the blockchain-based framework's potential to address key challenges in the aircraft lease phase-in process. The framework was well received, with 94% of respondents finding its purpose clear and 80% considering it relevant to their daily activities. Its usability scored positively (NPS of 22), reflecting its practical design and alignment with industry needs, particularly in enhancing transparency, traceability, and operational efficiency. The respondent demographic, predominantly experienced professionals (56% with over five years in the field), adds credibility to these findings.

Stakeholders provided valuable recommendations for improving the framework. These include integrating features for lifecycle data traceability, live operational platforms for real-time updates, and blockchain-based payment systems to enhance financial transparency. Additionally, expanding the framework's applicability to pilots and other roles could foster a broader organizational impact. Suggestions to leverage existing technologies, such as Aircraft Health Monitoring Units (AHMU), highlight opportunities to synergize with current systems.

Despite the positive reception, the study acknowledges limitations such as the narrow respondent pool and potential challenges in integrating blockchain with legacy systems. Future iterations should broaden stakeholder engagement, incorporate advanced features, and explore scalability to ensure the framework remains adaptable and impactful across the aviation industry.

6.4 Limitation

The survey results provide valuable insights but also highlight some limitations. The small sample size of 50 respondents, primarily from engineering roles, limits the diversity of perspectives and may not fully represent all stakeholders in the aircraft lease phase-in process. While the feedback from experienced professionals is credible, a broader range of experience levels and organizational roles would offer a more comprehensive understanding of the framework's applicability. Additionally, integrating blockchain with legacy systems poses technical and financial challenges, potentially hindering widespread adoption. Finally, continuous updates may be required to ensure the framework remains aligned with evolving industry trends and regulatory standards.

7 Conclusion

7.1 Main Contributions

To conclude and summarize the study, the findings show that blockchain technology has substantial potential to solve key challenges in the aircraft leasing phase-in process, particularly in improving the traceability of LLPs, enhancing the security and reliability of maintenance records, and managing undocumented repairs. By creating a tamper-proof ledger and utilizing smart contracts, the research demonstrates that blockchain can significantly reduce documentation errors, enhance transparency, and foster trust between lessors and lessees.

Despite its promising results, the study acknowledges limitations. The most significant limitation is the inability to fully implement and validate the blockchain system in a real-world environment due to constraints in time and resources. Moreover, challenges remain with blockchain scalability, high computational demands, industry resistance to change, and regulatory uncertainties surrounding decentralized data sharing.

In terms of practical application, the study’s conclusions suggest that blockchain can modernize the aircraft leasing phase-in process by offering a more secure and efficient documentation framework. Additionally, a greater focus on industry-wide collaborations would help address adoption challenges.

7.2 Future Work

Future research should prioritize refining blockchain-based solutions and exploring their integration with existing maintenance platforms such as OASES and AMOS. Techniques like process mining should also be examined to optimize these integrations. Additionally, full-scale implementations in real-world operational settings are crucial to better assess blockchain’s impact on the aviation leasing ecosystem. The feedback from question 7 of the survey provided valuable insights and will be instrumental for shaping future studies and evaluating industry readiness.

8 Bibliography

Aleshi, A., Seker, R., & Babiceanu, R. F. (2019). Blockchain Model for Enhancing Aircraft Maintenance Records Security. *2019 IEEE International Symposium on Technologies for Homeland Security (HST)*, 1–7. https://doi.org/10.1109/HST47167.2019.9032943

Andrei, A. G., Balasa, R., Costea, M. L., & Semenescu, A. (2021). Building a blockchain for aviation maintenance records. *Journal of Physics: Conference Series*, *1781*(1). https://doi.org/10.1088/1742-6596/1781/1/012067

Buterin, V. (n.d.). A Next Generation Smart Contract & Decentralized Application Platform. *White Paper*. Retrieved 8 September 2024, from ethereum.org

Eurocontrol. (2024). *European Aviation Overview 2023*. www.eurocontrol.int

European Union Aviation Safety Agency. (2023). *Guidelines on the use of electronic documents, records, and signatures* (Issue 1).

Government Accountability Office, U. (2019). *Blockchain & Distributed Ledger Technologies*.

