



iJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** IX **Month of publication:** September 2026

DOI: <https://doi.org/10.22214/ijraset.2026.84956>

www.ijraset.com

Call: ☎ 08813907089

E-mail ID: ijraset@gmail.com

Digital Twin for Aircraft Wing Maintenance with ML-Based Deviation Detection

R Kshamaa Rajoop¹, Ishanvi M H², Jesy Jeff Laura E³, Harshada G⁴, Mohan Babu G⁵

^{1, 2, 3, 4, 5}Department of Computer Science and Engineering (IoT & Cyber Security Including Blockchain Technology), Bangalore Institute of Technology, Bengaluru, Karnataka, India

Abstract: A growing need in the aviation industry is the development of smart maintenance systems that have the ability to not only improve aircraft safety but also reduce operating costs and time. Existing inspection technologies are mostly time-based and do not allow one to find structural defects between maintenance intervals. Digital Twin (DT) technology allows obtaining a virtual copy of the asset in real-time through integration of sensors, computational models, cloud communication, and predictive analysis. In this work, we propose a DT-based framework for aircraft wing maintenance with ML-based deviation detection. Our framework includes a physical aircraft wing model with a Flex sensor and MPU6050 accelerometer connected to an ESP32 microcontroller for real-time data collection. Data from the sensors are transmitted to the ThingSpeak cloud service and synchronised with a virtual twin of the physical wing created using MATLAB/Simulink and Simscape. Decision Tree classifier uses strain and vibration characteristics to classify the state of the wing as normal or abnormal to perform predictive maintenance.

Keywords: Digital Twin, Aircraft Wing, Structural Health Monitoring, Internet of Things, Predictive Maintenance, MATLAB/Simulink, Decision Tree, ESP32.

I. INTRODUCTION

The aviation industry is one of those industries that are characterised by being the most safety-critical; the structural integrity of any system will impact the reliability and safety of the airplane. The wings of an airplane are subject to constant aerodynamic loads, vibrations, cyclic stress, and environmental fatigue. These will continuously affect the performance of the structure and cause cracks or deformations, which can happen unexpectedly if they are not detected early. Therefore, structural health monitoring is an essential requirement today. The traditional aircraft maintenance process uses preventive or schedule-based inspection methods where components are inspected following a certain number of hours of flying. While this method ensures regulatory compliance, it often leads to unnecessary maintenance activities and delayed detection of structural problems. With the advancement in aircraft complexity and the generation of huge amounts of data from sensors, there has been a push towards Intelligent Condition-Based Maintenance using Digital Twin. Digital Twin is a cyber-physical system that forms a highly accurate digital copy of the physical entity and syncs it with real-time sensor data. In contrast to traditional simulations, a Digital Twin system facilitates a two-way communication channel between the physical and digital domains, allowing for monitoring, prediction, optimization, and decision-making. Contemporary Digital Twin solutions utilize the Internet of Things, Artificial Intelligence, cloud computing, edge computing, big data analysis, and mathematical models to reflect the real-time behaviour of engineering systems.

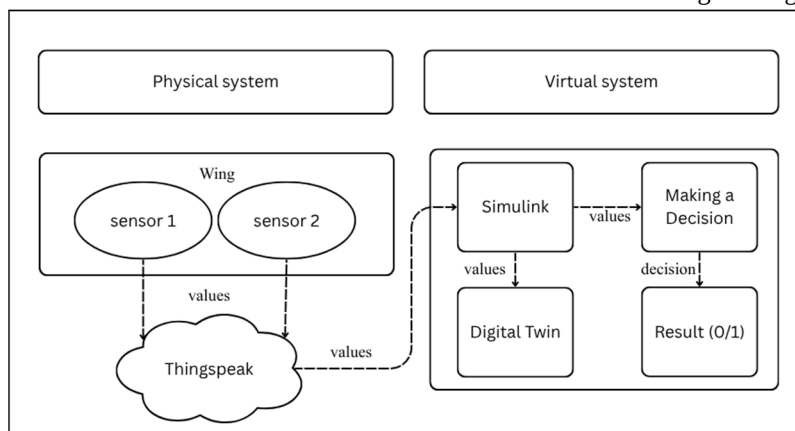


Fig. 1 A Digital Twin framework for aircraft wing monitoring and automated decision-making.

