# Equal Contribution, Corresponding Author Towards Digital Twin in Aerospace Industry

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Abstract

A digital twin is a virtual counterpart of any physical system created by a computer. The aerospace industry is one of the vividly growing fields of this era. Along with all the possibilities, this field also comes with various risks, dangers, and uncertainties because of the usage of complex mechanisms. By appending the digital twin in the aerospace industry, we can overcome those dangers and uncertainties. As this is an ongoing field, researchers are eager to work in this arena. Furthermore, in the aerospace business, the digital twin can boost efficiency and company value. Even industrialists are also willing to get benefitted from the digital twin. That is why this paper comes up with 31 research papers on digital twin models which are used in the aerospace industry in the design, manufacturing, regular monitoring, and management phases. This paper provides several findings along with possible recommendations.

Keywords: Digital Twin (DT), Artificial Intelligence (AI), Fatigue Life, Internet of Things (IoT), Machine Learning (ML), Model-based Design.

1.1 Introduction

The digital twin (DT) is a computerized counterpart of a physically complicated system that uses real-time data to foresee results and calibrates operational adjustments. Multi-physics modeling and data-driven analytics combine to create the digital twin. Sensor and quantification systems, simulation, industrial Internet of Things (IoT), machine learning (ML), physics-based model construction, and artificial intelligence (AI) are all part of its ecosystem, which is formed using super

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high simulation software (Bäßler et al., 2020). Designing, building, evaluating, and maintaining aircraft, rockets, missiles, and spacecraft are all part of the aerospace industry. Many aerospace companies are turning to DTs to achieve their goal of lowering unplanned motor, engine, and many other system downtimes. As, the current weather conditions, asset quality, and various relatable factors are considered by DT, that is why aerospace companies love to engage DT along with the main system.

Nowadays, DT models are proven to be cost-effective, and it allows airlines to keep in service for a longer period (Gavin, 1982)(Liu et al., 2018). “By utilizing digital twin asset creation, Boeing has been capable of achieving up to a 40% refinement in first-time performance of the parts and systems used to construct commercial and defense aircraft.” - Aviation Today reports (Boeing CEO, 2018). Furthermore, DTs can manage changes in the machine and extend the machine’s average lifespan (Aydemir et al., 2020). A DT allows you to anticipate the asset's remaining life with a high degree of accuracy. For example, sensors (brake temperature, hydraulic pressure) are installed on common failure points in a DT of the landing gear. This guarantees that the DT receives data from such points on a real-time basis. This information aids in predicting the likelihood of an early failure as well as determining the landing gear’s residual life cycle.

(Tuegel et al., 2012) reviewed several new structural modeling concepts for creating and maintaining airframes using DT. Several technical hurdles like initial conditions, continuous flight loads, selecting and integrating the sub-models, and managing uncertainties in constructing the Airframe DT were also discussed by the authors. (Aydemir et al., 2020)presented a thorough examination of the available approaches and technologies, as well as the challenges confronting Digital Twin and the future of DT for aircraft.

(Glaessgen et al., 2012) investigated various DT paradigms for upcoming NASA and US military vehicles. The authors also stated that future US Air Force vehicles and NASA must be more long-lasting. Statistical distributions of the properties of materials, heuristic design, and onsite testing are all used in existing practices. Those techniques are almost certain to fall short of meeting stringent requirements. That is why the authors concluded that a significant paradigm shift is required to address the shortcomings of traditional techniques.(Phanden et al., 2021) reviewed numerous recent contributions on DT-based virtual environment modeling in manufacturing, aerospace, and automation. The purpose of this review was to lay the conceptual framework for the development of DT virtual environment methodologies and techniques.

To make it simple to distinguish DT from other related terminology like "product avatar," "digital thread," "digital model," and "digital shadow," this work (Singh et al., 2021) aims to compile the many types of DT and interpretations of DT from the literature. To understand the value that DT may provide for specific industries; the article examines the concept from its origin to its anticipated future. They have observed the origin of DT in the aerospace industry which in the future was seen to have been implemented in other sectors as well.

Table-1: Comparison between existing review works.

Ref.	Main Contribution
(Tuegel et al., 2012)	Reviewed multiple new structural modeling concepts in the airframe DT for establishing and maintaining various airframes.
(Glaessgen et al., 2012)	Investigated various DT paradigms for upcoming NASA and US military vehicles.
(Phanden et al., 2021)	Examined several DT-based modeling approaches used in aerospace (production) and automation.
(Singh et al., 2021)	Compiled a variety of DT types and interpreted all of them.
(Aydemir et al., 2020)	Provided a comprehensive analysis of the methods and technologies available, as well as the difficulties facing DT and its prospects for use in aircraft.

Table 1 provides a clear comparison between existing review works. In this table, (Tuegel et al., 2012) stated various modeling concepts on airframe DT, (Phanden et al., 2021) discussed a few DT-based simulation methods, and (Glaessgen et al., 2012) stated DT paradigm for upcoming NASA and US military vehicles. (Singh et al. 2021) presented an interpretation of a variety of DT types. (Aydemir et al., 2020) provided an analysis of various DT methods. From this table, we can say that there is no existing work that reviews DT models from design and manufacturing to continuous monitoring and management in the aerospace industry.

The block diagram in Figure 1 shows the overall flow of our paper. Note that a few subpoints in this block diagram won't match the actual subpoints of the paper. It is important to understand the structure of the paper and for that few extra subpoints are added to the block diagram. Our paper starts with an introduction followed by the background and the research areas of DT. Then we focused on our core topic which is DT in the Aerospace industry. We have explained all the phases and sectors of aerospace and what role DT plays in each of those phases and sectors. Next, we have described the previous works on model-based design and simulation techniques. Finally, we have mentioned our findings and recommendations and concluded our paper.