Hasan, H. R., Salah, K., Jayaraman, R., Ahmad, R. W., Yaqoob, I., & Omar, M. (2020). Blockchain-Based Solution for the Traceability of Spare Parts in Manufacturing. *IEEE Access*, *8*, 100308–100322. https://doi.org/10.1109/ACCESS.2020.2998159

Hevner, A., & Park, J. (2004). *Design Science in Information Systems Research*. https://www.researchgate.net/publication/201168946

International Air Transport Association. (2017). *Guidance Material and Best Practices for Aircraft Leases Effective 4th Edition Guidance Material and Best Practices for Aircraft Leases* (Vol. 4th).

International Air Transport Association. (2018). Blockchain in Aviation. *White Paper*.

Kabashkin, I. (2024). NFT-Based Framework for Digital Twin Management in Aviation Component Lifecycle Tracking. *Algorithms*, *17*(11), 494. https://doi.org/10.3390/a17110494

Karamitsos, I., Papadaki, M., Al-Hussaeni, K., & Kanavos, A. (2023). Transforming Airport Security: Enhancing Efficiency through Blockchain Smart Contracts. *Electronics*, *12*(21), 4492. https://doi.org/10.3390/electronics12214492

Kumar, N., Singh, G. G., Srivastava, J. D., & Bisht, H. (2019). Blockchain for Loyalty Rewards Program Management Harshit Bisht Blockchain for Loyalty Rewards Program Management. *Journal of the Gujarat Research Society*, *21*(7). https://www.researchgate.net/publication/337305322

Nakamoto, S. (n.d.). Bitcoin: A Peer-to-Peer Electronic Cash System. *White Paper*. www.bitcoin.org

Peffers, K., Tuunanen, T., & Rossi, M. (2006). *The design science research process: A model for producing and presenting information systems research*. https://www.researchgate.net/publication/228650671

Poleshkina, I. (2021). Blockchain in air cargo: challenges of new World. *MATEC Web of Conferences*, *341*, 00021. https://doi.org/10.1051/matecconf/202134100021

Schyga, J., Hinckeldeyn, J., & Kreutzfeldt, J. (2019). *Prototype for a permissioned blockchain in aircraft MRO*. 469–505.

Su, Y. J., Chen, C. H., Chen, T. Y., & Yeah, C. W. (2024). Applying Ethereum blockchain and IPFS to construct a multi-party used-car trading and management system. *ICT Express*, *10*(2), 306–311. https://doi.org/10.1016/j.icte.2023.12.007

Takaoğlu Mustafa, Özyavaş Adem, & Ajlouni Naim. (2021). *AviChainDB: Blockchain Integration on Aviation Databases*.

Tapscott, D., & Tapscott, A. (2016). Blockchain Revolution. In *Age of Networked Intelligence* (1st ed.). Penguin Random House LLC.

Tozer-Pennington V. (2023). *Aviation Leaders Report 2023: New Horizons*. www.airlineeconomics.com

Vevera, A.-V., & Georgescu, A. (2024). The Impact of Blockchain on Critical Transport Infrastructure – The Case of Aviation. *Land Forces Academy Review*, *29*(3), 421–432. https://doi.org/10.2478/raft-2024-0045

vom Brocke, J., Hevner, A., & Maedche, A. (2020). *Introduction to Design Science Research* (pp. 1–13). https://doi.org/10.1007/978-3-030-46781-4_1

Welfare, A. (2019). *Commercializing Blockchain*. John Wiley & Sons Ltd.

Zhang, P., Schmidt, D. C., White, J., & Dubey, A. (2019). Consensus mechanisms and information security technologies. In *Advances in Computers* (Vol. 115, pp. 181–209). Academic Press Inc. https://doi.org/10.1016/bs.adcom.2019.05.001

Zheng, P., Zheng, Z., Dai, H.-N., & Kong, H. (2019). *XBlock-ETH: Extracting and Exploring Blockchain Data From Ethereum*. https://doi.org/10.48550/arXiv.1911.00169

