

BLOCKCHAIN-ENABLED PREDICTIVE MAINTENANCE FOR AEROSPACE COMPOSITE MATERIALS

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Abstract— The aerospace maintenance industry, particularly for composite materials, will continue to face challenges due to its complexity, involving multiple stakeholders, data sharing, and the need for high data security. The implementation of Blockchain technology can significantly contribute to the aforementioned characteristics. This project explores the implementation of Blockchain technology in Maintenance, Repair and Overhaul (MRO). The findings will highlight the value of data storage within MRO's and the benefits of Blockchain. The project also discusses the readiness/willingness of aircraft maintenance facilities to implement Blockchain and the barriers to implementation.

The aim of this project is to investigate the integration of Blockchain technology in aerospace Maintenance, Repair, and Overhaul (MRO) operations to enhance data integrity, traceability, and security, and to assess the readiness and barriers faced by aerospace maintenance facilities in adopting Blockchain as a solution.

Keywords—Blockchain, Maintenance Repair and Overhaul, Hashing (MRO), Ethereum, Nodes and Merkle root.

I. INTRODUCTION

A. Background

Every plane has to go under maintenance repair and overhaul after every certain period of time or when there is a need to change a part. Every component is very crucial for a plane, even with a small malfunction of any part of the plane, the plane will be in danger. During MRO some technicians are replacing the new original part with a fake part, and these original parts are sold to some aerospace industries which give them more money.

All these are happening due to lack of data of the components. Which is causing huge damage to airlines. The discovery has prompted airlines to change parts on a handful of planes and so far, only a fraction of the 23,000 existing CFM56 engines has been affected. Several false documents were identified. Some planes went through some emergency landings due to the improper function of the component or part and some planes have crashed also by killing several people.

B. Theory

1) Database

A database is an organized collection of structured information or data, typically stored electronically in a computer system. Databases are controlled by a Database Management System (DBMS), which serves as an interface between the database and its users or application

2) Blockchain

The blockchain is a distributed database of records of all transactions or digital events that have been executed and shared among participating parties. Each transaction is verified by the majority of participants of the system. The blockchain technology is majorly used in cryptocurrency. Bitcoin is the most popular cryptocurrency, an example of the blockchain.

3) Hashing

Hashing refers to the process of generating a fixed-size output from an input of variable size using the mathematical formulas known as hash functions. This technique determines an index or location for the storage of an item in a data structure. Hashing will work efficiently even with a large amount of data. Therefore, it is very useful in blockchain technology to access large amounts of data stored in it.

4) Merkle Root

A Merkle root is the result of hashing the transactions in a block, pairing those hashes, and hashing them again until a single hash remains. Some blockchains use it to verify transactions without hashing and pairing hashes to compare Merkle roots generated by other nodes. This technique reduces the time needed to verify the transactions included in a block.

5) Ethereum

Ethereum is a Blockchain network that introduced a built-in Turing-complete programming language that can be used for creating various decentralized applications (also called Dapps). The Ethereum network is fueled by its own cryptocurrency called 'ether'. The Ethereum network is currently famous for allowing the implementation of smart contracts. Smart contracts can be thought of as 'cryptographic bank lockers' which contain certain values. These cryptographic lockers can only be unlocked when certain conditions are met. Unlike bitcoin, Ethereum is a network that can be applied to various other sectors. Ethereum is often called Blockchain 2.0 since it proved the potential of blockchain technology beyond the financial sector. The consensus mechanism used in Ethereum is Proof of Stakes

II. LITERATURE REVIEW

A. Motivation and Objective

The studies investigate the usage of blockchain technology in aviation as well as other industries like automotive, food industries and military. Many interviews and one on one interactions are made to get more information and advantages as well as disadvantages.

Azian Ibrahim et al.,2024 investigated that the components of a plane are very crucial and important, even with a small malfunctioning the whole plane gets in danger. As these components go through assembly and testing, few of them are exchanging the original component with a fake part, which is very risky. So, they use the blockchain technology to secure the original component [1].