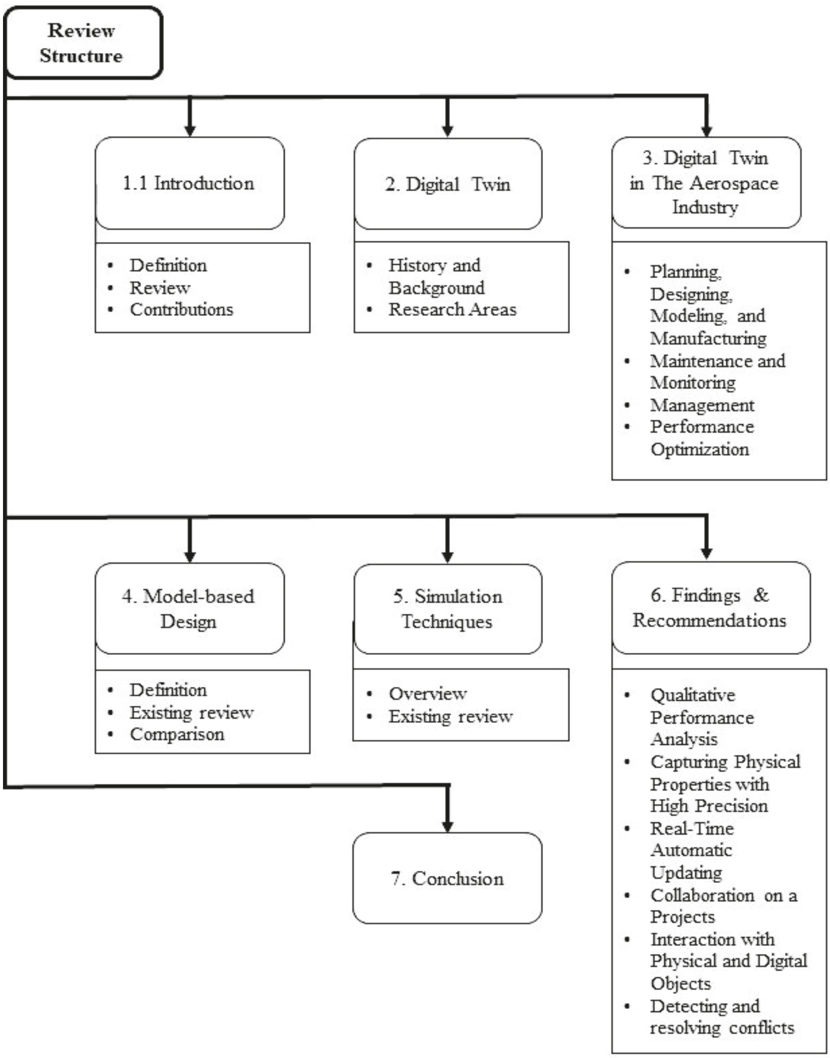

Figure 1: Block diagram mentioning the flow of this paper.

The demand for DT is growing day by day because it can assist the aerospace industry by designing, manufacturing, predicting risks, real-time monitoring, and providing a cost-effective solution. Considering these benefits of DT, researchers and manufacturers are willing to work on DT in the aerospace industry. To the best of our knowledge, there is no existing review paper that reviewed DT models used in all the phases (design, manufacturing, monitoring, management, and performance optimization) of the aerospace industry. That is why we are presenting this paper focusing on this research gap.

The main contributions of this paper are listed below:

a. Discussing the role of DT in all phases of the Aerospace industry (Design, manufacturing, maintenance, monitoring, management, and performance optimization).
b. Analyzing different model-based design approaches.
c. Discussing various simulation techniques.
d. Describing several findings & and recommendations.

The rest of the paper is structured as follows: Section two describes the basic concept of DT along with various research areas. The background of the aerospace industry, market statistics, all the stages and sectors of aerospace, and performance optimization are presented in section three. Section four comes with model-based design models that are used in this particular field. Section five consists of different simulation techniques that are used in DT. Section six comes with our findings and recommendations that include performance analysis and resolving conflicts. Finally, Section Seven provides concluding remarks. Figure 1 shows the organization of this work.

2. Digital Twin

2.1 History and Background of Digital Twin

DT is a perfect virtual representation of physical devices and systems. “Mirror Worlds” by David Gelernter, published in 1991, foreshadowed the concept of DTs (Gelernter, 1991). In 2002, Michael Grieves of the Florida Institute of Technology is acknowledged in academia and industry for creating DT as the theoretical framework of product lifecycle management (PLM) (Grieves, 2019). A famous quote from (Grieves et al., 2017) and(Greengard) who is the concept’s creator of DT is, “We have reached a point where it’s possible to have all the information embedded in a physical object reside within a digital representation.” In 2010 Roadmap Report, NASA’s John Vickers (NASA) dubbed this concept the “Digital Twin.”

The authors have offered an overview of the state of DT advancement both domestically and internationally from the perspectives of the DT idea, research advancement, interpretation, difficult issues, and DT system building (J. Wu et al., 2020). In this paper, they haven't focused specifically on the aerospace sector, but rather have provided a generalized idea of DT in addition to the above-mentioned perspectives. The physical object, the virtual or digital object, and the connections between the previous two products make up the digital twin concept. The linkages between the digital object and the physical object are data or information that flows from the real or physical object to the digital object and available information from the digitized representation to the practical environment. Later, the notion of DT was divided into other categories.

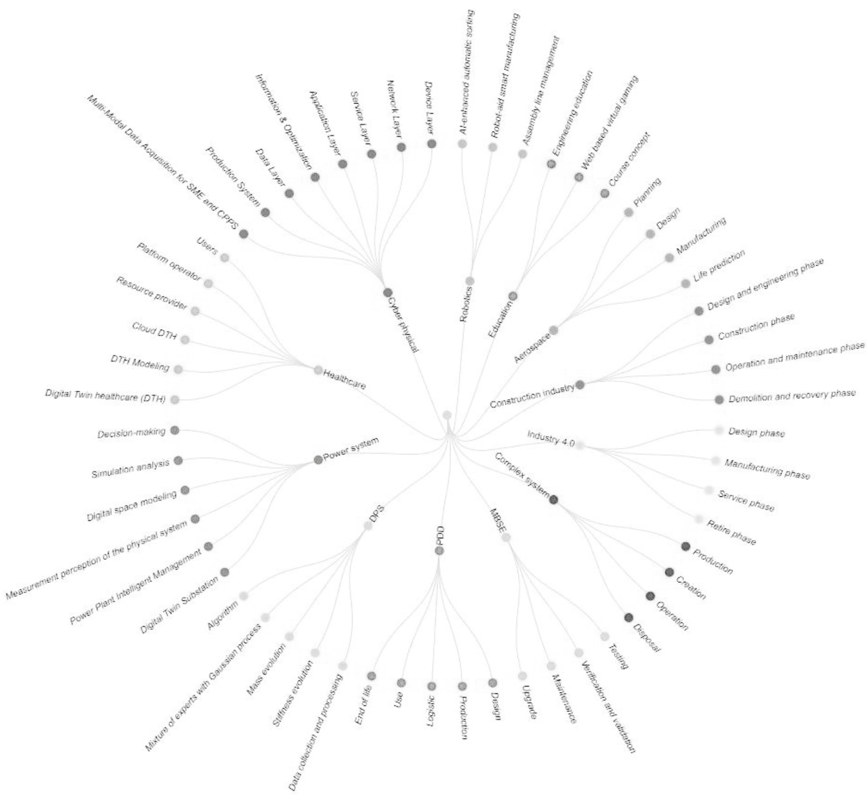

Figure 2: Research Areas of Digital Twin (MBSE = Model-based system engineering, PDD = Product design and development, DPS = Dynamical and Physical systems)

The DT Instance, DT Prototype, and DT Aggregate are the three types. The DTP entails the creation of physical products through analyses, designs, and processes. Before there is a physical object, there will be a DTP. The DTA is a collection of DTIs whose information can be used to probe cross-examination of the physical product and predict outcomes.

DTs have the potential to significantly increase the data-driven decision-making mechanisms in businesses. They communicate with their physical equivalents at the edge, and organizations use DTs to recognize the condition of physical assets, respond to changes, improve efficiency, and provide value to system applications. The next subsection is coming with the various research areas of DT.

2.2 Research Areas

A circular dendrogram is shown in Figure 2 that represents 12 different research areas of DT which are currently running in full swing. Rudimentary knowledge about these fields and in which subsectors DT is being applied are given below.

