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# ANALYSIS OF STATE-OF-THE-ART TECHNOLOGIES IN THE MODERN AEROSPACE INDUSTRY

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**Rezumat.** *Industria Aerospațială Modernă se află într-un proces de continuă dezvoltare, adoptând noi tehnologii pentru a îmbunătăți precizia, siguranța, eficiența și sustenabilitatea în fabricația de aeronave și vehicule spațiale. Analiza, pe care am efectuat-o, privind integrarea tehnologiilor state-of-the-art în industria aerospațială este realizată, folosind tehnici de analiză mixtă (cantitativă și calitativă) și tehnici de analiză computațională, pentru determinarea situației actuale din domeniul aeronautic și a tendințelor de dezvoltare. Scopul acestei analize este de a evidenția avantajele și riscurile utilizării noilor tehnologii asupra domeniului aerospațial, luând în considerare impactul creșterii vitezei de dezvoltare a proceselor de fabricație ce integrează IA.*

**Abstract.** *The modern aerospace industry is undergoing continuous development, adopting new technologies to enhance precision, safety, efficiency, and sustainability in the manufacturing of aircraft and spacecraft. The analysis conducted regarding the integration of state-of-the-art technologies in the aerospace sector is based on a mixed-methods approach (quantitative and qualitative), as well as computational analysis techniques, to assess the current state of the aeronautics field and identify emerging development trends. The aim of this analysis is to highlight the advantages and potential risks associated with the use of new technologies in the aerospace domain, considering the impact of the increasing pace of development in manufacturing processes that integrate artificial intelligence (AI).*

**Keywords:** state-of-the-art, analysis techniques, AI.

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## 1. Introduction

The aerospace industry continues to evolve rapidly, embracing state-of-the-art technologies to enhance precision, safety, efficiency and sustainability in the manufacturing of aircraft and aerospace vehicles. Leveraging state-of-the-art technologies for new generation manufacturing can unlock new market segments that were previously unexplored. These potential customers demand transparency regarding costs and environmental impacts associated with the products, technology level of developments, trends or services they use. Thus, success

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depends on delivering products that combine high quality, technology innovation and innovative design with durability and minimal environmental and societal impact. This new design paradigm integrates technological development, functionality, aesthetic and economic considerations with assessments of energy, resource, and material flows, with the environmental component assuming strategic importance.

The state-of-the-art components associated with new generation of industrialization, which represent the core focus of this study and serve as independent variables within this research, include: Robotics and Automation, Internet of Things (IoT), Augmented and Virtual Reality (AR and VR), Integrated Systems, Additive Manufacturing (AM), Big Data, Cloud Computing, Digital Twin and Simulation Technologies, Cybersecurity and Eco-design.