Raja Wasim Ahmad et al.,2020 studied the importance of blockchain in the defense sector. Private blockchain platforms ensure high privacy through private channels and access control policy, thus permissioned blockchain networks are more suitable for aerospace and military applications. Supply chain management of aerospace components using blockchain technology can help trace and track record of ownership details with trusted history and provenance of components throughout the life cycle [2].

Merlindo Andoni et al.,2019 investigated the usage of blockchain in the energy sector. Block chain technologies can clearly benefit the energy system operations, markets and consumers. They offer disintermediation, transparency and tamperproof transactions. Blockchain technologies can be disruptive for energy companies and face a large variety of challenges to achieve market penetration including legal, regulatory and competition barriers [3].

Rita Azzi et al.,2019 analyzed the usage of blockchain in the supply chain. They have found that adopting different technologies and techniques creates a reliable tracking system. Blockchain makes the supply chain secure, transparent, authentic and trustworthy.

The manufacturing of goods is becoming complex due to the increased number of intermediates between the producer and final consumer. Due to this some parts are getting smuggled and getting replaced with the original parts, With the help of the supply chain, we can ensure the data traceability and we can secure the components [4].

Marina Efthymiou et al.,2022 did exploratory research On blockchain in Aviation in the case of Maintenance, Repair and Overhaul (MRO). They have interviewed some MRO operators and obtained the data on how MRO's and blockchain are linked. They have also found some of the challenges in blockchain technology like data collection and management, cost, transition and integration of people, processes and technology, organizational requirements and readiness [5].

Jun Chen et al.,2022 did research on the use of Intelligent Transportation logistics Optimal Warehouse Location Method Based on IOT and Blockchain Technology. They have found that IOT provides convenience for Warehouse management systems but it also faces great challenges in terms of cost control and network security. Whereas the blockchain technology has a high network security. The combination of the IOT and blockchain provides high network security, network traceability and cost effectiveness [6].

Kakali Chatterjee et al.,2023 investigated the use of blockchain in smart agriculture. They found that Food consumers are more concerned about transparency, accountability, contamination risks, food safety and food quality. Blockchain is a promising technique to maintain product traceability in the agricultural food supply chain. All transactions are recorded to maintain high transparency and traceability across the supply chain ecosystem. A group signature scheme is applied to revoke the signer's identity in case of misuse or dispute [7].

Srinivas Jangirala et al.,2022 explored the usage of blockchain in the aviation industry. They found that Blockchain Technology has appeared as a landmark revolution in data encryption and storage. The distributed ledger system allows the hashes to be available with multiple nodes anytime and tampering or modification creates a new hash hence makes it easy to confirm the authenticity of the data files and track the node where the changes happened. In this way the data of the aviation is stored securely. Therefore, there won't be any malpractices that takes place during MRO [8].

S.M Masudur Rahman et al.,2024 investigated thee blockchain in the banking industry: a systematic review and bibliometric analysis. They found that prominent research topics within this domain include blockchain technology, fintech, financial systems, security, and privacy. The identified research trends highlight significant studies centered around the adoption of technology in the financial sector, fintech applications, blockchain frameworks for the banking industry, and related themes. Blockchain activities have become intertwined with regulatory measures aimed at ensuring reliable service delivery to stakeholders [9].

Meganathan Alagiah and Bino Joseph, 2020 studied the Smart Airline Baggage Tracking and Theft Prevention with Blockchain Technology. They found that This smart technology of blockchain, IoT with RFID baggage handling system proves to be best solution for real time tracking of passenger baggage with instant mobile alerts[10]

III. METHODOLOGY

For this project methodology is divided into 3 parts. First part includes designing the structure of blockchain. The second part includes the creation of database for the structure blockchain . The Third part includes testing the blockchain.

A. Selection of Blockchain type

In order to prepare a blockchain the selection of blockchain and platform to create blockchain plays an important role. There are four types of blockchain: Public, Private, Consortium and Hybrid. Consortium blockchain is selected as it is suitable for our case which is implementing supply chains for components. Consortium blockchain has permissioned access, multiple controlled entities, high controlled security and faster transactions. Its privacy focused while maintaining the selective transparency of the data. However, challenges are faced in the consortium due to decentralization and trust between consortium members.