Figure 2 shows multiple sectors consisting of the implementation of DT. These are briefly discussed below. Here we have mentioned a total of 12 sectors including Aerospace. Apart from it, the other 11 sectors with the application of DT in the specific phases of each sector are listed below.

i. Construction Industry
   a. Design and engineering phase
   b. Construction phase
   c. Operation and maintenance phase
   d. Demolition and recovery phase
ii. Industry 4.0
   a. Design phase
   b. Manufacturing phase
   c. Service phase
   d. Retire phase
iii. Power system
   a. Digital Twin Substation
   b. Power Plant Intelligent Management
   c. Measurement perception of the physical system
   d. Digital space modeling
   e. Simulation analysis
   f. Decision-making
iv. Product design and development
   a. Design
   b. Production
   c. Logistic

    d. Use
    e. End of life

v. Robotics
    a. AI-enhanced automatic sorting
    b. Robot-aid smart manufacturing
    c. Assembly line management

vi. Complex systems
    a. Production
    b. Creation
    c. Operation
    d. Disposal

vii. Dynamical and physical systems with multiple time scales
    a. Data collection and processing
    b. Stiffness evolution
    c. Mass evolution
    d. A mixture of experts with the Gaussian process
    e. Algorithm

viii. Model-based system engineering
    a. Testing
    b. Verification and validation
    c. Maintenance
    d. Upgrade

ix. Cyber-physical
    a. Multi-Modal Data Acquisition for SME and CPPS
    b. Production System
    c. Data Layer
    d. Information & Optimization
    e. Application Layer
    f. Service Layer
    g. Network Layer
    h. Device Layer

x. Medical and healthcare
    a. Digital Twin Healthcare (DTH)
    b. DTH Modeling
    c. Cloud DTH
    d. Resource provider
    e. Platform operator
    f. Users

xi. Education
    a. Engineering education
    b. Web-based virtual gaming
    c. Course concept

3. Digital Twin in The Aerospace Industry

The aerospace industry is a worldwide conglomerate of governments and individuals dedicated to product development, research, and manufacture in the areas of flight, atmospherics, and beyond which began in the United States in December 1903, after Wilbur and Orville Wright exhibited controlled sustained flights. It is among the most important and strong sectors in the United States. Various applications of DT models in the aerospace industry are described in this section.

To dispel myths that prevent the sustainable use of digital twin technology for protection systems, this article explains the complexities of innovation for the aerospace sector particularly and others generally (cnc et al., 2021). It includes a thorough analysis of digital twins and the parts that make them up. In their paper, they have described the concept of DT, its major components, some industrial applications, and its importance in the aerospace industry. They also mentioned the business challenges, modeling, infrastructure, visualization, and future trends.

3.1 Planning, Designing, Modeling, and Manufacturing of Aircraft

During the planning and designing phase, DTs can be used as virtual prototypes that can be modified to try new simulations. It can also be designed before investing it in a strong prototype. For modeling and manufacturing any complex part (e.g., the engine and the black box) of the aircraft, it is truly beneficial to make a virtual version of it using DT and validate it before building the physical one. This reduces the number of repetitions required to get the item into production, saving time and money.

3.1.1 Planning Stage

A closed-looped air cargo load planning system based on DT enhances container loading operations constantly using a virtual environment (Closed-loop, 2022). This work's major goal is to improve loading strategies, eliminate effort in container warehousing, and provide a feedback system for appropriate loading scenarios. The author's proposed model is constructed using three components and those are optimization simulation, physical operations systems, and Virtual Reality (VR) systems. Here, the optimization module contains the decision support tool which helps to create the simulation of cargo pallets in an aircraft. Based on the cargo nature, contour, weight, size, destination, and dangerous goods classification, the cargo pallets are simulated. This simulated data serves as source information and is transmitted to VR devices via a cloud environment. The VR module is a CAVE-based system with a capsule construction and four 3D projections and displays. This VR system detects the user's current location with sensors and then projects dynamic scenarios with an area of vision and stereo presentation. The simulated data from the optimization module is obtained and imitated by the VR module to verify the effectiveness of stacking the cargo onto the aircraft.

If overstuffed cargo is to be packed, the module can inspect that before loading it to the aircraft door. Users can engage with the aircraft stacking slots, and cargo can view the simulated actions and discover anomalies that require recovery.

Table-2: Comparison between various DT models used in the Aerospace Industry for Design and Manufacturing.

Ref.	Focused Area	Main Contribution	System Architecture	Limitation
(Closed loop, 2022).	Cargo load planning	A closed-looped air cargo load planning system that uses DT to simulate cargo loading operations to improve cargo loading operations.	A three-module-oriented DT model and those three modules are optimization simulation, physical operations system, and VR system.	The capabilities of this model for different aircraft designs, such as one and two-row aircraft, and primary and bottom decks, should be studied, analyzed, and expanded.
(Chang et al., 2021)	Designing aircraft assembly line	DT was able to create an architecture for AAL to improve its efficacy, quality, and visibility.	An interactive architectural knowledge repository is created, and design defects are identified based on its contents.	The proposed architecture's effectiveness and feasibility were not compared to other similar standard architectures.
(Liu et al., 2021)	Machine modeling	A biomimicry-based modeling method that can	The geometry module, behavior	The speed and accuracy of the

		provide high-fidelity multidimensional DT in the field of machining.	module, and context module comprise a three-module DT system.	model should be increased.
(Jinsong et al., 2019)	A modeling approach for manufacturing	Modeling and operational approach for the DT in the area of aerospace manufacturing.	The proposed DT models had 3 sub-models-product DT, process DT, and operation DT.	The authors should carry out workshop-oriented modeling and operation using DT technology.
(Zambal et al., 2018)	Creating a manufacturing dataset	A manufacturing dataset is created using real-time sensor and machine data to fabricate a portion of an aircraft wing cover (lower).	Sensor data was gathered using Gigabit Ethernet, while device information was analyzed using PowerLink. All of this data was pooled in two separate PCs capable of low-level computation. Data on defects was transmitted to two distinct servers. Part verification is performed by one of the PCs. On the	Because many unexpected scenarios emerge throughout production, requiring immediate decision changes depending on the current situation, the decision-making process should have been incorporated.

			other PC, the manufacturing database was hosted.	
(Mandolla et al., 2019)	Additive manufacturing	A case study for the aerospace industry where a DT-based end-to-end additive manufacturing model is described.	A layered model for creating a DT manufacturing model. The four layers are design, information, creating a blockchain, and hashing.	Only four layers are described. The testing and validation phases were not described properly.

Physical operations systems can cover the operations of aircraft cargo loading and the gate-in terminal on the air side of the airport. When the cargo is analyzed at the terminal gate, sensors inside the entrance terminal are employed to calculate the exact cargo dimensions. It detects cargo shape and weight and transmits this data to optimization and virtual reality systems via cloud storage. When enormous cargo is loaded aboard the airplane via the primary deck ground rollers, loading platform, and container doors, sensors are employed to measure any irregularities in activities and enhance the modeling procedures. One limitation of this work is the model's capability for various aircraft configurations was not considered here.

(A. Hänel et al., 2020) uses the instance of components in the aerospace sector to explain a technique for developing a DT depending on planning and process data for machining operations. They have provided descriptions of the information methods, fundamental composition, and pertinent calculation methods for identifying pertinent process features and its implementation will be represented in a milling process for the aerospace industry. Their structure for the machining process consists of the following steps-

i. Data acquisition
ii. Processing the acquired data with various models
iii. Data calculation
iv. Application of the calculated data

In the first process, they acquired 5 types of data. These are workpiece data, process data, technology data, machine data, and tools data. These data were further processed using 5 processed models namely, kinematic models, tool engagement models, path inaccuracies models, cutting force models, and surface quality models. And finally, before application, they visualized the model in software to check all the processed parameters. This technology makes it feasible to create a digital process twin to a milling process for the manufacture of aerospace elements with a significant number of pertinent process features.