Fig. 1 illustrates a framework which uses physical sensors on an aircraft wing to capture real-time operational data, sending it via the ThingSpeak cloud to a virtual system. Inside this virtual space, Simulink process the information to evaluate structural health and instantly output a binary decision status. Digital Twin model will show the live behaviour of the wing.

Modern research shows that the Digital Twin is already a critical enabling technology for aerospace applications like aircraft production, assembly, structural optimization, prediction, maintenance, fleet management, and safety. However, most of the current research focuses on large-scale industrial applications or the theoretical framework, but there are not many papers describing an integrated, cost-effective architecture of the Digital Twin for aircraft wing structural health monitoring with machine learning capabilities. In order to bridge this research gap, this study suggests a Digital Twin architecture that uses IoT sensing in real time, cloud communication, a MATLAB/Simulink simulation model, and Deviation Detection based on a machine learning algorithm. The design of a physical aircraft wing includes the use of a flex sensor and an MPU6050 accelerometer sensor for measurement of bending and vibration, respectively. Live readings from sensors are sent by the ESP32 microcontroller to ThingSpeak, and the data gets synchronized with the virtual aircraft wing created using MATLAB/Simulink. Based on the structural properties of the aircraft wing, the Decision Tree classifier determines whether the operation of the wing is healthy or abnormal.

The key contributions of this research are outlined below:

- Development of a Digital Twin framework in real time for maintenance of aircraft wings.
- Incorporation of IoT devices such as ESP32, flex sensor, and MPU6050 to perform constant structural monitoring.
- Cloud-based synchronization through ThingSpeak.
- Simulation of the virtual aircraft wing using MATLAB/Simulink software (Simscape).
- Use of Machine Learning for deviation detection based on a Decision Tree classifier.

A. Problem Statement

Traditional methods used in aircraft maintenance rely mostly on manual periodic inspection, which makes the early detection of fatigue cracks, abnormal vibration, and deformation almost impossible during the actual operation of an aircraft. Current systems that use sensors have no capability of providing smart analysis and visualization.

B. Research Objectives

Objectives of the suggested research include:

- 1) The creation of an IoT-based aircraft wing prototype that is able to detect changes in structure and vibrations in real-time.
- 2) The creation of a Digital Twin through MATLAB/Simulink in order to simulate the behaviour of the physical wing.
- 3) Synchronization between the physical system and the digital model through the cloud using ThingSpeak.
- 4) The development of a decision tree machine learning algorithm for real-time deviation detection.
- 5) Intelligent condition-based maintenance for aircraft safety and efficiency in maintenance.

II. LITERATURE REVIEW

The Digital Twin (DT) technology is currently one of the most innovative technologies in the realm of Industry 4.0, allowing the building of intelligent copies of physical objects by synchronizing the sensor data, computations, and cloud connectivity. For the aerospace industry, DTs have evolved from mere simulation tools to cyber-physical systems that can be used for Structural Health Monitoring, Predictive Maintenance, Lifecycle Management, and optimisation. Recent research has shown that using IoT, Artificial Intelligence, cloud computing and physics-based modelling substantially increases the reliability and efficiency of aircraft maintenance.

A. Evolution of Digital Twin Technology

The concept of the Digital Twin was first proposed in 2002 by Michael Grieves within the field of Product Lifecycle Management (PLM) and further extended by NASA to include three components, namely physical objects, digital representations of those objects, and constant two-way communication between the objects. Today, Digital Twins consist of five main components, including the physical object, digital object, data, connectivity, and intelligent services.