1)Structure of Blockchain

In the structure of blockchain the header block is created, the header block stores the previous block hash, merkle root, timestamp and nonce. The body block is created later on, the block body contains the transaction data and the number of transactions depends on the size of the block. At last the hash block is the main role, the conversion of the real time component takes place into unique hash code. the data of components like name, manufacturer, component id, batch are saved into unique code.

The creation of a genesis block is done. The genesis block is the foundation of the blockchain. the genesis block has a fixed timestamp and it doesn't have records of previous hash but it has hash of next block .it is the first block it is also divided into head, body and hash it saves the similar data. this genesis block is connected to the subsequent blocks , subsequent blocks are similar to genesis blocks but they maintain the records of previous block and hash .The transaction data of these blocks includes sender address, receiver address, amount, nonce and transaction hash.These unique hashes are what hold the data in the form of strings .The chain is created among the blocks with a link of hashes and any change in hash of a single block can invalidate the whole chain.

Nodes are computers that participate in blockchain networks. They can be full nodes, light nodes, mining nodes and validator nodes.

- a) **Full Nodes:** Store the entire blockchain and validate transactions.
- b) **Light Nodes:** Store only block headers for lightweight operation.
- c) **Mining Nodes:** Compete to add new blocks (PoW-based networks).
- d) **Validator Nodes:** Validate transactions and reach consensus (PoS-based networks).