9 Attachments

9.1 Annex I – Engine Documentation Checklist

Document required	Lease	Purchase
Latest Engine Certificate available	YES	YES
Current Operator LLP Status	YES	YES
Life Limited Parts Back-to-Birth	YES for the ones replaced during the lease	YES
AD status	YES	YES
SB / Modification Status	YES	YES
Latest Engine Test report or On-Wing Power Assurance	YES	YES
Latest Borescope Report and Video	YES	YES
Last 6 months of Engine Condition Monitoring	YES	YES
QEC/Accessory List	YES	YES
Missing Part List	YES	YES
Engine Installation/Removal History	YES	YES
Shop Visit reports and Mini Packs	YES	YES
Engine Logbook (if applicable)	YES	YES
Incident/Accident Clearance Statement	YES	YES
Previous operators statements (AD/LLP/ICS)	NO	YES
Manufacturer data (EDS/VSL/IIL/Logbook)	NO	YES
On-Wing Maintenance (Review the Maintenance Schedule Engine Tasks – Last done/Next Due, Water Wash, Borescope Inspections, Fan Blades Lubrication)	YES	YES
Shop Maintenance (Check which shop the airline is using for Off Wing maintenance and if they have a customized WPG/MPG)	NO short YES long	YES
Certificates for every component installed	YES for the ones replaced during the lease	YES
Review all technical log entries recorded against the engine in the last six months of operation and the action that was taken to clear them.	YES	YES
Preservation Status	YES	YES
Picture of the Engine Data Plate	YES	YES
"Carry Forward" or "Open Items" sheet	YES	YES
List of open OEM concessions	YES	YES
TRUEngine / Pure-V or other OEM status (if applicable)	NO	YES
Warranties - Identify assignable warranties available from the manufacturer or maintenance provider.	NO	YES

9.2 Annex II – SIAN TM-CAD

SAFETY INFORMATION AND ADVISORY NOTICE (SIAN)		Transport Malta Civil Aviation Directorate Safety and Compliance Unit Transport Malta Centre Triq Pantar Lija LJA 2021 Malta aviationsafety.tm@transport.gov.mt
SIAN Number: 03/23	Issue Date: 29/09/2023	
Subject: **Suspected Unapproved Parts – AOG Technics Limited**		

1.0 INTRODUCTION

1.1 The European Union Aviation Safety Agency (EASA) issued a Suspected Unapproved Parts (SUP) notification to alert owners, operators, maintenance organisations, and distributors of suspected unapproved parts distributed by AOG Technics, (Nova North, 11 Bressenden Place, London, SW1E 5BY, United Kingdom).

1.2 Suspected Unapproved Parts (SUP) includes products, components, or materials, from unknown, or suspect origin, or unserviceable critical components. The part itself or its associated paperwork can call it into question.

1.3 Occurrence reports have been submitted to the EASA indicating that several CFM56 engine parts distributed by AOG Technics have been supplied with a falsified Authorised Release Certificate (ARC). However, the full extent of AOG Technics Limited's distribution of SUPs is not yet known as investigations are still ongoing.

1.4 To date, AOG Technics has not provided EASA with information on the source of the parts, or of the falsified ARCs. EASA has therefore issued alert Aircraft Parts Distributed by AOG Technics to determine whether other parts with falsified ARCs have been supplied, and to limit the airworthiness impact of any potentially unairworthy parts operating in service.

2.0 APPLICABILITY

2.1 This Notice is to be disseminated to all personnel, and people who have direct involvement or interest in the purchasing, supply, distribution, installation and monitoring of aircraft components and/or parts.

Aerodromes:	Not primarily affected.
Air Traffic:	Not primarily affected.
Airspace:	Not primarily affected.
Airworthiness:	Approved Part 145 & Part CAMO organisations.
Flight Operations:	Air Operator Certificate (AOC) holders.
Licenced/Unlicenced Personnel:	Not primarily affected.

Safety Information and Advisory Notice Transport Malta is the Authority for Transport in Malta set up by ACT XV of 2009 Page 1 of 3
Civil Aviation Directorate Form TM/CAD/0387 Issue 2 – July 2021

9.3 Annex III – Airbus Price List

AIRBUS

Press Release

2018 price adjustment across Airbus' modern product range reflects continuous investment and customer value

Toulouse, 15th January 2018 – Airbus has increased the average list prices of its aircraft by two percent across the product line, effective from January 1st 2018.

John Leahy, Chief Operating Officer Customers, Airbus Commercial Aircraft said: "Our new 2018 pricing reflects Airbus' continuous investments into its aircraft programmes to maximise their value for our customers' satisfaction – with the winning combination of performance, operating economics and passenger experience."