In contrast to traditional simulation, the use of Digital Twins makes use of real-time sensor information to constantly update the virtual model, which makes it very appropriate for safety-critical applications in aerospace. The use of digital twins technology has helped in lowering costs in aircrafts maintenance. [3]

B. Digital Twin in Aircraft Maintenance

Bisanti et al. conducted a systematic review of Digital Twin applications in aircraft maintenance and operation, covering areas such as predictive maintenance, structural monitoring, and operational performance. The authors proposed an IoT-enabled modular architecture integrating physical systems, connectivity, data management, Digital Twin models, and application-level decision support. They also identified interoperability, data integration, security, scalability, and regulatory certification as important challenges for aircraft maintenance Digital Twins.

The review highlights predictive and condition-based maintenance as important applications of Digital Twin technology in aviation. By continuously integrating sensor data, aircraft operational information, and virtual models, Digital Twins can support maintenance decision-making and provide a foundation for transitioning from traditional scheduled maintenance toward condition-based approaches. [25]

C. Structural Health Monitoring of Aircraft Wings

The Structural Health Monitoring (SHM) system uses computational techniques and sensors to analyse the status of the structure of aircraft during their operation. Lai et al. presented the concept of a Digital Twin that uses experimental and computational data for monitoring the deformation of the wings of an aircraft in real-time. Their method proved that the combination of sensor data with finite elements enhances damage identification and prediction. [7]

The authors Ezhilarasu et al. proposed the concept of the generalised diagnosis approach for aircraft systems, which involved sensor acquisition, fault detection, and intelligent decision-making. This model serves as a systematic tool for detecting any abnormalities in aircraft systems and is the foundation of predictive maintenance of critical aircraft components. [6]

This is evidence that there is a lot of help for the monitoring of aircraft wings through the incorporation of physical sensor readings and the virtual structure model of the wing.

D. Digital Twins as an Extension of Cyber-Physical Systems

Kan and Anumba examined Digital Twin technology as an evolution of traditional Cyber-Physical Systems (CPS), particularly in the context of construction and infrastructure. Their work explains that while CPS connects computational systems with physical processes, Digital Twins extend this concept by maintaining a persistent virtual representation of the physical system with continuous data synchronization. The proposed framework combines Building Information Modeling (BIM), sensor networks, real-time location systems, and analytics to support structural monitoring, safety management, quality control, and predictive maintenance.

The study highlights that real-time monitoring and continuous data exchange can improve safety and quality compared with periodic inspection methods. However, challenges such as sensor reliability, communication infrastructure, changing physical environments, interoperability, and adoption of new workflows remain significant. Although the research focuses on construction, its CPS-based approach is relevant to aircraft Digital Twins because aircraft wings similarly require continuous interaction between physical sensing, virtual modelling, and intelligent analysis. [4]

E. Digital Twin for Continuous Flight Monitoring

Zhang et al. proposed FlightTwin, a generalized Digital Twin framework for fixed-wing aircraft covering pre-flight, in-flight, and post-flight operations. The framework consists of aircraft state estimation, structural health monitoring, performance prediction, and decision-support modules. Sensor fusion and Kalman filtering are used to estimate the aircraft state, while physics-based and data-driven models are combined to represent different aircraft subsystems.

The framework continuously updates the Digital Twin using flight data and can monitor fatigue accumulation, structural degradation, aircraft performance, and remaining useful life. The authors also consider communication bandwidth, computational latency, and uncertainty-aware decision-making. This work demonstrates that a Digital Twin can extend beyond isolated component monitoring and provide a continuous representation of the aircraft throughout its operational lifecycle. [8]

F. Uncertainty-Aware Aircraft Wing Health Monitoring

Li et al. proposed a Dynamic Bayesian Network (DBN) approach for aircraft wing health monitoring within a Digital Twin framework. The method integrates heterogeneous information such as sensor measurements, inspection results, physics-based models, and historical aircraft data. The Bayesian network represents the relationships between flight loads, material degradation, crack propagation, sensor observations, and inspection outcomes.

The Digital Twin is continuously updated as new measurements become available, allowing the system to estimate the current structural health and predict remaining useful life with confidence intervals. The approach is particularly useful because aircraft structural damage develops over time and measurements are affected by uncertainty. The study demonstrates how probabilistic modelling can improve information fusion and maintenance decision-making under uncertain operating conditions. [9]

G. Digital Twin Applications in the Aerospace Industry

Li et al. presented a comprehensive introduction to Digital Twin technology in the aerospace industry, covering its evolution, enabling technologies, applications, and challenges. The study explains how Digital Twins combine physical systems, virtual models, and continuous data connections using technologies such as IoT sensors, communication networks, cloud and edge computing, artificial intelligence, and simulation platforms.