3.1.2 Designing Stage

Digital-physical engagement and self-evaluation are two capabilities that modern aircraft assembly lines (AALs) must have. To provide this facility, (Chang et al., 2021) proposed a design architecture of knowledge-enabled DT for AAL to improve AAL's effectiveness, quality, and visibility. The proposed model is designed to introduce DT and knowledge. To begin, a one-of-a-kind vibrant layout knowledge repository is built to accommodate the multiple DT operations that occur during the design process. Ultimately, knowledge-based intelligent assessment is being used to comprehend and discover architectural defects that might lead to the layout plan's subsequent improvement. One limitation of this research work is the effectiveness and feasibility of the proposed architecture were not evaluated with other similar standard architecture.

In the designing phase, we also need to think about the design of the machines that will be used for the aircraft. Because this concern will impact the manufacturing phase. In general aspects, multiple high-performance machines are being used in the aerospace sector. Most of them fall under CNC (Computer Numerical Control) Machining. Certain factors are kept in mind when CNC machines are made. These are Lightweight metal components, CNC rapid prototyping, Complex design fabrication, AI-aided CNC machining, and High-grade precision. All the machines that are manufactured must meet these requirements.

3.1.3 Modeling Stage

To remove the scarcity of effective modeling methods in the aerospace industry, (Liu et al., 2021) proposed a biomimicry-based modeling method that can provide high-fidelity multidimensional DT in the field of machining. For this purpose, the authors have proposed three modules that are the geometry module, behavior module, and context module. These three modules are interactive and can imitate the real physical model. In the geometrical module, the manufacturing features are analyzed to understand the machining characteristics. The system gets the actual information with the help of performance-measuring and size-measuring instruments. As this module enables self-updating so the module updates its information systematically. With the help of the fusion technique, the real and the virtual system are merged. In the behavioral module, with the help of a system database, a theoretical process model and material information are obtained. Computer-aided Engineering (CAE) software help to obtain the structural features. The offline feature technique aids in the accumulation of physical attributes for the creation of the physical module before manufacturing. The rest of the physical property information is obtained and updated in real time by the digital twin system using surface measurement.

The establishment of the DT-based context mimic model includes two steps which are machining sequence generation and the machining process information collection. The development of the manufacturing series intends to build the operational route of the manufacturing entity in the procedure organizing before machining. During the computation, the system gathers pertinent architectural, temperature, current, motion, voltage, and actual procedure statistics. The modifications made to the computation product are then recorded by the data-capturing mechanism. The information obtained is examined and utilized to generate that product's processing information in the final stage.

In the area of production, (Jinsong et al., 2019) proposed DT models which had three sub-models and those are product DT, process DT, and operation DT. To begin, across the product designing and production stages, a unified model was utilized to develop the product DT, letting information be exchanged and distributed throughout phases. By adding interface and control qualities, process DT supported the interconnectedness and convergence of digital and real environments inside the manufacturing system.

Secondly, the multivariate model fusion was created by the authors for constructing the operation DT metamodel. Various interactive behaviors could be designed and simulated using the flexible mixture and integration of different operation DT metamodels.

Finally, the authors constructed a systemic component manufacturing cell AutomationML framework. It was a revolutionary method of carrying out activities in the manufacturing context involving products, techniques, and resources. One limitation of this work is the authors should carry out more detailed work on the workshop-oriented modeling and operation using DT technology.

3.1.4 Manufacturing Stage

Manufacturing a part of aircraft using carbon fiber composite material is complex work. DT can be a helpful solution to this type of manufacturing. With the help of a manufacturing database, creating this DT model will be very easy. To do so, (Zambal et al., 2018) proposed an architecture that collects different sensor data and machine data to create a DT that will help in manufacturing the lower wing of an aircraft. Sensor data was acquired over Gigabit Ethernet, whereas machine data was collected via a PowerLink interface in this case. All of this information was pooled in two separate PCs that do low-level computation. Fault data was routed to two different servers. One of the PCs performs a part verification. The manufacturing database was hosted on the other PC. In terms of information, the Gigabit network was used to transfer the most data. Here, the HDF5 file format was used by the database, which had a flexible structure that allows for the storage of multiple types of data.

The simulation program was used to poll occurrences regularly, and it would start analyzing once it had been informed that the faulty data was sufficient. A limit of security was estimated after the preliminary analysis through the mathematical framework. In the latest version, in response to a user request, a thorough bounded calculation was carried out. The database had been updated with the simulation findings, and the characteristics endpoint had been updated with the limit of security. The selection assistance tool came next, which updated the user with the most recent knowledge of the production cycle by checking the events per 15 seconds. With the help of Blockchain, (Mandolla et al., 2019) presented a case study for the aerospace industry where a DT-based end-to-end additive manufacturing model is described. For creating this model, the authors have constructed four steps which are design, block creation, information, and hash verification. With the help of "CatiaV" (3D CAD designing software), the authors have designed a blade compressor for airplanes. The information was infused into the common software named "Ultimaker Cura" by utilizing the design created in CatiaV5. For creating the blockchain, public and private were developed. The authors had altered the original basic scheme to create a Blockchain. In the initial subsection, the authors fixed every constant and primary function. In the final section of the code, the "readFileSync" function was inserted into the block. After all of these steps, the hashing operation took place. One limitation of this case study is the testing and validation step was not described properly. **Table 2** summarizes DT models.

3.2 Maintenance and Monitoring of Aircraft

The modern aviation sector is transitioning from responsive to aggressive and predictive service to increase platform functional reliability and effectiveness, expand its useful life span, and reduce its lifespan costs. In aviation service, the DT is used to reflect both the aircraft and the MRO (Maintenance, Repair, and

Overhaul) activities. For the progress, delivery, and procedure of an air vehicle, a well-qualified performance model for an airplane arrangement is required. (Kraft et al., 2018) discussed the methods and characteristics required to create and implement a single authoritative truth reference as an integral component of a DT strategy for aerial vehicle acquisition and maintenance.

3.2.1 Fatigue life prediction

The number of stress cycles of a particular character that an object can sustain before failure is defined as fatigue life. Submicroscopic cracks are the cause of fatigue failure. These appear on a material's surface. Those cracks eventually come together to form a visible crack. Crack initiation, Total life, and crack growth are the three main methods often used to predict fatigue life.

Using DT to predict the duration of aircraft components and guarantee their structural integrity, (Tuegel et al., 2012) established a theoretical foundation. To begin, a series of missions must be allocated to a specific aircraft. It is formed as a reasonable approximation of the flying trajectory and maneuverability that will be traveled during the quest. The aircraft's computational fluid dynamics (CFD) method is then "flown" virtually through all those aircraft to approximate the heavy loads and surroundings the aircraft will encounter. Aerodynamic forces on the airframe are implemented to the functional Digital Twin finite element model (FEM) over the interval of time of the flight as the airplane is "flown." The FEM and CFD models are tightly coupled, allowing the impact of aero-elastic vibrations and functional deflections on the aerodynamic flow to be studied. The temperature, stress, and vibration predictors data are sent to the damage predictor with the help of the driver, and the damaged states are estimated. Through this, the structural system reliability assessment phase takes place. Finally, after the execution of data, the aircraft's health information is passed to the digital twin to refine the information, and those refined data are passed to the reliability assessment block for damage prediction. Because it is a conceptual model, some new issues may arise during implementation.

(Leser et al., 2020) developed a systematic way to decrease unpredictability in fatigue life predictions by combining in-situ diagnostic tests in a probabilistic manner. As more of this diagnosis and treatment is achieved using Monte Carlo methods, to finally create probabilistic forecasts of fracture state throughout the duration of a complicated geometrical trial sample and anticipate residual stresses with decreasing unpredictability.

