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Next-Generation Black Box with IOT and Real Time Monitoring

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Abstract

The traditional black box, or Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR), has been instrumental in post-crash investigations. Its limitations, such as data loss, difficulty in retrieval from remote or underwater crash sites, and the inability to provide real-time insights, prompted the need for technological advancements. This paper aims to explore the integration of cutting-edge technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Satellite Communication, GPS, and advanced telemetry systems to revolutionize black box functionality and enhance aviation safety. Next-generation black boxes can leverage real-time encrypted data transmission through satellite connectivity, ensuring immediate access to crucial flight parameters, even before an accident occurs. The incorporation of GPS enables precise aircraft tracking, while telemetry techniques allow monitoring of critical flight parameters, engine health, and environmental conditions. Additionally, the use of underwater acoustic beacons and buoyant ejection modules can expedite black box recovery in case of oceanic crashes, reducing search and rescue operation time. AI-driven predictive analytics further strengthen aircraft monitoring by detecting anomalies and potential system failures, enabling preemptive measures to prevent disasters. The integration of IoT allows seamless connectivity between onboard sensors and ground control stations, ensuring that aviation authorities receive real-time alerts regarding abnormal flight behavior or malfunctions. Moreover, cloud-based data storage ensures redundancy, eliminating the risks of data loss due to hardware damage. By implementing IoT-enabled black boxes, the aviation industry can significantly reduce the risk of flight disappearance, improve accident investigations, and enhance proactive safety measures. The ability to access real-time flight data enhances situational awareness, minimizes investigation delays, and facilitates faster decision-making during in-flight emergencies. This technological evolution in flight data recording and transmission marks a significant step toward a safer, more efficient, and more transparent aviation ecosystem.

Keywords: Artificial Intelligence, Integrated deterrence, National Defense strategy, AI adoptive strategy

1. Introduction

In the aviation industry, black boxes have played a crucial role for ages. Flight data recorders or black boxes store important flight information or parameters (like altitude, speed, engine health, environmental conditions) and cockpit recordings. This stored information is investigated after an accident to better understand the condition of the plane before the crash. The crash-protected Flight Data Recorder (FDR) has been one of the most significant innovations in aviation safety. Nowadays, most civil aircraft must have FDR. The final seconds before an accident can be recreated using the data recovered from the FDR. It would be very helpful to construct the FDR's analogy for avionics software. It is frequently quite challenging to identify the exact reason of complex system failures. The main cause of this is an inadequate or improper data gathering procedure that makes it impossible to recreate the events leading to failure. The Software Black Box (SBB) is a framework that makes it easier to investigate and comprehend software failures. SBB offers a reconstruction technique that enables the creation of situations that would have caused software failure, as well as a system to capture the basics of an operating program [1]. The color of the black box is very different from its name; generally, it is bright orange or red. ICAO (International Civil Aviation Organization) requires black boxes to be painted in high visibility colors for easy identification. The paint is often heat-resistant and reflective. Black boxes are also wrapped with corrosion resistance. The attacks compromise the integrity of data and compromise confidentiality. The main issues to address with an increasing amount of cyberattacks are data availability, authorization, integrity, confidentiality, and access control [2]. Figure 1 represents the contribution of different technologies in Next-gen Black Box.