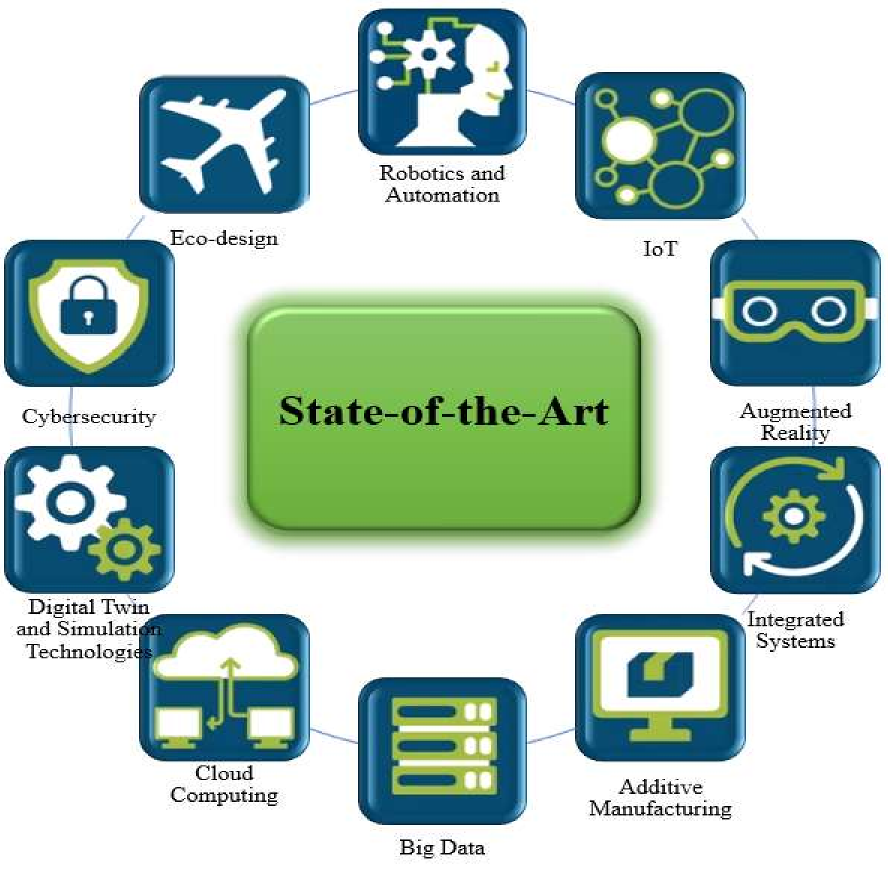


**Fig. 1.** The various state-of-the-art technology in the aerospace industry.

This research specifically focuses on robotics and automation in aerospace manufacturing, including assembly, control, machine learning, and the deployment of automated robots in space operations.

## 2. State-of-the-art technologies associated to the aerospace industry

### 2.1. Additive Manufacturing (3D Printing)

Unlike traditional subtractive manufacturing methods, which involve removing material from a solid block (like turning, milling or cutting), Additive Manufacturing (AM) is a progressive production process that builds three-dimensional components layer by layer based on computer-aided design (CAD) data, using materials such as metals, advanced alloys, polymers, and composite materials. AM builds components by adding material in accordance with well-defined coordinates.

The primary AM technologies used in the aerospace industry include:

- Selective Laser Sintering (SLS) – for polymers and composite materials.
- Direct Metal Laser Sintering (DMLS) – for metallic alloys.
- Electron Beam Melting (EBM) – used for titanium and other superalloy components.

Ongoing global efforts are being made to integrate and developed AM standards, with a particular focus on the stringent requirements of the aerospace industry. The materials used in AM play a crucial role in determining the performance of aerospace components. The concept of efficient, lightweight design promotes the use of light materials such as titanium and aluminium alloys, which can significantly reduce the mass of aircraft components. AM contributes to minimizing material waste compared to conventional subtractive manufacturing technologies, an essential aspect in the aerospace sector, where extremely expensive and difficult-to-machine materials such as titanium alloys, nickel-based superalloys, or ultra-high-temperature ceramics are frequently used.

In addition to using AM for small and medium scale part production, another important application involves the repair and restoration of aerospace components, prototyping, and manufacturing of spare parts-emphasizing the critical role of regulatory frameworks, aviation safety, and certification processes in achieving these goals.


**Fig. 2.** Advantages and disadvantages of Additive Manufacturing.[24]

In recent years, the aerospace industry has increasingly adopted AM for design, research, and prototyping, as it is particularly well-suited for low and medium volume production. Nowadays, the global additive manufacturing market size is estimated at 25.92 billions of dollars and is expected to exceed approximately 125.94 billions of dollars by 2034, accelerating at a compound annual growth rate (CAGR) of 19.29% from 2025 to 2034