It is claimed that the suggested DT system is appropriate for exhaustion lifespan diagnosis and has to be developed considerably deeper with an emphasis on increasing implementation reality by demonstrating the potential to anticipate accurately as well as in the face of ambiguity. The research’s conclusions showed that the integration of the suggested diagnostic techniques enabled the application of DT for predicting exhaustion lifespan in a lab environment. The four probabilistic edges of life projection’s average scores were all under 0.2% of the actual final result. All four deterministic predictions of the product's residual lifetime was within 10% of the genuine residual lifetime seen throughout the experiment.

(Keivanpour et al., 2022) designed a methodology for estimating the remaining useful life (RUL) of retrieved parts that includes fuzzy modeling and DT. The presented framework incorporates DTs: disassembly process, health management, and retrieval parts. A fuzzy smart decision-making algorithm produces the rules for estimating a part's RUL based on various sensor measurement techniques and operational setups. The model’s implementation in aircraft engines is also discussed by the authors. For illustration, the PHM08 prognostics records database was used here. The data collection includes deterioration information from 21 sensing devices along with operational and maintenance parameters. Time series analysis's initial 14% are seen as robust, while its latter 14% are regarded as a failed system.

3.2.2 Health monitoring & maintenance

Aircraft health monitoring methods rely on Digital Twins to use real-time data captured by various sensors incorporated into aircraft parts to improve the aircraft's safety and reliability. It aids in the reduction of operational costs, support costs, and unexpected accidents. Quality deviation problems are difficult to find and fixing them requires a while. A quality variation regulation methodology for DT was put forth by (Cai et al., 2021). DT simulation based on the asset management shell approach can be used to extract and combine multiple origins and diversified quality variation information. In addition, a quality deviation scheme based on DT has been developed to address the second issue. The FP-growth association rule method analyzes the aircraft quality deviation information in this system, and the outputs are displayed through the scheme to guide the assembly facility.

The systemic health status of an aircraft differs from one to the next due to differences in production, mission history, material properties, pilot diversity, and so on. (Li et al.) built an aircraft health monitoring framework for the prediction and diagnosis of each independent aircraft using the idea of dynamic Bayesian networks (DBN) and demonstrated the proposed scheme using an aircraft's wing fatigue crack propagation example. The DBN model is used in diagnosis to monitor the progression of time-dependent factors and fine-tune time-independent factors. In diagnosis, the DBN model is used to make probabilistic predictions about crack formation in upcoming loading time steps.

The book section of (Wang et al., 2015) includes an introduction to DT, its generation, and its different components. Then the maintenance process and the applications of DT in aircraft maintenance are described. MRO (maintenance, repair, and overhaul) is a requirement for commercial aircraft to ensure the safety of passengers which are often done with DT's assistance. Four technologies drive the development of DT. These are Big data, IoT, modern analytics, Cloud computing, Accessibility, and interaction. They gathered real-world MRO utilizing different IoT sensors aboard the aircraft as part of their system architecture. After that, the raw data is processed on a cloud or edge platform before connecting with the DT database. They also keep a close eye on what's happening in the hangar. Then the Virtual MRO is created using DT technology, and different operations are done using real-world data to match the expected outcome. The MRO facilities system offers pertinent services for managing service operations, monitoring current health, and predicting prospective states.

To prevent the major loss, early diagnosis of damage in composite structures is critical. The computer method that forecasts the dynamic features of a chopper sandwich construction struck by a bird was developed by (Ibrion et al., 2019). The prototypes are intended to serve as simulated procedures for a brand-new defect identification approach that uses a digital twin in the coming years. A high-fidelity (HF) LS-DYNA FE/SPH model was first developed and tested against soft body effect studies. After that, a low-fidelity (LF) model that was operationally efficient was developed and compared to a high-fidelity (HF) framework. It was discovered that the high-fidelity framework can correctly forecast the strains captured by the detectors, and the volume of the projected debonding region toward the sandwich panel's frontal side matches the experimentally measured delamination area extremely well. The HF framework can be viewed as a simulated serious damage discoverer and damage outgrowth predictor before the scheduled observation, meanwhile, the LF framework can be utilized as a quick numerical tool for determining the load situation.

(Singh et al., 2021) provided a comprehensive overview of DT in aircraft manufacturing, as well as a proposed model for collecting and examining information about aircraft wings. Crack growth and spreading are common issues in airframes. According to the authors, the suggested framework will allow professionals and information management experts to collaborate closely in the development and maintenance of DT. The physical level of the author's four-layered architecture recognized the system's current needs, which were recorded in the shape of developed-in accordance. Following that, the information accusation layer comprises various on-ground sensors and IoT-enabled techniques for reading, pre-processing, and transferring data. The amount of fatigue on the wing was identified by this layer. Data were converted into useful information and insights at the model layer. A fatigue crack computation behavioral model was developed for the wing structure's design and analysis purpose. Information had been subsequently organized and saved throughout the DT lifespan at the Data modeling level, which is where it is now. The proposed framework's dependability has not been assessed. For the ongoing safe operation of an airplane, load levels should be maintained under a reduced load-carrying ability to avoid unsteady, catastrophic harm propagation throughout a flight. As a result, for constructions with complex harm/damage configurations, the inability for exact real-time forecasts of serious harm size and safe load-bearing capacity is required. As a result, (R. Seshadri et al.) proposed a method for monitoring damage using guided wave reactions. The signal dampens in some orientations and tends to reflect in others when the guided wave communicates with damage. This results in changes in signaling amplitude and phase changes among structural reactions that have been fractured or cracked and those that have not. Only a genetic algorithm (GA) driven optimization technique is used to analyze the collective signal reactions at several previously selected sensor locations to produce an accurate estimate of the size, position, and orientation of the damage. The damage size and direction are obtained by minimizing the variation between the reference reactions and the reactions obtained from the finite component calculation of the propagation of waves for various typical crack formations, geometrical damage, and sizes. A Piezoelectric (PZT) sensor-based Guided wave may be a better way to monitor aircraft damage.

Table-3: Comparison between various DT Models used in the Aerospace Industry for Maintenance and Monitoring.

Ref.	Main Contribution	Limitation
(Tuegel et al., 2012)	A theoretical framework for estimating the lifespan of airplane structures and ensuring their structural integrity utilizing the DT.	Because it is a conceptual model, some new issues may arise during implementation.
(Kraft et al., 2018)	Discussed the methods and characteristics required to create and implement a single authoritative truth	-

	reference as an integral component of a DT strategy for aerial vehicle acquisition and maintenance.	
(Keivanpour et al., 2022)	DT and fuzzy modeling were used to create a system for determining the retrieved parts' residual useful lifespan (RUL).	-
(Cai et al., 2021)	A DT-related performance variation controlling approach. DT simulation based on the asset management shell approach can be used to extract and combine multi-source and diversified quality variation information.	-
(Li et al.)	An aircraft health monitoring framework for prediction and diagnosis of each independent aircraft using the idea of dynamic Bayesian networks (DBN) and demonstrates the proposed scheme using an aircraft's wing fatigue crack propagation example.	-
(Ibrion et al., 2019)	The computational system that predicts the dynamic characteristics of a helicopter sandwich structure hit by a bird.	-
(Singh et al., 2021)	A model for collecting and examining information about aircraft wings.	The proposed framework's reliability has not been evaluated.
(Seshadri et al., 2017)	A method for examining damage using guided wave reactions.	-
(Zakrajsek et al., 2017)	A DT model to improve the tire touchdown wear estimation.	Several aspects of the DT model introduced in this study remain unfinished.

