

LEVERAGING DIGITAL TWINS FOR PREDICTIVE MRO IN AVIATION

Abstract

The emergence of digital twin technology is redefining predictive maintenance and MRO in aviation, offering a proactive approach to aircraft safety, efficiency, and reliability. Digital twins create real-time, virtual replicas of aircraft systems, supporting advanced diagnostics and training, thus marking a pivotal shift in aviation maintenance tech. Despite challenges like integration complexity and cybersecurity concerns, digital twins have tremendous potential to enhance operational excellence, making them an essential tool for shaping the future of the aviation industry.

Introduction

Aviation is a heavily technology-driven sector, where airlines and aircraft manufacturers now have to rethink how they approach design, operation, and maintenance workflows. Incidents like Alaska Airlines aircraft panel detachment mid-flight have put traditional MRO practices under intense scrutiny. Events like these underscore the persistent

safety and quality challenges the aviation industry faces. In response, digital twin technology has emerged as a promising, innovative solution, as experts estimate the global digital twin market will grow from \$17.73 billion in 2024 to \$259.32 billion by 2032, growing at a staggering CAGR of 39.8%. Aviation maintenance tech has long been

relying on outdated manual processes, limiting operational effectiveness. Digital twins offer a way out of this challenge – creating real-time, virtual replicas of physical assets. By enabling predictive insights and precise maintenance, digital twin technology enhances predictive maintenance in aviation for enhanced safety, efficiency, and reliability.

Understanding digital twin technology





Digital twin technology refers to the real-time, virtual models of physical assets, processes, or systems that mirror their real-world counterparts. These “twins” continuously receive data from sensors and connected devices, enabling advanced simulations, predictive analytics,

and data-driven decisions. NASA was among the first to develop digital replicas for mission-critical systems in the early 2000s. Since then, digital twins have evolved rapidly, with advances in IoT, AI, and data analytics driving innovation. In aviation, digital twins offer

a dynamic, precise method for enhancing maintenance processes, optimising performance, and predicting potential failures, marking a pivotal shift in aviation maintenance tech.

Key components of digital twins in aviation

The success and effectiveness of digital twin technology in aviation hinge on four key components that work in harmony to drive predictive maintenance and enhance aviation maintenance tech for improved MRO. These key components include:

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|  Data collection |  Simulation models |  Visualisation |  Feedback loop |
| Data is the backbone of digital twins and predictive maintenance in aviation. Sensors provide real-time information on engine performance, fuel levels, and structural health, enabling accurate digital replicas that support predictive MRO. | Simulation models are adept at replicating real-world conditions, allowing digital twins to test various scenarios virtually. By simulating operational wear or environmental disturbances, these models can help predict. | Visualisation tools can help build interactive 3D models of aircraft systems, helping maintenance teams diagnose issues and assess performance in real time. This makes repairs faster and more accurate. | A feedback loop ensures digital twins stay up to date. Real-world data refines the digital models, while insights from the model inform MRO workflows, ensuring ongoing performance optimisation. |

Constant advancements in technologies like AI, 3D modelling, and AR/VR applications are playing a pivotal role in enhancing digital twins. They are powering predictive analytics, improved visualisation, and more efficient training, thus improving the effectiveness of aviation maintenance tech.

Role of digital twins in aviation maintenance tech

The role of digital twin technology has been no short of revolutionary in the modern aviation industry, redefining how airlines approach everything from design to ongoing maintenance. They create real-time, data-driven replicas of aircraft assets to streamline design, enhance manufacturing precision, and improve fuel efficiency. They also leverage advanced simulations to boost flight safety by proactively identifying potential issues. When it comes to aviation maintenance tech, the role of digital twins is equally important as they facilitate:



Predictive maintenance in aviation

One of the most transformative roles of digital twin technology is facilitating predictive maintenance in the aviation industry. By continuously analysing real-time data from aircraft sensors, digital twins can help maintenance teams anticipate component wear and address potential issues before they lead to critical failures. This proactive approach significantly reduces unplanned downtime, keeping aircraft in operation longer and reducing maintenance costs.



Optimising aviation maintenance schedules

Digital twins also help optimise maintenance schedules, basing them on actual component health. This condition- and usage-based approach ensures maintenance occurs only when necessary, increasing operational efficiency and reducing costs. Operators can also schedule inspections and repairs based on real-time insights, leading to fewer service interruptions and extended aircraft life.



Enhancing diagnostics and troubleshooting

Simplifying diagnostics and troubleshooting is one of the key aims of aviation maintenance tech. Digital twins support this goal by providing maintenance teams with an up-to-date, virtual view of the aircraft system. This comprehensive overview allows the team to identify issues faster and with greater precision, reducing the time necessary to locate and address the faults. This minimises aircraft downtime, improving the overall fleet efficiency.



Improving training and knowledge transfer

Through advanced simulation tools, digital twin technology supports training and knowledge transfer for the maintenance teams. Virtual models of aircraft systems and assets can allow new technicians to practice maintenance procedures in a controlled environment, gaining valuable hands-on experience without risking the safety and integrity of the aircraft assets. This also facilitates smoother knowledge transfer across teams and new generations of technicians.