About Airbus
Airbus is a global leader in aeronautics, space and related services. In 2016 it generated revenues of €67 billion and employed a workforce of around 134,000. Airbus offers the most comprehensive range of passenger airliners from 100 to more than 600 seats and business aviation products. Airbus is also a European leader providing tanker, combat, transport and mission aircraft, as well as one of the world's leading space companies. In helicopters, Airbus provides the most efficient civil and military rotorcraft solutions worldwide.

Airbus Investor Relations contacts:

Julie KITCHER	tel. +33 5 82 05 53 01	julie.kitcher@airbus.com
Thorsten FISCHER	tel. +33 5 67 19 02 64	thorsten.t.fischer@airbus.com
Mohamed DENDEN	tel. +33 5 82 05 30 53	mohamed.denden@airbus.com

NB: Price list on next page…

9.4 Annex IV - Smart Contract Proposed Template

Listing 1. Smart Contract Proposed Template

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.0;

contract AircraftOwnershipTransfer {

   struct Aircraft {
      uint256 aircraftId; // Aircraft Identification (could be tail number or
other unique ID)
      address currentOwner;
      uint256 price; // The agreed price of the aircraft
      string[] ipfsDocumentHashes; // Array to store IPFS hashes for
aircraft-related documents
      bool isDocumentValidated;
      address[] externalValidators;
      bool isOwnershipTransferred;
   }

   // Mapping to store aircraft data based on aircraftId
   mapping(uint256 => Aircraft) public aircrafts;

   // Events to log important actions
   event AircraftRegistered(uint256 aircraftId, address owner, uint256
price, string[] ipfsDocumentHashes);
   event DocumentValidated(uint256 aircraftId, address validator);
   event OwnershipTransferred(uint256 aircraftId, address
previousOwner, address newOwner, uint256 price);

   // Modifier to ensure only the current owner can perform certain actions
   modifier onlyOwner(uint256 _aircraftId) {
      require(aircrafts[_aircraftId].currentOwner == msg.sender, "Caller is
not the current owner");
      _;
   }

   // Modifier to ensure the ownership has not yet been transferred
```

```
    modifier notTransferred(uint256 _aircraftId) {
        require(!aircrafts[_aircraftId].isOwnershipTransferred, "Ownership is already transferred");
        _;
    }

    // Modifier to ensure that all documents are validated before proceeding
    modifier allDocumentsValidated(uint256 _aircraftId) {
        require(aircrafts[_aircraftId].isDocumentValidated, "Documents not yet validated");
        _;
    }

    // Function to register a new aircraft with IPFS document hashes
    function registerAircraft(uint256 _aircraftId, address _owner, uint256 _price, string[] memory _ipfsDocumentHashes, address[] memory _externalValidators) public {
        require(aircrafts[_aircraftId].currentOwner == address(0), "Aircraft is already registered");

        aircrafts[_aircraftId] = Aircraft({
            aircraftId: _aircraftId,
            currentOwner: _owner,
            price: _price,
            ipfsDocumentHashes: _ipfsDocumentHashes,
            isDocumentValidated: false,
            externalValidators: _externalValidators,
            isOwnershipTransferred: false
        });

        emit AircraftRegistered(_aircraftId, _owner, _price, _ipfsDocumentHashes);
    }

    // Function to allow external entities (validators) to validate the aircraft documents
    function validateDocuments(uint256 _aircraftId) public notTransferred(_aircraftId) {
        Aircraft storage aircraft = aircrafts[_aircraftId];
```

```
        // Ensure the caller is one of the authorized external validators
        bool isValidator = false;
        for (uint i = 0; i < aircraft.externalValidators.length; i++) {
            if (aircraft.externalValidators[i] == msg.sender) {
                isValidator = true;
                break;
            }
        }

        require(isValidator, "Caller is not an authorized validator");

        aircraft.isDocumentValidated = true;
        emit DocumentValidated(_aircraftId, msg.sender);
    }

    // Function to update the price of the aircraft before transfer (based on
business agreements)
    function updatePrice(uint256 _aircraftId, uint256 _newPrice) public
onlyOwner(_aircraftId) notTransferred(_aircraftId) {
        aircrafts[_aircraftId].price = _newPrice;
    }