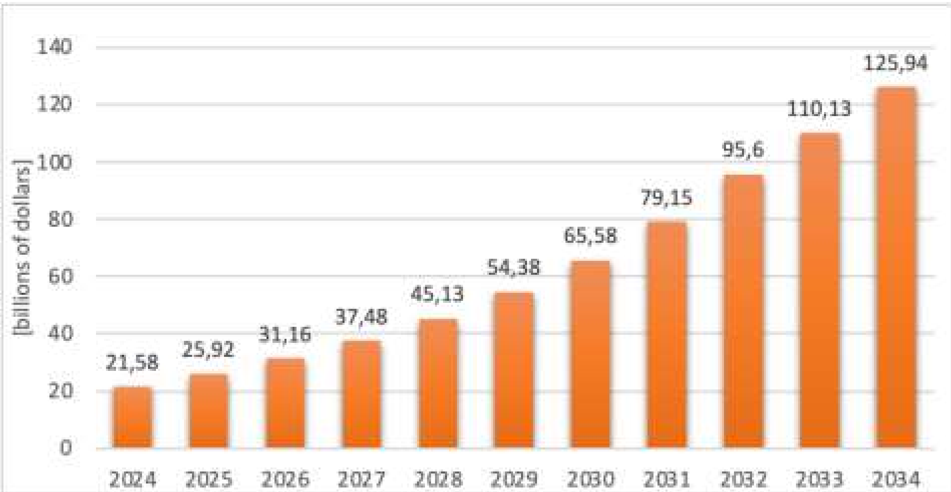


**Fig. 3.** Additive manufacturing market size and forecast (2025 - 2034).

### 2.2. Automation and robotics in aerospace manufacturing

Following an in-depth review of the specialized literature, a major recurring theme in the field of aerospace manufacturing is the challenge of integrating robotic production lines, automated systems, and collaborative robots “cobots”. Within the production ecosystem, organizations often rely on system integrators to design assembly lines. Many leading robotics manufacturers also act as system integrators, incorporating both their own hardware and components from other companies into integrated solutions.

Market research on the development, production, and integration of automation technologies in aerospace enterprises has revealed that robots themselves are not the most significant investment- the primary cost lies in the integration of acquired technologies, training of skilled personnel, and monitoring and ensuring the continuous operation of these systems.

A current topic of growing research interest involves collaborative industrial robots, which could benefit from the concept of anticipation: integrating the prediction of a human’s action or intent a robot’s planning and execution. The underlying idea of such methods is to exploit new capabilities that enable dynamic collaboration between a human operator and a robot-either by enhancing human safety through proactive distance management, or by improving human-machine system performance through more fluid interaction.

**Cybersecurity** emerges as a parallel concern within interconnected systems, where threats such as unauthorized access and data breaches can be mitigated through blockchain technologies (significantly reducing risk) and AI- based anomaly detection.

The rise of smart manufacturing has further strengthened the role of robotics in industrial environments. Companies are increasingly integrating robotic solutions to optimize production processes, address labour shortages, and enhance operational flexibility in a rapidly evolving global market.

### 2.3. Digital twin and advanced simulation

A digital twin (DT) is a virtual representation that mirrors the behaviour of a physical system throughout its operational lifecycle. A DT is created by collecting real-time data from actual components via sensors and systematically storing and processing this data to build a digital replica. Fundamentally, the DT concept is closely linked to simulation technologies and their associated software platforms.