The authors identify applications throughout the aircraft lifecycle, including virtual prototyping, manufacturing, assembly, flight monitoring, predictive maintenance, and lifecycle management. Aerospace examples demonstrate how Digital Twins can support condition-based maintenance and real-time aircraft monitoring. However, challenges involving cybersecurity, interoperability, model validation, computational requirements, and regulatory certification remain important barriers to large-scale adoption. [10]

H. Airframe Digital Twin for Structural Integrity

Tuegel introduced an important early concept of the Airframe Digital Twin, focusing on aircraft structural integrity and lifecycle management. The proposed approach aims to move beyond conventional safe-life and damage-tolerant maintenance by continuously combining aircraft-specific operational data, inspection results, and physics-based degradation models.

The framework considers uncertainty in material properties, loading conditions, measurements, and damage progression. Bayesian inference and reduced-order physics models are proposed to estimate the structural state and remaining life of individual aircraft. Fatigue crack growth in wing structures is used as a primary example. The work established the foundation for using Digital Twins to perform aircraft-specific structural life prediction rather than relying only on fleet-average assumptions. [11]

I. Real-Time Acceleration-Based Aircraft Wing Monitoring

Yang et al. investigated the use of real-time acceleration measurements for aircraft wing Digital Twins. The study addresses the difficulty of obtaining complete structural information from a limited number of sensors. Instead of directly measuring strain and displacement throughout the wing, acceleration measurements are processed to reconstruct velocity, displacement, and strain fields.

The proposed method combines filtering techniques with modal expansion and finite element models. Adaptive Kalman filtering and recursive least-squares methods are used to reduce the effects of sensor drift and measurement noise. The approach demonstrates that low-cost accelerometers can provide useful information for estimating the structural state of an aircraft wing in real time. This is particularly relevant to low-cost Digital Twin systems where installing a large number of strain sensors may not be practical. [12]

J. Digital Twin for Aircraft Assembly Quality Control

Cai et al. applied Digital Twin technology to quality deviation control during aircraft manufacturing and assembly. Their framework combines the nominal geometry obtained from CAD models, actual geometry obtained through measurement systems, and models describing how assembly deviations propagate through the aircraft structure.

The Digital Twin is continuously updated using measurements collected during assembly, allowing deviations to be detected before the assembly process is completed. Monte Carlo simulation and deviation propagation analysis are used to predict the effect of component-level deviations on final assembly quality. The system can also identify possible sources of deviations and support corrective actions such as rework, shimming, or component replacement. The study demonstrates that Digital Twins can be used not only for aircraft maintenance but also for preventing structural deviations during manufacturing. [13]

K. Hybrid Digital Twin Using Machine Learning

Uzun et al. proposed a hybrid Digital Twin for aircraft flight performance that combines physics-based modelling with Machine Learning. The motivation is that purely physics-based models require detailed aerodynamic and propulsion information, whereas purely data-driven models may produce unreliable predictions outside their training conditions. Their framework uses a physics-based model to predict parameters such as lift, drag, thrust, and fuel flow, while a Machine Learning model learns the difference between predicted and actual aircraft behaviour.

Bayesian fusion is then used to combine the two sources while considering uncertainty. The Digital Twin can be updated using real-time flight parameters such as airspeed, altitude, throttle setting, fuel flow, and acceleration. This demonstrates the benefit of combining physical knowledge with data-driven learning for aircraft monitoring and prediction. [15]

L. Online Digital Twin for UAV Engine Anomaly Detection

Peng and Chen proposed an online Digital Twin approach for anomaly detection in rotary engines used in fixed-wing UAVs. The system combines a physics-based engine model with an online Machine Learning anomaly detection module. Measured parameters such as RPM, exhaust gas temperature, fuel flow, and vibration are compared with Digital Twin predictions to identify abnormal behaviour.