    // Function to transfer ownership of the aircraft once documents are
validated and price is agreed
    function transferOwnership(uint256 _aircraftId, address _newOwner)
public onlyOwner(_aircraftId) allDocumentsValidated(_aircraftId)
notTransferred(_aircraftId) {
        Aircraft storage aircraft = aircrafts[_aircraftId];

        address previousOwner = aircraft.currentOwner;
        aircraft.currentOwner = _newOwner;
        aircraft.isOwnershipTransferred = true;

        emit OwnershipTransferred(_aircraftId, previousOwner, _newOwner,
aircraft.price);
    }

    // Function to retrieve the IPFS document hashes for a specific aircraft
    function getAircraftDocuments(uint256 _aircraftId) public view returns
(string[] memory) {
```

```
        return aircrafts[_aircraftId].ipfsDocumentHashes;
    }

    // Function to get details about the aircraft (owner, price, validation status, external validators)
    function getAircraftDetails(uint256 _aircraftId) public view returns (address, uint256, bool, address[] memory, bool) {
        Aircraft storage aircraft = aircrafts[_aircraftId];
        return (
            aircraft.currentOwner,
            aircraft.price,
            aircraft.isDocumentValidated,
            aircraft.externalValidators,
            aircraft.isOwnershipTransferred
        );
    }
}
```

9.5 Annex V – Interview Questionnaire

Blockchain Technology on an Aircraft Lease Phase In

Master Thesis Survey

How can the phase-in process of used aircraft be optimized to address challenges related to incomplete documentation, including Back to Birth Traceability, maintenance records, and the identification of prior repairs?

Secure Back to Birth traceability documentation for Life Limited Parts during a phase in

To address the incompleteness of documentation related to LLPs and records, we propose the creation of blockchain software based on Ethereum and Smart Contracts. This proposal, allows us to create a private blockchain network for the upload of files related to the most important components and contracts including the relevant information about an item (like localization on the engine, material, and maintenance logs). On the other hand, Smart Contracts can provide an automatic contract for the lease of the aircraft and can contain different allocations of money depending on findings during the Pre-Delivery of the aircraft.

9.6 Annex VI – Survey Results

ID	What is your main role in the organization?	What is your academic degree?	What is your experience in your area?
1	Other	Bachelor	3 - 5 years
2	Engineer (Aviation, Mechanic, etc)	Master	1 - 3 years
3	Engineer (Aviation, Mechanic, etc)	Master	3 - 5 years
4	Engineer (Aviation, Mechanic, etc)	Master	1 - 3 years
5	Engineer (Aviation, Mechanic, etc)	Bachelor	More than 5 years
6	Consultant	Master	3 - 5 years
7	Engineer (Aviation, Mechanic, etc)	Bachelor	More than 5 years
8	Engineer (Aviation, Mechanic, etc)	Master	More than 5 years
9	Engineer (Aviation, Mechanic, etc)	Other	More than 5 years
10	Engineer (Aviation, Mechanic, etc)	Master	1 - 3 years
11	Teacher	Bachelor	1 - 3 years
12	Engineer (Aviation, Mechanic, etc)	Master	1 - 3 years
13	Engineer (Aviation, Mechanic, etc)	Master	More than 5 years
14	Engineer (Aviation, Mechanic, etc)	Master	1 - 3 years
15	Engineer (Aviation, Mechanic, etc)	Other	More than 5 years
16	Other	Bachelor	More than 5 years
17	Engineer (Aviation, Mechanic, etc)	Master	1 - 3 years
18	Engineer (Aviation, Mechanic, etc)	Other	More than 5 years
19	Engineer (Aviation, Mechanic, etc)	Bachelor	More than 5 years
20	Engineer (Aviation, Mechanic, etc)	Master	More than 5 years
21	Engineer (Aviation, Mechanic, etc)	Master	1 - 3 years
22	Other	Other	1 - 3 years
23	Other	Master	More than 5 years
24	Engineer (Aviation, Mechanic, etc)	Master	More than 5 years
25	Engineer (Aviation, Mechanic, etc)	Bachelor	More than 5 years
26	Engineer (Aviation, Mechanic, etc)	Bachelor	More than 5 years
27	Teacher	Master	More than 5 years
28	Engineer (Aviation, Mechanic, etc)	Master	3 - 5 years
29	Teacher	Bachelor	1 - 3 years