		Increasing the levels and testing the additional factors are two major areas for improvement.
(Leser et al., 2020)	Developed a systematic way to decrease unpredictability in fatigue life predictions by combining in-situ diagnostic tests in a probabilistic manner.	-
(Wang et al., 2015)	Explained the maintenance process and the applications of DT in aircraft maintenance. Discussed MRO and what services it provides.	-

Underperforming airplane tires can result in high expenses as well as an increase in the aircraft's integrated logistics and environmental footprint. Airplane tire wear methods are intricate and reliant on a slew of interconnected variables. A DT model of a particular plane tire at touchdown was established by (Zakrajsek et al., 2017) and it is used to improve the above tire touchdown wear estimation. The derivation of a physics-based formula, slip Wear percentage is used in a non-linear touchdown wear reaction model. Based on the above-mentioned variables, high-fidelity testing data is detailed in this paper. The response model was created as a function of variable factors that can be seen in a field setting. After that, the DT method is used to calculate the Probability of Failure (POF) for various sink rates, yaw incidence angles, tire situations, and touchdown velocities. The findings of the DT touchdown model indicate future potential benefits for airplane mission decisions, such as cost reductions and tire continuous monitoring at touchdown. Several aspects of the DT model introduced in this study have yet to be completed. Two major areas for improvement are raising the levels and testing the additional factors. **Table 3** summarizes all the mentioned models along with their limitations.

3.3 Management

3.3.1 Airport management

The Digital Twin concept allows an airport authority to make decisions inside a data model, analyze the results, and optimize the outcome. The truth is that airports are lagging in embracing DT, which is already widely used in high-tech manufacturing and the fields of engineering, architecture, and construction.

Related to time savings, cost cutbacks, design, and performance improvement skills, these sectors already get benefitted from the immense gains in productivity.

In general, an airport DT can offer new sections of strategic value, such as:

a. Platform vision is achieved by combining existing resource operational optimization with combined stakeholder circumstance development and future strategic initiatives.
b. New Innovation and savings are made possible by DT.
c. System advancement is based on collaborations with the tech industry to simulate new operations and commercial services using DT.
d. Revenue generation for first-mover contractors who develop airport-specific applications for global distribution to other airports.

Table-4: Comparison between various DT Models used in the Aerospace Industry for Management.

Ref.	Main Contribution	Limitation
(Saifutdinov et al., 2020)	A DT model-based airport traffic control scheme based on the Decision Support Tool.	The combination of DT with ML was explained in a theoretical manner. The practical application procedure was not described.
(Reifsnider et al., 2013)	Based on the observation and scientific justification of fluctuations in several physical substance characteristics, a rational engineering approach to real-time composite structure "tail number" diagnosis.	The utilization of dielectric spectroscopy in introspective geology, sensing and danger detection, electrical circuitry, and a variety of bio-based methods is still in its infancy.
(Zaccaria et al., 2018)	A scheme for aircraft fleet monitoring, and management.	This model is not tested using real flight data.

A DT of an airport contains more than just the building infrastructure; it also includes the associated operational processes. It acts as a major data repository, allowing it to enhance performance and acquire data more quickly. Advertisement, assets management, operational processes, engineering, and servicing departments are among the business sectors that will benefit. The DT model should also encourage a climate conducive to digital transformation. A business strategy is required for the successful implementation of such virtual models so that DTs can be used successfully by organizations to produce positive results.

(Saifutdinov et al., 2020) proposed a DT model-based airport traffic control scheme based on the Decision Support Tool. The authors described various types of relationships that can exist between a DT and an actual physical element. The innovative aspect of the investigation is the continuous linkage between the DT and the physical thing in question. The most efficient response seems to be a distinct and precise division of the information system and applications in the manner of the DT. The DT can therefore be utilized as a substantial information source for the development and evaluation of different approaches to centralized ground transportation control at airports. Theoretical explanations were provided for the combination of DT and ML. The procedure for carrying out the practical application was not described.

3.3.2 Fleet management

The goals of fleet management are usually readiness, accessibility, risk reduction, and cost reduction. Data management is required to handle massive datasets from various platforms. The science and technology behind the interpretation used in each “tail number” are, however, at the heart of any successful, assertive fleet management.

(Reifsnider et al., 2013) discussed a logical engineering scheme for real-time composite structure “tail number” diagnosis based on the measurement and scientific explanation of changes in multi-physical material characteristics. The strategy has been demonstrated with examples, and application paths will be mentioned. There will be connections made between durability, trustworthiness, threat, and liability. The use of dielectric spectroscopy in exploratory geology, sensing and threat detection, electrical circuitry, and a variety of bio-based methodologies is still in its early stages.

(Zaccaria et al., 2018) developed a scheme for aircraft fleet monitoring, and management. The framework takes a multi-level strategy: it starts with monitoring thresholds, then isolates troublesome engines, which are then subjected to a fault detection technique. Various fault isolation, recognition, and estimation methods were explained and compared by the authors. This theoretical strategy is evaluated on fleet data obtained by a turbofan engine efficiency model, considering flight-to-flight and engine-to-engine variants as well as sensor measurement uncertainties. The above-mentioned model has not been validated using real-world flight data. **Table 4** summarizes all DT models used in management along with their limitations.

3.4 Performance Optimization

With digital twins actively monitoring and duplicating the performance of real aircraft systems, operators and companies will be able to predict and prevent a much broader range of problems before they happen. As a result, uptime and airplane availability will be significantly improved.

The precision spool valve is a crucial element of the electro-hydraulic servo motor control system, and its behavior has a significant impact on automotive and aerospace flight control. (Tang et al., 2021) proposed a novel technique for evaluating the mating output of precision spool valves that uses DT technology to account for identifying surface topographical errors. First, a basic framework for analyzing highly precise spool valve mating performance using the proposed DT. Following that, key technologies such as construction interface geometrical modeling, corresponding behavior modeling, and performance comparison are investigated. Finally, a quantitative relationship is discovered between the mating parameters and the spool valve's oil leakage. The technique is put to the test in a real-world scenario. This technique can provide theoretical justification for precise estimates and examination of the spool valve's mating results. In this mating performance optimization model, geometrical topography parameters were not taken into account.

(Sisson et al., 2021) presented a methodology for optimizing rotorcraft flight variables to reduce the stress on serious mechanical parts based on their current and projected states while meeting technical constraints. To assist probabilistic diagnosis, and utilization, a digital twin strategy is being pursued. A detailed rotorcraft analysis was used to determine the rotorcraft's load capacity under specific flight circumstances, and a finite element analysis was used to anticipate the correlating stress in the element of interest. After each flight, diagnostic data is taken and then used to approximate the disparity in the damage prediction model. The up-to-date prediction technique is used to predict the component's condition for a given future mission. The ideal flight specifications for the upcoming mission are then recognized by taking into account the component's anticipated state and reducing stress in the element under ambiguity. Numerical experiments are used to demonstrate the proposed method.

A two-stroke large-fuel airplane engine with a poppet control valve has an inefficient manufacturing process since the fuel interchange system contains several components. Furthermore, due to the higher valve variables, actual experimental optimization wastes a lot of money and time. A DT-based optimization framework for the system was put forth by (Xu et al., 2021) and uses a variety of DT components to digitally recreate, enhance, and produce the parameters while engaging with and storing the information. To rectify problems as they happen throughout the optimization process, the DT elements leverage actual real-time feedback data from production measurement techniques and system effectiveness testing. The results demonstrate that the iterative computation for the optimal parameters is successfully carried out, and the simulated engine model with response and adjustment is quite realistic and convincing when compared to test results. Real-world testing demonstrated the effectiveness of DT-based refinement, with both power and gas transfer effectiveness increasing by around 4% at various engine loads and speeds. Other than the gas exchange, this aero-engine optimization technique did not focus on any other fuel system.