The system uses lightweight online learning techniques, including recursive least squares and online sequential extreme learning machines, so that anomaly detection can be performed under the computational limitations of UAV hardware. The Digital Twin continuously adapts to normal engine behaviour and detects deviations associated with problems such as misfire, bearing degradation, fuel-system faults, and overheating. This research demonstrates how Digital Twins can perform real-time anomaly detection even when computational and sensor resources are limited. [16]

M. Digital Twin for Aircraft Structural Life Prediction

Tuegel et al. proposed the use of Digital Twin technology to reengineer aircraft structural life prediction. The authors identify limitations in traditional safe-life and damage-tolerant approaches, particularly their dependence on conservative assumptions, fleet-average usage data, and limited consideration of the individual aircraft's operational history.

The proposed Digital Twin combines high-fidelity fracture and fatigue models with probabilistic descriptions of material properties, geometry, and loading conditions. Aircraft-specific flight loads, usage information, and nondestructive inspection results are incorporated through Bayesian updating. As additional information becomes available, uncertainty in the estimated structural condition and remaining useful life decreases. The approach therefore provides a foundation for aircraft-specific structural life prediction rather than relying only on generalized fleet-level assumptions. [17]

N. Six-Degree-of-Freedom Digital Twin for Fixed-Wing Aircraft

Dong et al. developed a six-degree-of-freedom Digital Twin model for fixed-wing aircraft. The framework represents the three translational motions—surge, sway, and heave—and the three rotational motions—roll, pitch, and yaw. The model incorporates aerodynamic forces and moments, propulsion, gravity, atmospheric conditions, and sensor behaviour.

The Digital Twin operates in both simulation and estimation modes. In simulation mode, it predicts aircraft behaviour from control inputs, while in estimation mode, sensor measurements are combined with model predictions using filtering techniques. The modular framework can be adapted to different aircraft configurations and sensor systems. The research demonstrates the feasibility of high-fidelity aircraft flight simulation and state estimation using Digital Twin technology. [18]

O. Digital Twin-Based Damage Identification of Aircraft Components

Chen et al. investigated Digital Twin-based damage identification for important aircraft components such as wing structures, fuselage frames, and attachment fittings. Traditional inspection techniques such as visual inspection, ultrasonic testing, and eddy-current testing can be labour-intensive and are generally performed at scheduled intervals.

The proposed Digital Twin combines finite element models, reduced-order models, sensor measurements, and damage identification algorithms. Measurements from strain gauges, accelerometers, and acoustic emission sensors are compared with the expected behaviour of the virtual model. Model updating and Bayesian inference are used to estimate the location and severity of damage such as cracks, corrosion, disbonding, and impact damage. The study demonstrates the potential of Digital Twins to support condition-based structural monitoring and reduce dependence on periodic manual inspection. [19]

P. Displacement Field Perception for Aircraft Assembly

Liang et al. proposed a Digital Twin method for reconstructing the displacement field of aircraft components during assembly. Aircraft components may differ from their nominal CAD geometry because of manufacturing tolerances, assembly stresses, and environmental conditions. Therefore, representing only the nominal geometry may not accurately describe the actual assembled structure. The proposed approach uses sparse displacement measurements together with a reduced-order finite element model to reconstruct the complete displacement field.

Modal superposition and shape-function interpolation are used to estimate the full structural configuration from limited sensor measurements. The Digital Twin is then updated in real time as assembly progresses. This approach can support gap prediction, shim optimization, interference detection, and assembly stress monitoring while reducing the need for expensive full-field measurement systems. [20]

Q. Digital Thread-Based Digital Twin for Aircraft Assembly

Zhang et al. proposed a digital thread-based framework for Digital Twins in aircraft assembly. The study focuses on the problem of disconnected information between aircraft design, manufacturing, quality inspection, and final as-built configuration.