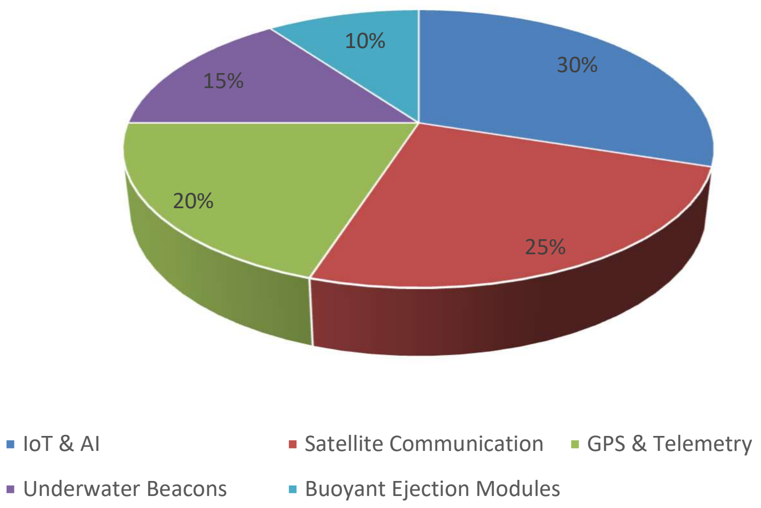

Figure 1. Contribution of technologies in Next-Gen Black Boxes

Traditional black boxes suffer from major limitations such as the risk of data loss due to impact damage, delayed recovery in remote locations, and the inability to provide real-time insights. If the crash is over a deep ocean, dense forest, or rough terrain, retrieving the black box can take months or even remain impossible, leaving investigators without crucial flight data. For decades, black boxes required physical recovery, which can take more than weeks. The primary outcome is that the learnt model is accurate in relation to a previously hand-made design and equivalent in size [3]. The disappearance of Malaysia Airlines flight 370 led to a multinational search effort in southeast Asia and the southern Indian Ocean that became the most expensive search in the history of aviation. The Air France Flight 447 (2009) black box took almost two years to locate in the Atlantic Ocean. These incidents highlighted the urgent need for real-time data transmission, as the black box was never found. IoT-based black boxes can transmit real-time encrypted flight data to aviation monitoring systems. Airbus and Boeing are testing IoT-based satellite-connected black boxes to stream real-time telemetry and cockpit audio. Next-gen black boxes can use underwater acoustic beacons and buoyant ejection modules to improve post-crash retrieval. By integrating IoT, AI and blockchain, black boxes can evolve beyond passive data storage into proactive aviation safety systems. This paper aims to address these challenges by integrating the IoT-based black boxes for real-time flight monitoring and improving post-crash forensics. Google paid $3.2 billion to acquire Nest, a manufacturer of such a gadget, in 2014 [4]. Aviation is an industry considered to provide a safe mode of transport; even though that is the case over the past years, several plane crashes and missing planes have been recorded.

This paper aims to explore some of the technologies that are being adopted and to research new ways of integrating these technologies and techniques to provide a much safer environment for flying, even use this technology in rocket propulsion (Solid [5-6], liquid [7-8], or hybrid rocket propulsion [9-11]) also. The Commission includes data security and privacy under the heading "Lifting the obstacles to the uptake of the Internet of Things" in its 2009 Action Plan on the IoT [12]. Black boxes, or flight data recorders (FDRs), and cockpit voice recorders (CVRs) are important components in modern aerospace safety systems. The integration of IoT (Internet of Things) in the aviation industry has revolutionized real-time equipment monitoring, data transmission, fault detection, and safety measures. Self-awareness of the video's quality offers a diagnostic tool and a maintenance alert [13]. This integration of IoT in black boxes, focuses on how it enhances their functionality, the data they collect, and the overall safety of flight. The goal is to develop IoT-based black boxes by integrating satellite monitoring and other AI-integrated sensors. The traditional black boxes lack real-time data, which sometimes leads to loss of data or other important information after losing contact with the plane after an unfortunate crash. An IoT-based, satellite-connected black box is a revolutionary evolution of the traditional black box. The robotics community has recently become more interested in autonomous aerial vehicle navigation in GPS-denied settings. Shen et al. showed how to navigate a quadrotor indoors using a laser range sensor [14]. It enables continuous real-time data transmission from an aircraft to ground control. The purpose is to provide immediate access to critical flight data, improving flight safety, reducing search times, and providing quicker investigation after a crash. Presently, black boxes store flight data and cockpit voice recordings on the aircraft, which are only accessible after the box is physically recovered. IoT-based black boxes rely on terrestrial networks, which may not provide full coverage of oceans and polar regions.

Companies involved in satellite communication, such as SpaceX and Iridium, should continue expanding their Low Earth Orbit (LEO) satellite constellations to provide consistent and reliable global coverage. By improving the satellite network's coverage, we can address connectivity gaps over remote and polar regions, where traditional systems struggle. In the event of an emergency, satellite-based communication systems can provide direct communication between aircraft and emergency responders on the ground. Iridium satellites provide global tracking of aircraft through the Aircraft Tracking System. IBM adds a fourth "V" of veracity to the Big Data analysis challenge to provide trust and noise filtering. Chatter from social networks, web server logs, traffic flow sensors, satellite imagery, broadcast audio streams, banking transactions, MP3s of rock music, web page content, scans of official documents, GPS trails, telemetry from cars, financial market data, and more could all be used as input data for big data systems [15].