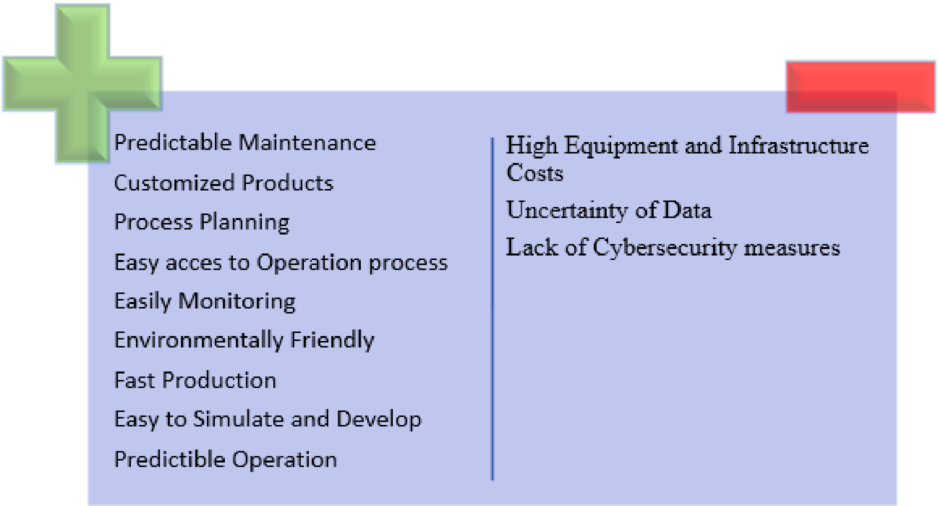


**Fig. 4.** Advantages and disadvantages of simulation and Digital Twin

Throughout the entire life cycle of a product, simulation using CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), and CAE (Computer Aided Engineering) can be employed for design, manufacturing, and research purposes. By analysing data flows, combining datasets, performing simulations, and developing Digital Twins, it is possible to generate predictions based on objectively measured or calculated data.

### 2.4. Artificial Intelligence and Big Data

Artificial Intelligence (AI) is being adopted across all segments of the aerospace industry to enhance and optimize production cycles. AI has become essential for safety management, component design, manufacturing process development, inspection, maintenance, repair and overhaul (MRO), and fuel efficiency. While AI encompasses a broad array of concepts, Machine Learning (ML) and Big Data are the most impactful in aerospace manufacturing.

ML consists of methods that enable systems to learn from and adapt to large data sets, often surpassing traditional statistical approaches. Key advantages include improved production efficiency, environmental compliance, productivity, and operational flexibility through the analysis of Big Data collected via cyber-physical systems within smart factories.

Thanks to Big Data technologies, enterprises benefit from access to vast data networks, real-time situational awareness, instant change detection, competitive benchmarking, and accelerated decision-making. Moreover, the evolution of Big Data has led to the emergence of a complementary technology known as Cloud Computing. However, Big Data and Cloud Computing are not mutually dependent technologies. Cloud Computing broadly refers to services that enable shared data exchange among computing-enabled devices. It supports enterprises by allowing rapid scalability, cost reduction, independent resource allocation, and global network accessibility.

Big Data Analytics has the potential to provide comprehensive feedback and a high degree of coordination-both essential for achieving high production efficiency. Data obtained from various sources and channels, such as sensors, actuators, network traffic, and files can supply statistical input for real-time monitoring and control, as well as far dynamic reconfiguration and system optimization, thereby expanding business opportunities.

AI and Big Data analytics are profoundly transforming the aerospace industry, affecting every stage of the product lifecycle, from design and manufacturing to maintenance and operations.

### 2.5. Sustainability and eco-design

There is a strong, synergistic connection between: Green Technologies, Eco-design and Sustainability, in the modern aerospace industry. These concepts are not only interrelated but also mutually reinforcing, forming a strategic and operational framework focused on reducing environmental impact while improving economic and social performance.

Leveraging state-of-the-art technologies for green manufacturing can unlock new market segments that were previously unexplored. These potential customers demand transparency regarding costs and environmental impacts associated with the products or services the use. Thus, success depends on delivering products that combine high quality and innovative design with durability and minimal environmental and social impact.

This new design paradigm integrates aesthetic, functional, and economic considerations with assessments of energy, resource, and material flows, with the environmental component assuming strategic importance.

Eco-design is the process of defining the environmental impact a product will have over its entire lifecycle, from production to end-of-life disposal. Therefore, it is essential to employ operational strategies such as Life Cycle Assessment (LCA), which facilitate the use of low-impact resources and technological solutions that minimize waste production and extend product lifecycle longevity, including considerations for disassembly and recyclability.

As a result of the review and analysis of the legislative framework concerning the new requirements for manufacturing processes in the aerospace industry, focused on risk assessment, environmental performance evaluation, environmental impact analysis and the identification of potential changes at each phase of the product life cycle that may lead to environmental benefits and overall cost saving, the LCA cycle, illustrated in Fig. 5, is outlined. This management technique is aimed at identifying the flows of materials, energy and waste generation associated with a product throughout its life cycle and assessing their impact on the environment.