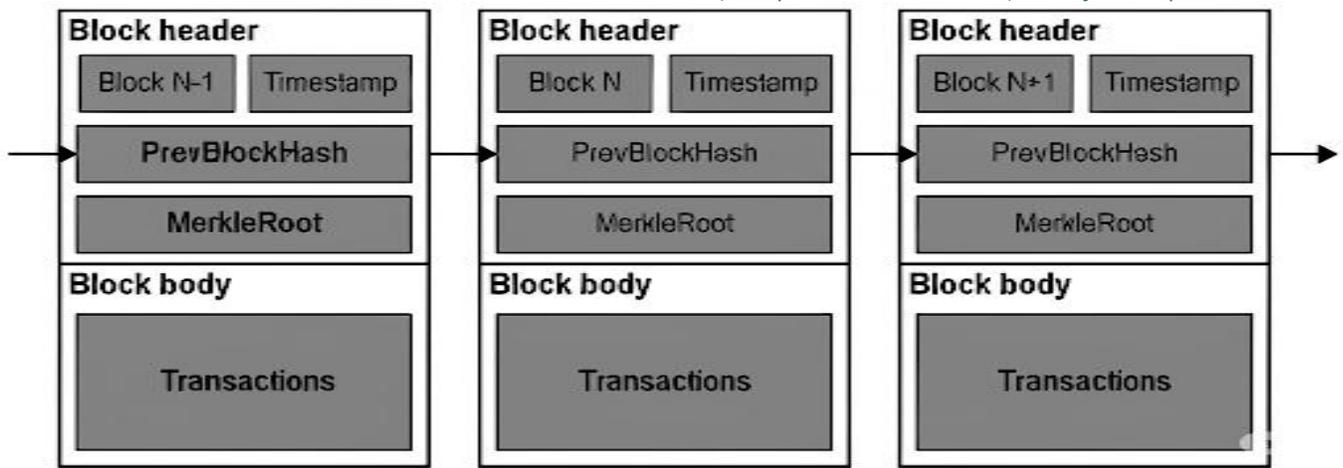


Fig (3.1). Structure of Blockchain

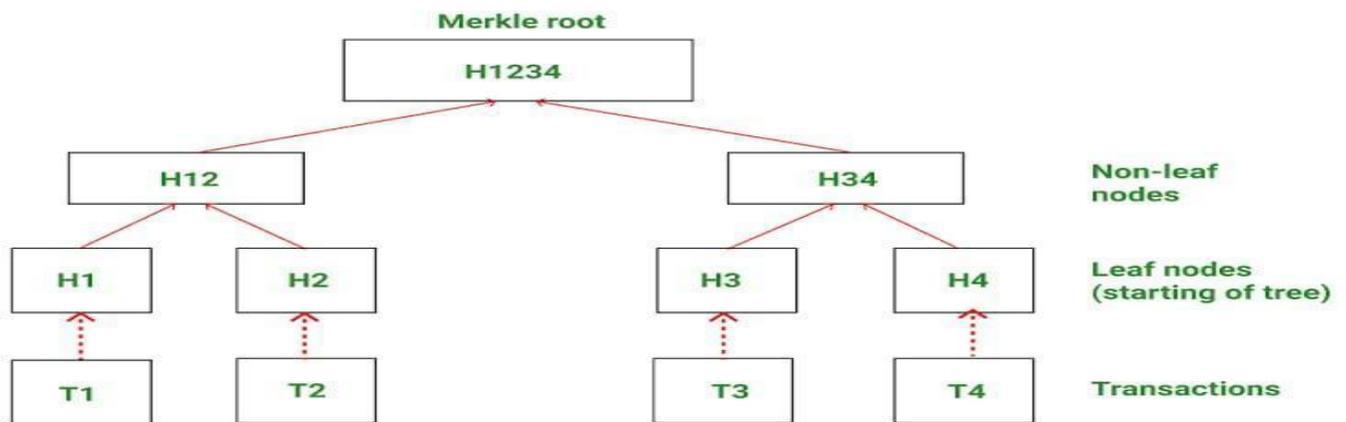


Fig (3.2). Merkle Root Tree.

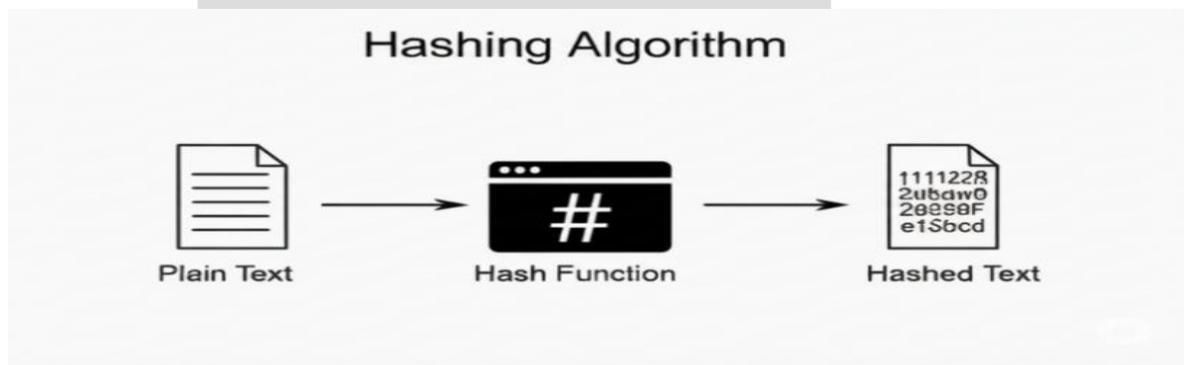


Fig (3.3). Hashing Algorithm.

B. Data Collection and Component Registration

1) Identification of Critical Aircraft Components

To ensure comprehensive tracking, the aircraft components which under go in maintenance have to be selected for blockchain-based maintenance logging.

Some of the aircraft component parts are given below with their functions and an assumed tracking id.