The Iridium Communications System employs 66 low Earth orbit processing satellites that support user-to-user, user-to-gateway, and gateway-to-gateway communications. The 66 satellites are evenly distributed in six orbital planes with an 86.4° inclination, with one or more in-orbit spares for each orbital plane. Except for planes 1 and 6, the orbital planes are co-rotating and spaced 31.6° apart. The first and last orbital planes are spaced 22° apart and form a seam where the satellites are counter-rotating. While real-time transmission is ideal, a robust crash-proof storage mechanism is still necessary in case of transmission failure. Combining 5G, LoRa, and satellite networks can optimize cost and efficiency. Next-gen black boxes integrate AI-driven analytics to predict and mitigate flight risks before accidents occur. Technologies like electable black boxes can be proposed that detach from the aircraft before impact to save the information. IoT, AI, and connectivity via satellite have fueled the development of black box technology, which is improving aviation safety and accident investigation. Reliability is increased via real-time data transmission and sophisticated storage approaches, but issues like cybersecurity risks, expensive implementation, and retrieval efficiency still need to be resolved.

To guarantee thorough and reliable data recording systems, future research should concentrate on creating hybrid communication networks, energy-efficient black boxes, and AI-driven predictive analytics. One of the most significant features of the developing Internet of Things is its amazing reach and breadth, as more and more observers come to understand. In a few years, there will be many more IoT devices than people on the earth, and the number of devices will only increase. A network never seen before will be formed by billions of devices worldwide [16]. Next-generation black boxes will greatly increase aviation safety by incorporating these developments, making air travel safer and more resilient to unanticipated events. This can be defined as the communication between objects that are enabled with internet connectivity with a unique IP address. Figure 2 shows the impact of IoT adoption on flight safety metrics.

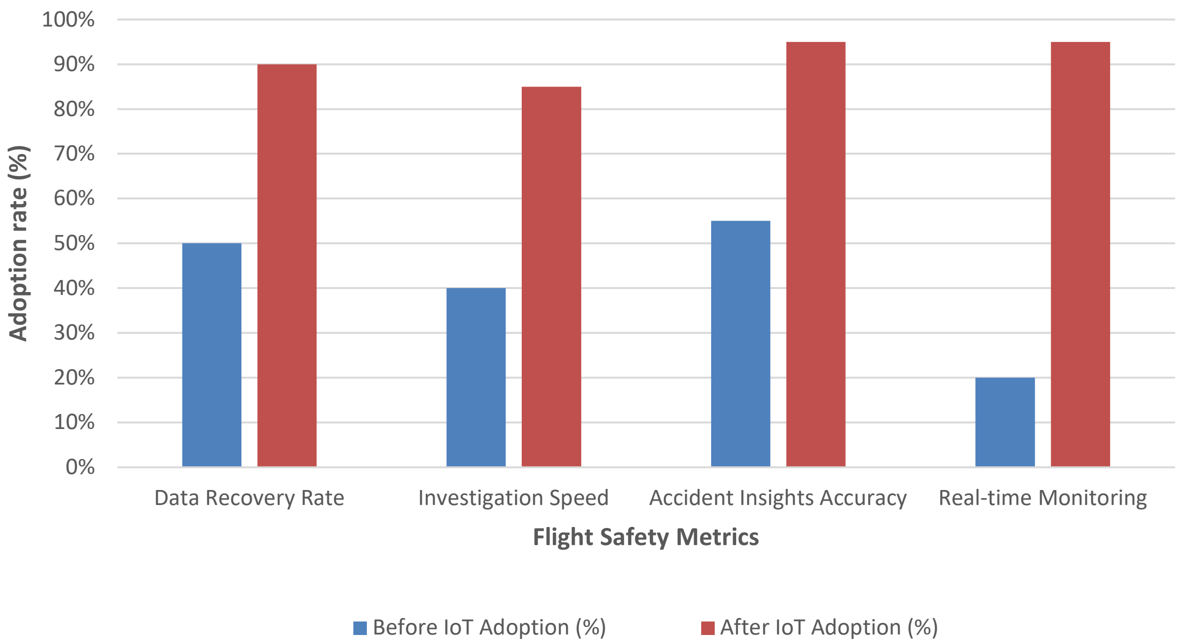

Figure 2. Impact of IoT Adoption on Flight Safety Metrics

2. Methodology

The main subject of studies presented in this paper is Aviation Company's flight data and flight monitoring. To decide whether or not to rebroadcast the message, other methods combine the probabilistic approach with another locally calculable mechanism, such as counter-based, distance-based, location-based, or any combination of those [17]. The main objective of this is the automated processing of flight data delivered from the aircraft in online mode, 24 hours a day, 7 days a week, 365 days a year, to improve flight safety and operational communication between the ground crew and aircraft crew and improve Airlines commercial transportation's efficiency and profitability. In addition to the current use of the global positioning system (GPS), an in-flight communication link is established for short burst data (SBD) from the cockpit and circuit switched data (CSD) toward the carrier.