Facilitating real-time monitoring of aircraft components

Real-time monitoring is another key benefit of digital twins, allowing operators to track the health and performance of individual aircraft components, a crucial part of predictive maintenance in aviation. Digital twins can alert operators when certain parts need maintenance or replacement, helping prevent unexpected failures. Such oversight through aviation maintenance tech ensures that aircraft are safe, operational, and always in optimal condition.



Ensuring safety and regulatory compliance

Lastly, digital twins also support regulatory compliance through detailed, real-time records of component performance and maintenance history. This ensures the aircraft systems stay up-to-date with safety standards and regulatory requirements, ensuring every aircraft in the fleet meets stringent aviation guidelines. Aligning predictive maintenance and MRO in aviation with safety protocols, digital twin technology contributes to safer operations and easier compliance audits.

Examples of digital twin technology in aviation

Industry leaders in aviation have already started leveraging digital twin technology to enhance the performance, safety, and maintenance of their aircraft fleet. Some of the notable examples include:



Rolls Royce:
Engine monitoring and
maintenance

Rolls Royce uses digital twin technology as a part of their aviation maintenance tech arsenal when it comes to monitoring and maintaining their jet engines. By collecting real-time data from integrated sensors, the company is able to perform predictive maintenance, helping prevent engine issues before they impact flights, which reduces downtime and operational costs.



Boeing:
Battery safety

The Boeing 787 Dreamliner employs digital twins to monitor its battery system, monitoring performance to prevent safety risks. By incorporating digital twins in the design and development process, the company is able to identify potential issues early, enact necessary design changes, enhance reliability, and ensure compliance with safety standards.


AIRBUS

Airbus:
Performance optimisation





Airbus uses digital twin technology to monitor and optimise the performance of its A350 XWB aircraft through real-time data insights. The company has used digital twins to strategically modify aircraft design, refine flight parameters, and facilitate predictive maintenance of their aviation fleet to boost operational efficiency and sustainability.

Benefits and implementation challenges of digital twin technology in aviation maintenance

The benefits digital twin technology offers when it comes to aviation maintenance and predictive MRO are substantial, with key benefits including:

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|  Achieving cost savings |  Maximising aircraft availability |  Improving safety standards |  Advancing sustainability and environmental goals |
| Digital twins are crucial when it comes to optimising maintenance costs through predictive maintenance, which, in turn, can minimise unplanned downtime and extend asset life. Such a proactive approach to maintenance in aviation prevents costly, unscheduled repairs and improves the financial efficiency of maintenance operations. | Basing maintenance on real-time data, digital twins can optimise scheduling and keep aircraft in operation longer. This availability boost supports better fleet management and operational reliability. | The aviation maintenance tech is responsible for ensuring the safety of the operational aircraft. Digital twins enhance this safety by identifying potential issues before they become critical in-flight failures. This proactive monitoring ensures that aircraft operate within safe parameters, improving passenger and crew safety. | Digital twin technology not only optimises the design process and fuel efficiency but also reduces unnecessary maintenance activities. These contribute to sustainability goals and align the airline with industry-wide environmental initiatives through lower fuel consumption and reduced waste from fewer replacement parts. |

While digital twins offer significant benefits, implementing them for predictive maintenance in aviation comes with challenges that airlines must address to ensure success. The major challenges airlines must overcome include:

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|  Integrating with existing systems |  Overcoming high initial investment |  Mitigating cybersecurity risks |  Addressing technical and implementation barriers |
| Integrating digital twins with the existing aviation systems can be complex. Disparate data formats and legacy systems often make it challenging to achieve seamless data flow and interoperability. | Digital twin technology requires substantial upfront investment in infrastructure, expert teams, and training. This high initial investment can be a barrier for small operators to adopt the technology despite its long-term benefits. | Digital twins require vast amounts of data to work effectively. This raises concerns about data security and privacy, requiring airlines to invest in cybersecurity measures to maintain operational integrity. | Digital twin technology has complex technological requirements and requires skilled personnel for implementation. These can present significant barriers that airlines must address to ensure smooth adoption. |

Despite these challenges, the long-term impact of digital twins on aviation maintenance tech will be transformative. As technology advances, collaboration between the aviation industry and various tech stakeholders will further drive innovation, potentially setting new industry standards for efficiency and safety.

End note

Digital twin technology is proving to be an invaluable tool in advancing [predictive maintenance and MRO in aviation](#). Through real-time monitoring, diagnostics, and optimised maintenance schedule, it is driving cost savings, enhancing safety, maximising aircraft availability, and improving training capabilities for

maintenance teams. Digital twins are also supporting a more sustainable future in aviation with reduced environmental impact. Although challenges like integration, implementation costs, and cybersecurity remain, the long-term benefits and potential for innovation continue to

encourage widespread adoption of this aviation maintenance tech. Thus, embracing digital twin technology has become a critical step in the evolution of aviation MRO, setting new standards in aviation maintenance and operations.

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