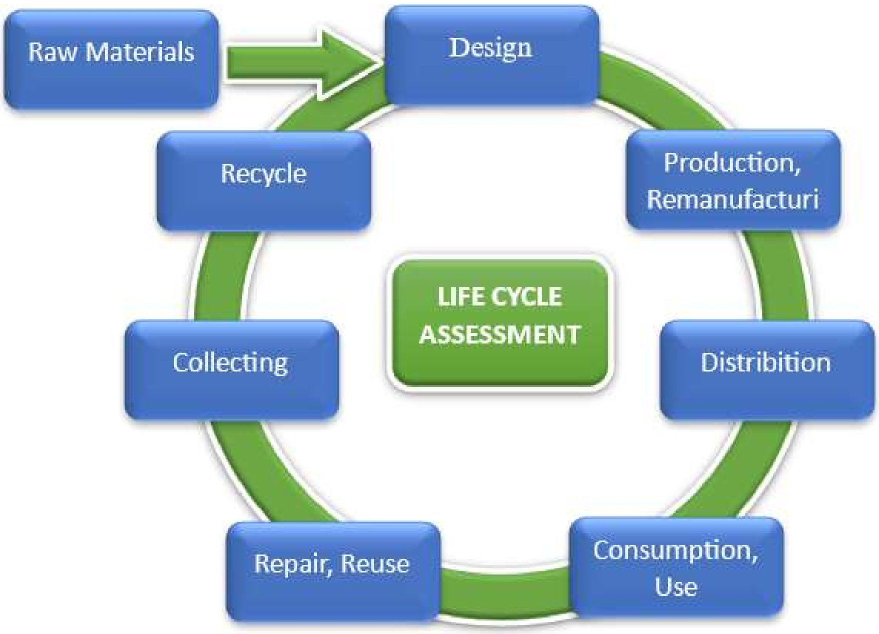


**Fig. 5.** Life Cycle Assessment

One of the most established and widely used methods for assessing the environmental footprint of a system is the life cycle assessment. LCA studies of components, systems, or aircraft are often conducted retrospectively, focusing on evaluating the environment impacts of existing aircraft. However, LCA can also be applied prospectively as a tool for eco-design.

This research specifically focuses on robotics and automation, technology innovation and eco-design in aerospace manufacturing, including assembly, control, machine learning, and the deployment of automated robots in space operations.

Numerous ongoing projects focus on the development of innovative technologies to tackle current environmental challenges while aligning with the EU's goal of achieving net-zero flights by 2050. This ambitious objective can be approached from multiple angles, including:

- Modernization of production technologies,
- Adoption of additive manufacturing with the use of next-generation recyclable materials,
- Energy efficiency in processes,
- Emissions reduction,
- And improvement in air traffic management and maintenance services.

The use of biodegradable polymers supports compliance with regulatory requirements and corporate sustainability goals within the aerospace sector. As governments and regulatory bodies worldwide impose stricter environmental and waste management regulations, aerospace manufacturers face growing pressure to adopt more environmentally friendly alternatives.