The framework consists of a data acquisition layer, a digital thread layer, a Digital Twin modelling layer, and an application layer. The digital thread provides continuity between design specifications, manufacturing data, quality measurements, and as-built information. This allows the Digital Twin to maintain traceability throughout the aircraft lifecycle. The framework was demonstrated for aircraft wing box assembly and fuselage joining operations, showing its potential for reducing assembly errors, improving root-cause analysis, and reducing assembly time. [21]

R. Digital Twin for Aircraft Structural Lifecycle Management

Liao et al. investigated Digital Twin technology for aircraft structural lifecycle management, covering the complete lifecycle from design and manufacturing to operation, maintenance, and retirement. Their framework integrates finite element and fatigue models with manufacturing history, operational flight loads, inspection results, and maintenance records.

Bayesian updating is used to combine these different sources of information and reduce uncertainty in structural condition estimation. The approach was demonstrated using aircraft structural components such as wing skins, fuselage panels, and attachment fittings under accelerated fatigue testing and seeded damage conditions. The study highlights how Digital Twins can support structural life extension decisions and provide confidence bounds for remaining-life predictions. [22]

S. Digital Twin-Based Assembly Visualization

An IEEE 2024 Symposium study investigated the use of Digital Twins for visualization of aircraft component assembly. Traditional assembly instructions based on static drawings and models cannot always represent the actual condition of components during assembly. The proposed framework uses sensors, cameras, and tracking systems to capture the position, orientation, and deformation of components. The collected information updates the Digital Twin, which provides colour-coded deviation information and assembly guidance. Augmented Reality is also used to overlay Digital Twin information onto the physical assembly environment. The study demonstrates that real-time visualization can help technicians identify assembly deviations, reduce rework, and improve assembly accuracy and traceability. [23]

T. Digital Twin for Aerodynamic and Structural Interaction

Makuni et al. investigated Digital Twin modelling of the interaction between aerodynamic forces and aircraft structural deformation. This interaction, known as aeroelasticity, is important because aerodynamic loads deform the wing, while the resulting deformation changes the aerodynamic loads acting on the wing. The proposed framework combines reduced-order computational fluid dynamics models with finite element structural models and real-time sensor measurements. Pressure sensors, accelerometers, and strain gauges are used to update the Digital Twin. The framework can be used for flutter monitoring, flight-envelope protection, maneuver-load prediction, and estimation of structural responses to gusts. The study demonstrates that combining aerodynamic and structural models can provide a more complete representation of aircraft wing behaviour than considering structural behaviour alone. [24]

U. Digital Twin Architecture for Aircraft Maintenance

Bisanti et al. conducted a systematic literature review of Digital Twin applications in aircraft maintenance and operation and proposed an IoT-enabled modular architecture. The review identifies predictive and condition-based maintenance as important application areas and examines the technologies required for implementing aircraft maintenance Digital Twins. The proposed architecture contains physical, connectivity, data management, Digital Twin core, and application layers. IoT sensors provide operational data, while communication protocols such as MQTT, CoAP, and OPC-UA support connectivity between heterogeneous systems. The Digital Twin core contains geometric, behavioural, physics-based, and data-driven models, while the application layer provides maintenance dashboards and decision-support functions.

The study identifies interoperability, data integration, security, scalability, and regulatory certification as major challenges. The modular architecture provides a foundation for gradually implementing Digital Twin technology across different aircraft maintenance and MRO environments. [25]

III.CONCLUSIONS

In this paper, we present a Digital Twin framework for aircraft wing maintenance with machine learning-based deviation detection. The framework combines IoT sensing, cloud communication, virtual simulation, and intelligent structural health monitoring into a single cyber-physical framework. We propose a system for real-time visualisation of structural behaviour and predictive analysis through continuous synchronisation of the physical aircraft wing prototype with the virtual counterpart using ESP32, Flex Sensor, MPU6050, ThingSpeak, and MATLAB/Simulink.

The developed Digital Twin, in contrast to traditional maintenance based on scheduling, continuously monitors the condition of the aircraft by capturing deformation and vibration data, updating the virtual aircraft wing, and classifying the condition of the structure through the Decision Tree classifier. Machine Learning adds value to maintenance by helping detect any deviations in the structure before catastrophic failure.

