STUDY ON THE USE OF 3D PRINTED PARTS FOR AIRCRAFTS AND DRONES

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Abstract: *In the last decade it became obvious the need to provide fast manufacturing technologies and to reduce parts costs for the aeronautical industry in general and for the rapidly developing flying drones segment. This demand led to the development of new technologies and materials like CFRP and GFRP composite materials, but also additive manufacturing (3D Printing) using different metallic compounds or thermoplastic materials. In this paper is presented a study related to the possibility of using these new 3D printing materials and technologies in the aeronautical industry (light aircrafts and drones), with emphasis on the reduction of costs versus weight. The main goal of the study is to find if fast printing thermoplastics like ABS, PLA or PETG are acceptable from a design and stress point of view.*

Keywords: *3D printing, additive manufacturing, aircraft, drone, weight, rapid prototyping*

1. INTRODUCTION

Additive manufacturing technologies, commonly known as 3D printing, have revolutionized the way complex technical components are designed and manufactured. Especially in the aerospace industry, where low weight, structural strength and design flexibility are essential, 3D printing technologies have opened up new engineering possibilities [1].

In parallel, the use of aerial drones has seen explosive growth in both commercial and military and research applications. In this context, 3D printing offers major advantages: on-demand production, rapid customization and cost reduction of functional prototypes. This paper aims to analyze the technologies, materials and impact of additive manufacturing on the aerospace industry and the drone field.

2. 3D PRINTING TECHNOLOGIES USED IN THE AEROSPACE INDUSTRY

The main technologies used in the manufacture of aerospace components by 3D printing are described in detail, each method being analyzed from the perspective of operating principles, compatible materials and specific areas of applicability. Also, for a complete understanding, the advantages offered by each technology are highlighted, such as high precision, the possibility of reducing the mass of components or optimizing the structural design, but also the related disadvantages, such as limitations in the size of the parts that can be made, production costs or difficulties associated with post-processing processes. This comparative analysis provides a clear perspective on the real potential and challenges of implementing 3D printing in the modern aerospace industry.

2.1 Fused Deposition Modeling (FDM). Fused Deposition Modeling is the most widespread technology due to its affordable cost and simplicity of the process. It consists of melting a thermoplastic filament which is then deposited layer by layer to build the desired object.

Fused Deposition Modeling (FDM) technology is primarily distinguished by the low cost of both printing equipment and consumables required for the manufacturing process, which makes it extremely affordable for individual users, educational institutions, and even for small-volume industrial prototyping [2]. Another major advantage is its simplicity of operation: users can configure, calibrate, and maintain FDM printers without requiring advanced technical knowledge, an aspect that has significantly contributed to the widespread popularization of this technology. Maintenance of these equipment is also easy and mainly involves cleaning the nozzle, periodic calibration of the print bed, and occasionally replacing consumable components.

However, FDM technology has notable limitations that affect its applicability in high-performance industries, such as aerospace. First, parts made by FDM tend to have lower mechanical strength than those made by other additive manufacturing methods, mainly due to the phenomenon of imperfect adhesion between layers, which can lead to structural weaknesses. Also, the dimensional accuracy of the components is lower, especially for complex geometries or large parts, which can require additional finishing operations. In addition, when printing complicated geometric shapes or with extended cantilevers, it becomes necessary to use support structures, which not only prolong the manufacturing time and material consumption, but can also introduce additional surface imperfections after their removal process.

2.2 Selective Laser Sintering (SLS). Selective Laser Sintering (SLS) is an advanced additive manufacturing technology that uses a high-power laser to sinter polymer or metal powders into solid structures by depositing them layer by layer. The process begins by spreading a thin layer of powder material onto a build platform, after which a high-energy laser focuses on the areas specified by the digital CAD model, selectively melting the powder particles only in those regions [3]. Once the first layer is sintered, the build platform is lowered by a distance equal to the layer thickness, and a new layer of powder is deposited on top, repeating the process until the entire component is completed.

This technology is particularly appreciated in the aerospace field due to its ability to manufacture parts with complex geometry, with superior mechanical properties and a density almost equivalent to that of conventionally processed materials. Additionally, the fact that the unused powder remains stable around the part during the process eliminates the need for additional supports, which reduces post-processing and the risk of geometric defects. SLS thus enables the fabrication of lightweight and topologically optimized structures, adapted to the critical requirements of aerospace and advanced drone applications.