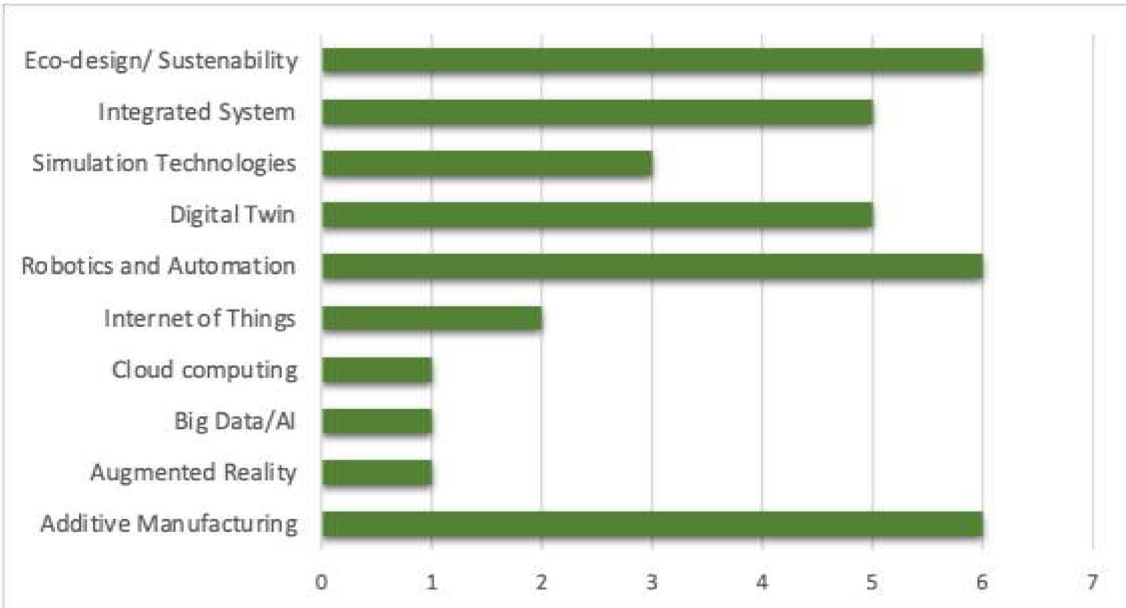


**Fig. 6.** Number of mentioned papers per technology.

As reported in the result of the technical literature review, the Robotics and Automation, Additive Manufacturing, Eco-design and Sustainability represent the greatest maturity and interest at the present time in the aircraft industry.

## Conclusions

The modern aerospace industry is undergoing a profound transformation, driven by increasing pressure for sustainability, operational efficiency, and technological innovation. In conclusion, additive manufacturing represents a major paradigm shift in aerospace engineering, providing innovative solutions to produce complex, lightweight and high-performance components-thereby contributing to technological advancement and cost optimization across the sector.

Artificial Intelligence facilitates complex decision-making processes, optimizes supply chains, enables predictive maintenance of equipment, and enhances safety through advanced data analytics. AI also plays a pivotal role in automated design and flight condition simulation, significantly reducing product development time.

Automation is primarily intended to reduce human labour costs, but it must not eliminate human interaction altogether. Therefore, automation should be implemented in a manner that optimally distributes tasks between humans and robots. The automation of manufacturing processes through robotics and other advanced technologies significantly reduces the risk of human error, particularly in cases involving design flaws. Practical environmental assessments can support artificial intelligence systems related to highly developed aeronautical vehicles.

The Internet of Thing introduces extended connectivity into aerospace infrastructure, enabling real-time monitoring of critical aircraft systems. Through data collection and analysis, potential failures can be anticipated, maintenance procedures optimized, and both passenger experience and flight safety improved.

Robots, integrated into manufacturing and maintenance processes, enhance precision and reduce the risks associated with hazardous or repetitive tasks. Industrial automation powered by robotics enables aerospace factories to achieve high standards of quality and efficiency.

Machine Learning (ML) plays a pivotal role in the aerospace industry by enabling various optimization strategies, such as stochastic algorithms. In diverse aerospace applications, cognitive human-machine interfaces and interactions support flexible automation, allowing systems to adapt to complex and dynamic environments.

Nevertheless, machine learning also presents certain limitations. Human-robot interaction can enhance overall system efficiency by improving awareness of different operational modes, assessing applied methods and techniques, and leveraging gaps in current implementations.

Green technologies are becoming increasingly relevant in mitigating aviation’s environmental impact, using sustainable materials, alternative propulsion systems, and fuel consumption optimization. Innovations in this area not only address environmental requirements but also contribute to lower operational costs and increase the social responsibility of aerospace companies.