TABLE I
TRACKING IDS RESPECTIVE TO COMPONENTS

<i>Components</i>	<i>Tracking ID</i>	<i>Function</i>
Rudder	AC-RUD-001	Controls yaw movement
Ailerons	AC-AIL-002	Manages roll stability
Elevator	AC-ELE-003	Adjusts pitch attitude
Flaps	AC-FLP-004	Enhances lift during take-off/landing
Landing Gear	AC-LDG-005	Supports ground operations
Spoilers	AC-SPL-006	Reduces wing lift
Thrust Reversers	AC-TRV-007	Assists in deceleration during landing

2) Maintenance Record Attributes

For each component, maintenance records were structured to include:

- a) **Timestamp:** Date and time of service (ISO 8601 format). In this, every component which under go in maintenance will have different time stamps, which specifies at what time which part is in maintenance or in repair or overhaul.
- b) **Maintenance Type:** There are different types of maintenance where each and every component will undergo during their MRO's. some of the maintenance types are given below:
 - i. Routine Inspection
 - ii. Part Replacement
 - iii. Software Update
 - iv. Emergency Repair
 - v. Lubrication/Calibration

- c) **Technician Details:** Name, certification ID, and organization.
- d) **Location:** Hangar/airport code (e.g., JFK, LAX) with GPS coordinates (simulated).
- e) **Blockchain Verification:**
 - i. **Block Hash:** 64-character hexadecimal string. For every single update there will be a separate block hash. (e.g., 0x4a3b2c1d9e8f7a6b5c4d3e2f1a0b9c8d7e6f5).
 - ii. **Transaction ID:** Unique identifier for audit trails.

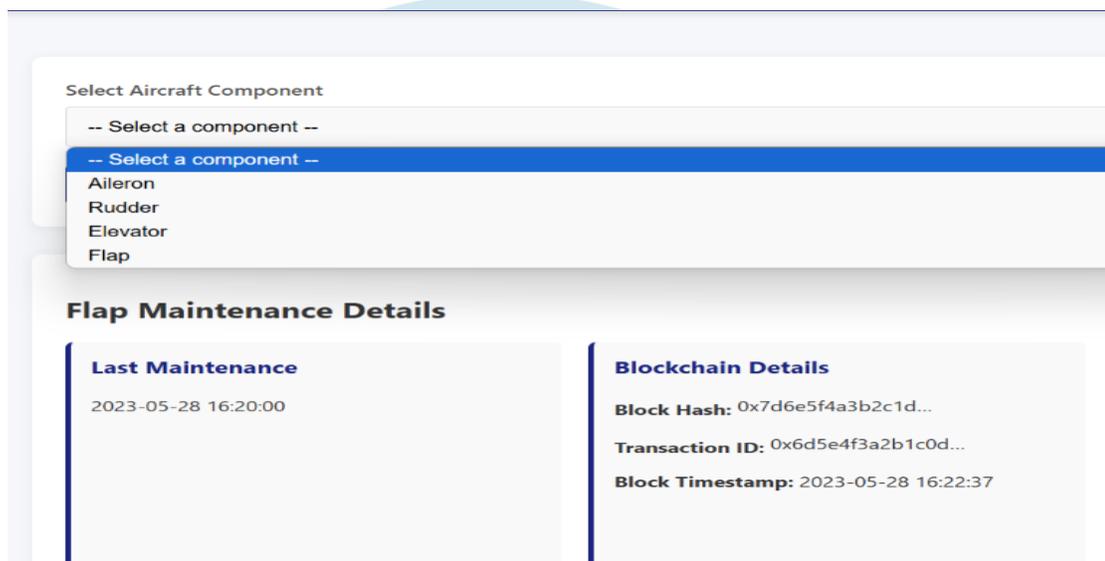


Fig (3.4). Database-Driven HTML Website for Component Management.

Maintenance History

Date	Maintenance Type
2023-05-28	Routine Inspection
2023-02-18	Lubrication
2022-11-10	Part Replacement
2022-07-05	Routine Inspection

Fig(3.5) Maintenance Record Attributes.

Fig(3.2.2) displays the maintenance record with time stamp ,technician name, block hash and the location where the maintenance has occurred.

3) Blockchain Integration Framework

To emulate a decentralized ledger, the system generated:

- a) **Immutable Hashes:** SHA-256 algorithms created unique block hashes for each transaction.
- b) **Timestamp Validation:** Coordinated Universal Time (UTC) synchronization for audit compliance.