Numerous models for data separation and sharing are offered by computing systems. For instance, the process/thread distinction is usually characterized in a single processing system as follows: a group of threads share a common memory space, whereas processes occupy distinct memory regions. Additionally, models for distinct and shared memory spaces are offered by distributed computing [18]. During regular fleet activities, in addition to searching into flight incidents and errors, flight data/cargo monitoring is a tool for efficiently handling and evaluating processed flight information (parametric, voice, and video information) collected by the on-board flight data recorder. In addition, it provides the job of 4D flight tracking.

The goal of the flight data monitoring system is to connect the requirements of the governing normative documents regarding the operator's continuous monitoring of the aircraft's position and technical condition, establish a unified information space that will allow the aviation specialists involved to receive the necessary information (voice, video, and parametric) about each flight of the aviation aircraft, including technical characteristics of the condition of the aircraft and its systems, at any time, while making sure protected personalized access to the information, separately collect and gather technical information from aircraft on aviation hardware with subsequent processing and distribution for particular user groups within airline departments, and elevate the level of informing aviation specialists by providing the aircraft.

Given that various access points allow users to obtain permission according to various regulations, an aircraft operator's complicated data access control system presents a hurdle. As a result, there are greater numbers of legal permissions, which raises the risk overall. The network administrator will be able to arrive at better decisions and respond to incidents faster with a universal and user-friendly tool for testing access control systems. By protecting UAV identification and communication privacy, this method seeks to stop external attacks that would compromise the communication system [19].

2.1 Telemetry Solutions

Based on anomaly detection, information traffic analysis tools, and on-board signs, telemetry technologies may help improve the security of an air cargo monitoring system. This suggests a multi-module back-end system that consists of a ground station to monitor flight statistics, a real-time database to store flight data, and an in-range medium of communication channel to create a connection. GPS coordinates, flight speed, and altitude are frequent waypoints considered when tracking numerous cargoes in confined airspace [20]. Figure 3 represents a cargo monitoring system.

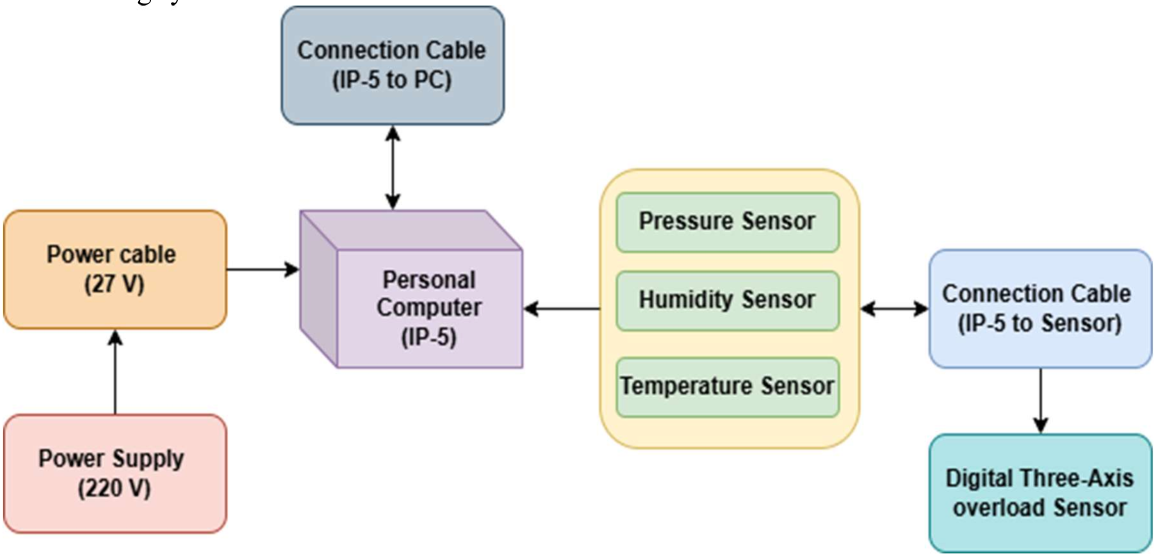

Figure 3. Cargo monitoring (status, wired approach)

Furthermore, to monitor requests to connect to unusual network access points, machine learning technologies created by TELEMETRY partners will assist with recognizing suspicious network activity and abnormal actions taken by on-board information sensors (temperature, pressure, and humidity). We update the inner round mentioned by increasing the number of bits of the key utilized in each round in order to create a quick black-box implementation of a white-box cipher. Specifically, we substitute a key-dependent circular bit shift transformation for the missed AES Shift Row transformation [21].