The variability in results among independent systems increases as systems age because they may be conducted in various environments and with varying degrees of severity. As a result, a need has been recognized to shift paradigms and connect models to personal vehicles rather than fleets of identical vehicles. This allows for the acquisition of performance-specific characteristics and, as a result, a reduction in performance estimation uncertainty. (Jeon et al., 2019) proposed a framework for building and demonstrating a DT representation of a quadcopter to improve estimates of end-user-relevant metrics like maximum range. The performance predictive capability refers to these metrics. To enhance this capability, models for the multiple elements of the quadcopter structure are being developed. These metrics of interest are predicted by the models before undertaking experiments. The results of the research are analyzed after it is completed to gain a better realization of the physics and to achieve a good prediction accuracy of the models by upgrading them. Only one phase-off flight (hover) was validated in the framework.

4. Model-based Design

Model-based design is an arithmetical and visual approach for problem-solving in the design of critical control, data processing, and communication frameworks. It has numerous applications in gesture control, industrial machinery, aerospace, and automobiles. In the industrial domain, managing or handling the lifecycle of the components of a complicated and safety-critical process, from core conceptual design to operational support, is still a noteworthy challenge. Model-based design (MBD), model-based engineering, and other tasks involving the identification of requirement specification of the system, physical and functional attitudes, and model-based engineering is subjected to considerable trade studies aimed at choosing the most appropriate solution.

(Bachelor et al., 2020) discussed how the model-based DT and threads ideas will alter the way of process to overcome issues such as federated IT infrastructures and services. Notably, perspectives of non-lifecycle and lifecycle inter-operability are explained, with a particular emphasis on the use of benchmarks for lifecycle help and diverse simulation. As a case study, the architecture of an ice protection system for a regional aircraft was chosen and described by the authors.

(Miller et al., 2018) tried to improve method interconnectivity by incorporating spatially connected non-geometric data into computer-aided design schemes. Inside the computer-aided design widget toolkit, a tool was developed to capture, illustrate, and search for spatial information. This allows both researchers and users to access information previously only available in separate software from within the CAD tool.

A safety-critical system's layout necessitates an accurate prediction of its RAMS (reliability, availability, maintainability, and safety). This is a tough action since the RAMS analysis tries to deal with the hazard assessment of parts of the system, which is never easy to abstract at the conceptual stage. Through functional and dysfunctional assessments, (Brusa et al., 2021) examined how model-based systems endorse this work and drive the allotment of system reliability. The toolchain must be set up before the proposed approach can be implemented. It must be agreeable with existing product creation practices, guidelines, and tools in the industrial environment.

Table-5: Comparison between various DT Models used in the Aerospace Industry for Model-based Design.

Ref.	Main Contribution	Limitation
(Bachelor et al., 2020)	Discussed how the model-based DT and threads ideas will alter the way of the process to overcome issues such as federated IT infrastructures and services.	Integration of voice recognition or virtual reality with ML-based analytics was not shown.
(Miller et al., 2018)	Tried to improve method interconnectivity by incorporating spatially connected non-geometric data into computer-aided design schemes.	This model was just a starting point for creating a digital twin using previous behavioral data from the CAD model.
(Brusa et al., 2021)	Examined how model-based systems endorse RAMS analysis	-

	and drive the allotment of system reliability.	
(Liang et al., 2020)	Introduced a real-time full-field displacement recognition method.	-

Full-field deflection perception in the high exactness production sector, such as aerospace production, is crucial. (Liang et al., 2020) presented a real-time full-field displacement recognition method for the integration of digital multicast dispersion tracking and grid achievement ideas. To begin, a theoretical full-field dispersion perception model is established based on the measured information from the multi-points. Major elements of full-field displacements are obtained by breaking them up into numerous discrete points that are both recognized and unrecognized and then creating a link between the identified spots and the full-field separations. The full-field displacement prospective model's solution is then proposed by the authors. The optimization approach is used to function the model, while the pseudo-code is used to put forward, based on big data and the matrix completion principle. Finally, full-field displacement perception experiments are carried out. Experimental studies show that the median error should be less than 0.054 mm and the maximum error of the displacements should be less than 0.094 mm. This result was very promising as it if providing high precision and efficiency for large aircraft gathering and arrangement. **Table 5** summarizes all Model-based DT.

5. Simulation Techniques

Simulation is a broad topic with a hazy definition. In general, DTs can be considered a simulation method, but not all simulation models are DTs. Regarding the degree of visualization, the strategies used to adopt DT simulation nowadays can be classified into three main levels (Ezhilarasu and Jennions, 2020). Abstract frameworks are the first level. The topology method and Simulink or Matlab model represent an abstract simulation using simple symbols and lines (West and Blackburn, 2017), (Dröder et al., 2018). Instead of displaying the shape and detailed information, the above type of model emphasizes promising principles of physics guided by the physical object (Zhidchenko et al., 2018). In today's DT applications, abstract models, particularly Simulink or Matlab models, are really common(Aivaliotis et al., 2019). The low-cost visual representation of physical items is an added benefit of the abstract model (Cimino et al., 2019). The major drawback is that users or customers without a specific level of prior knowledge will be unable to comprehend the models, particularly since they are commonly non-3D models (Rocca et al., 2020).

The study presented by (R.K. Phanden et al., 2020) provides a variety of current accomplishments on simulation-based DT and DT-based simulation modeling put forth by academics working in the fields of robotics, manufacturing, and aerospace. In the simulation of the aerospace industry, simulation techniques like Monte Carlo simulation, Finite Element Methods (FEM), and Computer-Aided Engineering (CAE) are being used to acquire the simulated data for various operations of the aircraft.

The 3D models are at the next level. 3D models are much more convenient to present the details of physical entities than abstract models. 3D modeling has progressed considerably in recent years (Breaking news). Nx, Computer-aided Design and Drafting (CAD), Analysis of Systems (ANSYS), and Computational Fluid Dynamics (CFD) are a few examples of 3D modeling software that can be used to visualize DTs (Goraj et al., 2019), (Botkina et al., 2018). Submerged simulation is in the third level, which refers to Virtual Reality (VR) (Thomas et al., 2006) and Augmented Reality (AR) (Tadeja et al. (a), 2020). VR is a technique that generates an interactive digital or virtual environment that recognizes the interaction between both the virtual and actual fact, whereas AR is a mixture of the real-world environment and the simulation world that provides virtual assistance to a real scenario. These techniques play a significant role in several specific tasks, such as VR for UAV activities in open terrain (Tadeja et al. (b), 2020). The use of AR for remote aircraft maintenance.

6. Findings & Recommendations

After reviewing various DT-based papers, qualitative and quantitative performance analyses of different models are found. Besides, a few challenges and their possible recommendations are also stated in this section.

6.1 Qualitative Performance Analysis

6.1.1 Planning

(Closed loop, 2022) validated the simulated cargo load plan by comparing it to the load plan generated by the airline's system. Here for performance comparison, the number of available unit load devices, score, number of selected unit load devices, destination, actual loading operation time, and optimization simulation model run time is used. The simulated results show an improvement, particularly in terms of minimizing center of gravity deviations and, as a result, lowering fuel consumption.