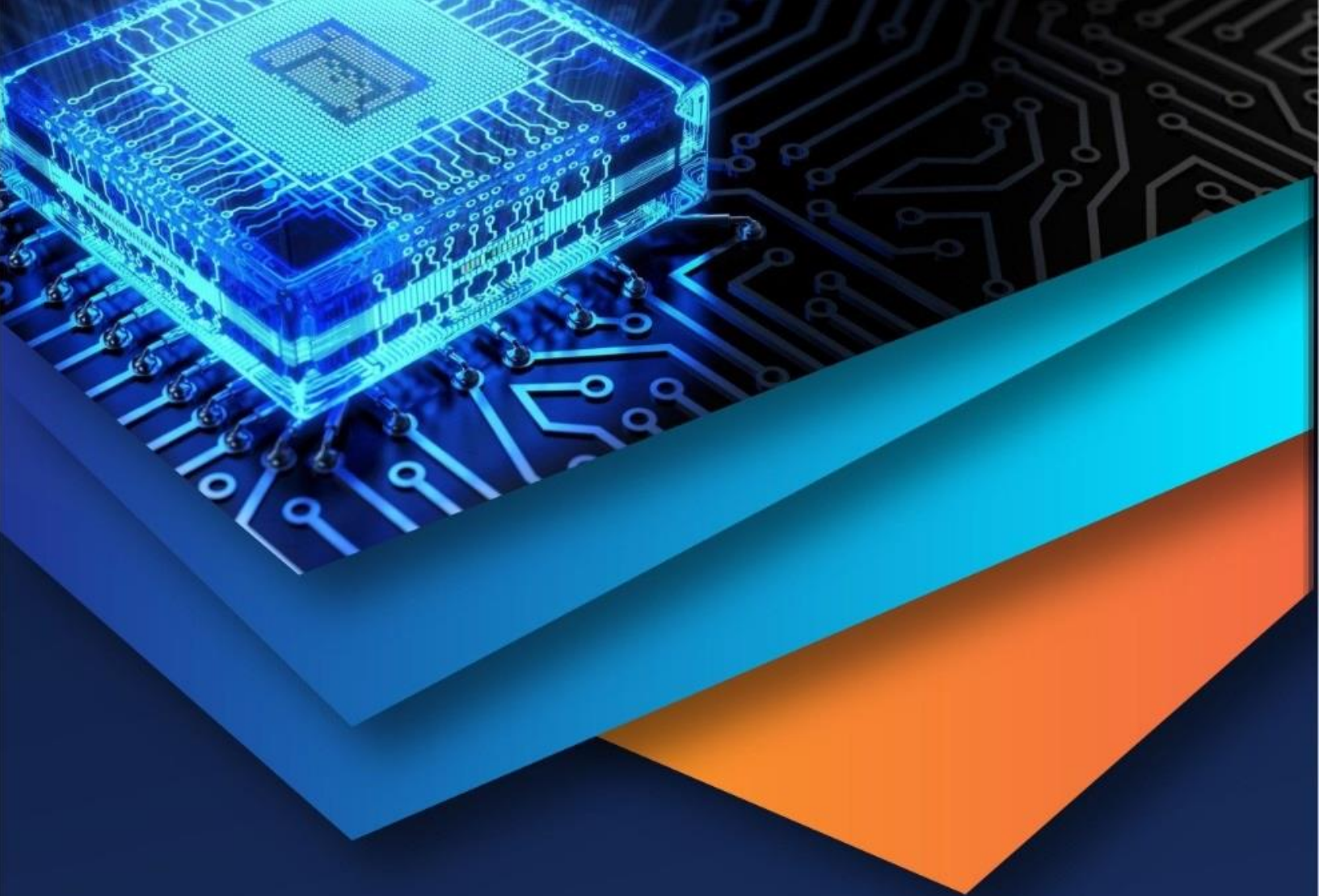
The practical realisation confirms the low cost, scalability, and intelligence of the proposed approach as a solution for aircraft structural health monitoring. Indeed, the integration of physical sensing, cloud synchronisation, virtual modelling, and automatic anomaly detection can be considered effective for future applications in aerospace maintenance and digital twin-based smart aviation systems.