Table 1 Violation in the Aviation use case

Data Protection Violation	Description
Anomalies in operation	Detection of anomalies in network traffic and assignment of risk profile to reach device.
Realtime alarm system	The cargo is expose to too high/too low temperature for a prohibitively long time. It could be prevented during the flight.

In turn, testing the cybersecurity of ground-based and on-board IT systems will enable monitoring of their typical or atypical behavior and help identify vulnerabilities in limiting access to system components. It will additionally guarantee that problems related to vulnerabilities are attended to at the HW and SW level (closing user rights, ensuring security logging, sending clusters to quarantine, alerting responsible employees, setting timings, issuing recommendations in case of violation of the conditions or rules for resolving an incident, logging actions when resolving an incident, etc.) [22].

3. Results and Analyses

The IoT-based system collects data from various sensors, vibration, and temperature and transmits it via an IoT platform.

Comparison of traditional black boxes and IoT based black box is shown in table 2.

Satellite-based remote monitoring allowed real-time tracking of high-value aerospace equipment across multiple manufacturing sites. GPS helps to locate or find the exact location data, enhancing predictive maintenance accuracy and preventing failures before they occur. It will also enable continuous global monitoring.

The results demonstrate that integrating IoT, satellite communication, GPS, and other sensors enable more reliable equipment monitoring, significantly reducing downtime and operational costs.

Table 2. Comparison of traditional black boxes and IoT based black box

S. No	Parameter	Traditional Black Box	IoT Based Black Box with Telemetry	References
1.	**Data Storage**	Stored Locally	Cloud + Edge Computing for real-time processing.	[23]
2.	**Data Retrieval**	Requires physical recovery	Instant access with advanced analytics.	[24]
3.	**Real-Time Monitoring**	Not possible	Continuous Monitoring with real time alert.	[25]
4.	**Connectivity**	No network connectivity	Enhanced connectivity with low -latency satellite links.	[26]
5.	**Fault Detection**	Post-event analysis	Advanced diagnostic with telemetry for real-time issue detection.	[27]
6.	**Data Loss Risk**	High if black box is damaged/lost	Minimal risk with redundant data transmission and edge storage.	[25]
7.	**Analysis Speed**	Slow, post-recovery decoding	Ultra-fast with real-time telemetry processing.	[28]
8.	**Security & encrypt**	Secure but vulnerable to loss.	Advanced security with end-to-end encryption and blockchain integration.	[23]
9.	**Scalability**	Limited to a single aircraft's storage.	Highly scalable with fleet-wide telemetry analysis.	[26]

4. Conclusions

A significant advance in aviation safety and crash recovery efforts is the incorporation of internet of things (IoT) devices into black aircraft boxes. Advanced GPS, real-time data streaming, and satellite-based monitoring represent a few of the advancements that could significantly enhance aviation safety through making it simpler to identify crash sites. Enhanced GPS Integration with IoT in Black Boxes: Modern black boxes can be equipped with cutting-edge GPS technology that turns on when it senses unusual acceleration or impact. It makes it possible for sending satellites precise location data. Real-Time Data Streaming: Flight data can be continuously streamed across satellite networks thanks to technologies like FLYHT's Automated Flight Information Reporting System (AFIRS).

Timely recovery efforts could rely on this real-time data. Satellite-Based ADS-B: Even at remote locations, real-time airplane monitoring is made conceivable through the integration of satellite-based automatic dependent surveillance broadcast, or ADS-Quicker Recovery Time Search and recovery efforts can be initiated quicker with real-time data and precise location monitoring. Enhanced safety data streaming and continuous surveillance may help in spotting issues before they turn into events. Regulation Compliance These technologies assist in guaranteeing adherence to the International Civil Aviation Organization's (ICAO) Global Aeronautical Distress and Safety System (GADSS) demands. For further growth we can implement 5G + Satellite Hybrid Networks Combining both 5G connectivity with satellite communication to enhance data speed and reliability. Developing self-repairing components using AI-guided robotics.

Declaration of competing interest

The author declare that she had no known financial and non-financial competing interest in any material discussed in the paper.

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