6.1.2 Designing

According to (Chang et al., 2021), using the proposed KDT-SD structure, it is probable to use DT to minimize the complexity and reveal design flaws in AAL design. Furthermore, the knowledge library provides DT with the ability to perform fast modeling and intelligent evaluation, which improves design quality and efficiency.

6.1.3 Modeling

For validation of the model, (Liu et al., 2020) tested their DT model on an air rudder. The DT method recognizes the state of the machine tool, the instrument, the process variables, and other details, and then performs real-time monitoring. According to the authors, their mimic model can include 3D- As-Designed and 3D- In-Process models as well as product specification, structural features, modeling mode, planned process, and background relevant data. But the model-based definition or we can say the physical system cannot provide information on the physical characteristics, simulation mode, planned process, and context information. So, the DT-based mimic model provides more information than the model-based physical system. Authors should work on the speed and accuracy of the model.

(Jinsong et al., 2019) used five performance metrics to evaluate their aerospace-based DT model: execution time, quality inspection batch, total running time, downtimes, and logistic accuracy rate. Here, for comparison, the authors picked the manual+NC machines and the manufacturing using the DT model. Using the manual+NC machines, the execution time, quality inspection batch, running time, downtime, and logistic accuracy rates are 36min, 128 pieces, 43 mins, 1, and 95.5%, respectively. Whereas Using the DT model, the execution time, quality inspection batch, running time, downtime, and logistic accuracy rates are 19min, 4 pieces, 23 mins, 0, and 99.2%, respectively. So, it can be stated that the DT model is more efficient than the manual+NC machine.

6.1.4 Manufacturing

For the result analysis, (Zambal et al., 2018) used a modular variant of the LScan (depth data) and FScan (fiber orientation measurement) sensors to cover the full width of the carbon material. Using those sensor data or the proposed manufacturing dataset, the effect of the defects was calculated in near real-time with the help of an analytical model. In the case of severe defects, a finite-element model was required, which generates results in about 5 minutes. This performance was adequate for use in real-world manufacturing.

6.2 Capturing Physical Properties with High Precision

DT is a complicated procedure that requires the collection of a variety of physical parameters. By accurately capturing their material characteristics, simulating their behavioral patterns, and adjusting their scale, DT technology should be capable of simulating both small items (such as a vehicle, aircraft, building, or a living person) and complicated relationships (such as a shopping process, irrigation facilities, a store, a metropolitan area, and so on). Even noise is also a factor that affects the quality of DT. Modern Multi-Loop Feedback filters can help to reduce noise from data. Noise removal can also be accomplished using Real-time noise reduction using deep learning. Instead of using a single sensor, we can use multiple sensors for collecting data and the weighted average of those data can be used to increase the accuracy of physical properties.

6.3 Real-Time Automatic Updating

DT is a simulation-based model that runs in real time. It is extremely difficult to collect and process all data in real time. Because of the Internet of Things, this process has become easier in recent years. Nonetheless, it is a really difficult task. The DT model should be self-aware of changes in its size and functionality in real time and adjust or adapt as necessary. Researchers can use a heterogeneous multicore based on Field Programmable Gate Arrays (FPGAs) running on the ReconOS (the operating system for reconfigurable computing) to solve this problem.

6.4 Collaboration on a Project

The DT technology should be able to collaborate on a wide range of projects. Digital twins, for example, can efficiently work within a merged DT. A digital twin can collaborate and link with other DT modules in a variety of settings. By using data from various connected sensors to express the story of a module or asset through its complete life cycle, a DT can create collaboration between different modules. The usage of the shared dataset can also solve this obstacle.

6.5 Interaction with Physical and Digital Objects

Interacting between physical and virtual schemes is highly tough because DT collects data from numerous physical infrastructures and uses that info to operate in a virtual environment. It can take on the look of a human user and communicate with other virtual items or digital twins in an immersive manner. A data interaction mechanism that combines message middleware, relational databases, and memory databases can be configured to support virtual-physical interaction. To send production and manufacturing instructions, responses, and execution results message middleware such as Kafka and MQTT (MQ Telemetry Transport) can be used. Throughout production, a memory database, such as Redis (Remote Dictionary Server), can be used to capture real-time operating data. Information management for simulation models can be done with relational databases such as Oracle, MySQL, SQL Server, and others.

6.6 Detecting and resolving conflicts

The DT model is designed to detect and respond to changes in a real-world setting. To ensure that such interactions are accurate, it must also be able to recognize and correct execution differences. A conflict checker, which indicates possible normative conflicts, can be used to overcome this barrier. Figure 3 shows an overview of all the possible challenges and recommendations.

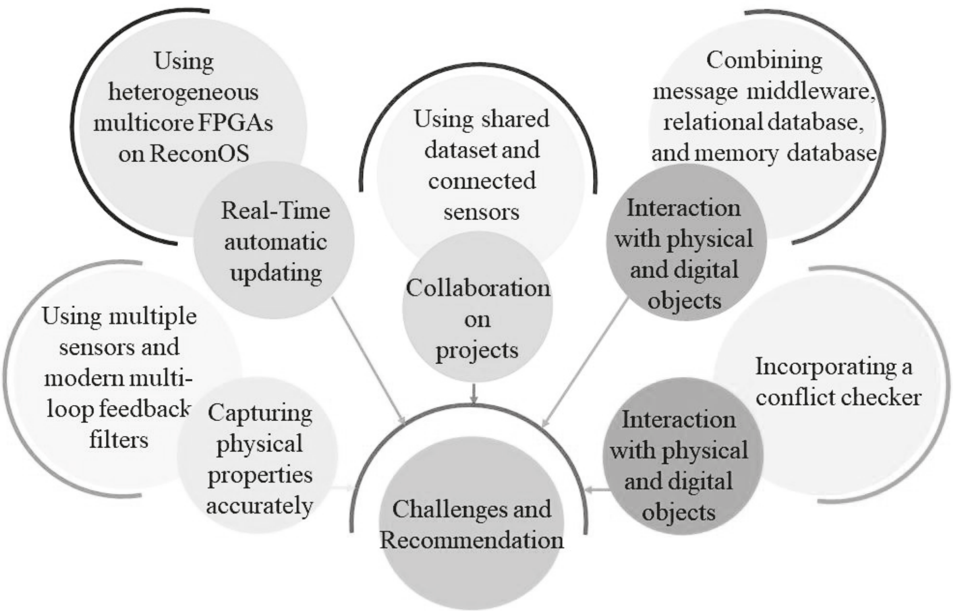

Figure 3: Challenges of DT base models in the Aerospace Industry along with possible recommendations.

7. Conclusion

Today, the DT is an important phenomenon that exists, starting from the design process to maintenance and management. The Digital Twin is also associated with the need to defend the item throughout its life cycle. When the item or object is used, the digital copy, which is fed with simulation studies and design information, should strive to evolve with data obtained through sensors and user inputs from the product's application domains. This comprehensive review is fully focused on the applications of various DT models in the aerospace industry. We have reviewed different useful DT models for designing manufacturing, monitoring, management, and performance optimization in the aerospace industry field. We have also provided a clear concept of the history and research fields of DT. A few model-based DT models and simulation techniques are also discussed in this paper. One limitation of our work is that we could not describe specific DT models for important parts of aircraft. After reviewing all models, we concluded that DT would help with future versions of aerospace production. So, improvements must be made by reducing the number of copies and errors. Simultaneously, by running numerous tests on the virtual copy, solutions to current mistakes can be found safely. We hope this comprehensive review will help future researchers to perform revolutionary research in this field. In the future, we want to focus on artificial intelligence-based DT models in the aerospace industry.

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