4) Data Authenticity Measures

Tamper-Evident Design: Altering any record invalidates its hash, triggering system alerts.

Read-Only Access: Maintenance history restricted to append-only operations.

TABLE II**Test Cases for Data Integrity**

Test Scenario	Expected Outcome
Duplicate Transaction Hash	Rejection due to hash collision
Invalid Date Format Entry	Automated correction/error
Missing Technician Details	Form submission blocked

IV. RESULTS

In this project , the development of a blockchain-based system to address challenges in aerospace Maintenance ,Repair and Overhaul(MRO) processes. The block chain solution effectively tracks critical aircraft components, including ailerons , fuselage , flaps , elevators, etc; by recording their transaction history and location data. Each components transaction data and corresponding hash are automatically generated by the blockchain , ensuring a secure and immutable record. This implementation enhances the traceability and security of aerospace components, streamlining MRO operations and improving Overall reliability.

V. CONCLUSION

In the present day scenario the key challenges that the aerospace industries are facing are

- Record Adulteration
- a) Fake Parts
- b) Cyber Attacks
- c) Digital Inefficiency
- d) Missing Logs

About 28000+ fake parts incidents have occurred in just 4 years.

The below figure show the number cyber attacks that occurred in just 4 years.

Costs of the cyberattacks in aviation

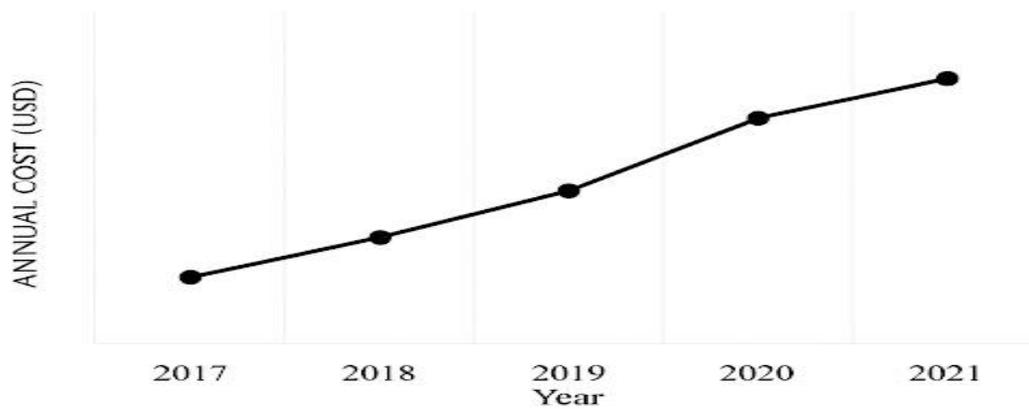


Fig (5.1) Cyber Attacks

Few years ago, a group of attackers have attacked Russian authority and wiped out about 40 tera bites of data. A lot of paper is also missing during MRO's of an aircraft which are very important.

Therefore, the idea of the project is to create a block chain linked database for the aviation industries so that the data is secure and decentralised, immutable, data traceability, etc. becomes much easier.

The advantages of using block-chain in aviation industry are as follows:

1. Enhanced Maintenance and Safety Tracking

- Immutable maintenance records:** Blockchain allows storing aircraft maintenance logs in a tamper-proof ledger, providing a clear and trustworthy history of all repairs and checks.
- Parts traceability:** Every aircraft part can be tracked from manufacture to installation and retirement, ensuring authenticity and reducing counterfeit risks.

2. Improved Supply Chain Transparency

- Real-time tracking:** Blockchain ensures all stakeholders in the aviation supply chain (manufacturers, logistics, airlines) have access to a single source of truth.
- Reduced fraud and errors:** Immutable records help prevent document falsification and enhance inventory accuracy.

3. Enhanced Cybersecurity

- Decentralized data storage:** Blockchain's distributed nature makes data less vulnerable to centralized attacks or manipulation.
- Secure communication:** Blockchain ensures data integrity in communications between aircraft systems, air traffic control, and ground operations.

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