IV.ACKNOWLEDGMENT

We, the authors, sincerely thank the Department of Computer Science and Engineering (IoT & Cyber Security Including Blockchain Technology), Bangalore Institute of Technology, Bengaluru, for providing the facilities and guidance needed to complete this major project. The authors also thank the project guide and department faculty for their invaluable technical support during the research work.

REFERENCES

- [1] B. Stanton, Digital Twin Technology. Atkins Global, Jan. 2017.
- [2] S. Haag and R. Anderl, "Digital Twin-Proof of Concept," Manufacturing Letters, vol. 15, pp. 64-66, 2018.
- [3] Z. Bing et al., "Digital Twin: Concepts, Enabling Technologies, and Applications," Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2024.
- [4] C. Kan and C. J. Anumba, "Digital Twins as the Next Phase of Cyber-Physical Systems in Construction," in ASCE Conference, 2019.
- [5] M. Mugundan, S. S. Sabithulla, S. Vignesh, A. Vijayalakshmi, and K. Virumandi, "Digital Twin Technology for Aircraft Wing Maintenance," 2025.
- [6] C. M. Ezhilarasu, Z. Skaf, and I. K. Jennions, "A Generalised Methodology for the Diagnosis of Aircraft Systems," IEEE Access, vol. 9, 2021.
- [7] X. Lai, W. Sun, L. Yang, X. He, Y. Pang, and X. Song, "Digital Twin-Based Structural Health Monitoring by Combining Measurement and Computational Data: An Aircraft Wing Example," Journal of Manufacturing Systems, 2023.
- [8] W. Zhang et al., "FlightTwin: A Generalized Digital Twin Framework," IEEE Access, 2024.
- [9] C. Li et al., "Dynamic Bayesian Network for Aircraft Wing Health Monitoring," AIAA Journal, 2017.
- [10] L. Li et al., "Digital Twin in Aerospace Industry," IEEE Access, 2022.
- [11] E. J. Tuegel, "Airframe Digital Twin Challenges," in AIAA Conference, 2012.
- [12] Y. Liangliang et al., "Real-Time Acceleration Integration for Aircraft Wing Digital Twin," 2024.
- [13] H. Cai et al., "Quality Deviation Control for Aircraft Using Digital Twin," Journal of Computing and Information Science in Engineering, 2021.
- [14] T. Wang and Z. Liu, Digital Twin for Aircraft Maintenance. Springer, 2022.
- [15] M. Uzun et al., "Hybrid Digital Twin Flight Performance Model," in IEEE Aerospace Conference, 2019.
- [16] C. C. Peng and Y. H. Chen, "UAV Rotary Engine Anomaly Detection via Digital Twin," IEEE Transactions on Aerospace and Electronic Systems, 2024.
- [17] E. J. Tuegel et al., "Reengineering Aircraft Structural Life Prediction Using a Digital Twin Paradigm," 2011.
- [18] C. Dong et al., "6-DOF Digital Twin for Fixed-Wing Aircraft," Springer, 2025.
- [19] L. Chen et al., "Damage Identification Using Digital Twin," Engineering Proceedings, 2025.
- [20] B. Liang et al., "Displacement Field Perception for Digital Twin," Sensors, vol. 20, no. 18, 2020.
- [21] Q. Zhang et al., "Digital Thread-Based Digital Twin Framework," Journal of Manufacturing Systems, 2022.
- [22] M. Liao et al., "Digital Twin for Aircraft Structural Lifecycle," in SPIE Proceedings, 2023.
- [23] M. Li et al., "Assembly Visualization Using Digital Twin," IEEE, 2024.
- [24] T. E. Makuni et al., "Digital Twin for Aero-Structural Interaction," 2026.
- [25] G. M. Bisanti et al., "Digital Twin for Aircraft Maintenance: A Systematic Review," Internet of Things, 2023.



10.22214/IJRASET



45.98



IMPACT FACTOR:
7.129



IMPACT FACTOR:
7.429



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089  (24*7 Support on Whatsapp)