### **Notations** and/or **Abbreviations**

**AI** – Artificial Intelligence, **IoT**- Internet of Things, **AR**- Augmented Reality, **VR** – Virtual Reality, AM **–** Additive Manufacturing, **DT –** Digital Twin, **CAD -** Computer Aided Design, **CAM** - Computer Aided Manufacturing, **CAE** - Computer Aided Engineering, **MRO -** Maintenance, Repair and Overhaul, **ML -** Machine Learning, **LCA-** Life Cycle Assessment

## R E F E R E N C E S


[1] Ryalat, M.; ElMoaqet, H.; Al.Faouri, M. Design of a Smart Factory Based on Cyber-Physical Systems and Internet of Things towards Industry 4.0. Appl. Sci. 2023, 13, 2156;

[2] Krish V. Raibole, Sachin R. Deshmukh, „Applications and Limitations of Additive Manufacturing Techniques for Manufacturing Components of Aerospace Industry," Researchgate, 2023.

[3] Abdul Hai Alami, Abdul Ghani Olabi, Adnan Alashkar, Shamma Alasad, Haya Aljaghoub, Hegazy Rezk, Mohammad Ali Abdelkareem, „Additive manufacturing in the aerospace and automotive industries: Recent trends and role in achieving sustainable development goals," Ain Shams Engineering Journal 14 (2023) 102516, 2023, https://doi.org/10.1016/j.asej.2023.102516

[4] Pierrick BOUGAULT, Raphael Anwar EL HADDAD, Liang MA, „Industrial Applications of AI in Aircraft Manufacturing: A PRISMA Systematic Literature Review," Research Square, DOI: https://doi.org/10.21203/rs.3.rs-6199323/v1

[5] Mostafa Yakout, Andrea Cadamuro, M. A. Elbestawi, Stephen C. Veldhuis, „The selection of process parameters in additive manufacturing for aerospace alloys," Springer-Verlag London 2017, The International Journal of Advanced Manufacturing Technology, CrossMark, Int J Adv Manuf Technol;

[6] A. Minocha, „Advanced Manufacturing Techniques in Aerospace Engineering," SHODH SAGAR, Darpan International Research Analysis, vol. 12, 2024.

[7] F. Richter, „Statista, INDUSTRIAL ROBOTS, Rise of the Robots," November 2023. [Interactiv]. Available: https://www.statista.com/chart/26210/operational-stock-of-industrial-robots/.

[8] Rakesh Kumar Phanden, Priavrat Sharma, Anubhav Dubey, „A review on simulation in digital twin for aerospace, manufacturing and robotics," ELSEVIER, Materials Today: Proceedings, 2020.

[9] Sakshar Chowdhury, Mohaimen Siddique, Mashhunur Rahman, Irfan Talukder, „Study of Robotics and Automation in the Aerospace Industry," ResearchGate, 2022.

[10] Jie Chen, Jian Sun, Gang Wang, „From Unmanned Systems to Autonomous Intelligent Systems," ELSEVIER, Engineering, vol. 12, pp. 16-19, May 2022.

[11] Meral Calıs¸ Duman, Bunyamin Akdemir, „A study to determine the effects of industry 4.0 technology components on organizational performance," ELSEVIER, Technological Forecasting & Social Change, February 2021.

[12] Giacomo Parolin, Aliny T. Borges, Luis C. C. Santos, Anderson V. Borille, „A tool for aircraft eco-design based on streamlined Life Cycle Assessment and Uncertainty Analysis," în 28th CIRP Conference on Life Cycle Engineering, Sao Paulo, 2021.

[13] „Additive Manufacturing Market Size, Share, and Trends 2025 to 2034, Report Code : 3332," Precedence RESEARCH, 31 January 2025. [Interactiv]. Available: https://www.precedenceresearch.com/additive-manufacturing-market.

[14] „World Robotics, Industrial Robots 2024," IFR International Federation of Robotics, September 2024. [Interactiv]. Available: https://ifr.org/ifr-press-releases/news/world-robotics-2024-report.

[15] Gabriel Zutin, Gustavo Barbosa, Pedro Cabegi de Barros, Eduardo Bizeli Tiburtino, Frederico Leoni Franco Kawano, Sidney Bruce Shiki, "Readiness levels of Industry 4.0 technologies applied to aircraft manufacturing—a review, challenges and trends", The International Journal of Advanced Manufacturing Technology (2022) 120:927–943, https://doi.org/10.1007/s00170-022-08769-1.