One of the main advantages of Selective Laser Sintering (SLS) technology is the ability to produce parts with excellent mechanical properties comparable to those produced by conventional casting or machining methods [3]. Parts manufactured using SLS are characterized by good mechanical strength, dimensional stability, and high durability under demanding conditions of use, which makes them suitable for critical applications in the aerospace industry. Also, due to the nature of the process, in which the surrounding powder acts as a temporary support, it is not necessary to build auxiliary support structures, as is the case with other additive technologies. This allows the fabrication of very complex geometries, such as internal channels, lattices, and topologically optimized organic shapes, without major design limitations.

In addition, the possibility of reusing part of the remaining powder contributes to reducing waste and optimizing long-term operational costs. However, SLS technology also presents a number of significant disadvantages that must be taken into account. First, the initial costs of sintering equipment are considerable, requiring substantial investments in the acquisition of industrial printers and the necessary supporting infrastructure (such as thermally controlled chambers and powder handling systems) [3]. Also, the materials used, especially metal or polymer powders specially formulated for SLS, are more expensive compared to traditional raw materials. In addition to these aspects, parts obtained by SLS often require additional post-processing operations, such as sandblasting, chemical finishing or heat treatments, to improve the surface quality and final mechanical properties. These additional steps can extend the total production time and increase the costs associated with each manufactured part.

2.3 Stereolithography (SLA). This technology, known as stereolithography (SLA), uses photosensitive liquid polymers that undergo a photopolymerization process under the action of ultraviolet (UV) light, transforming from a liquid material into a solid structure layer by layer. In the process, a UV laser beam or a directed projection light source is used to trace the contour of each layer of the 3D model into the photopolymer material, causing it to selectively harden. By repeating this process for each successive layer, three-dimensional objects of very high geometric fidelity are built.

SLA technology stands out for producing parts with exceptional resolution, both in terms of fine details and surface quality, which makes it extremely valuable in applications that require extreme precision, such as functional prototyping, optical components, or detailed medical models [4]. Also, the thickness of the hardened material layer can reach several microns, allowing the manufacture of parts with tight dimensional tolerances and geometric complexity that would be impossible or extremely expensive to achieve using conventional manufacturing methods.

One of the main advantages of SLA technology is the ability to achieve an exceptionally smooth surface finish, comparable to that of parts made using traditional high-precision manufacturing methods. This feature often eliminates the need for additional post-processing or grinding operations. Also, due to the high resolution of the layer-by-layer polymerization process, SLA printing allows for extremely fine details and complex geometries, making it ideal for the production of highly detailed prototypes, functional test components, or models used in industries such as medical, dental, or optical [4]. Dimensional accuracy is another major advantage, which allows parts made using SLA to fit tightly within the manufacturing tolerances required for critical applications.

Despite these benefits, SLA technology also has some significant limitations. The materials used – mainly photopolymer resins – are often more fragile compared to thermoplastics or metal materials used in other 3D printing methods. This brittleness can lead to cracking or damage in applications where mechanical stress is high. In addition, many of these resins have potentially toxic or irritating chemical compounds, which requires strict safe handling measures, such as the use of personal protective equipment and adequate ventilation of workspaces. Also, the parts produced may require additional post-curing treatments to achieve their optimal mechanical properties, which adds complexity and additional time to the production process.

2.4 Direct Metal Laser Sintering (DMLS). Direct Metal Laser Sintering (DMLS) is an advanced 3D printing method for manufacturing high-performance metal parts, commonly used in industries such as aerospace, medical, and automotive.

The process involves the selective sintering of extremely fine metal powders, layer by layer, using a high-power laser that localizes and partially melts the material only in areas corresponding to the cross-section of the designed part.

This technology allows for the production of components with complex geometries that would be difficult or impossible to achieve using conventional machining methods such as casting or milling [5]. DMLS provides near-full material density, excellent mechanical characteristics, and a high degree of design freedom, making it ideal for manufacturing critical components where mechanical strength, high-temperature resistance, and dimensional accuracy are essential.

In addition, the technology allows the integration of multiple functionalities into a single part, thus reducing the total number of components and the complexity of mechanical assemblies, which brings significant benefits in terms of weight, reliability and maintenance costs of the final systems.

One of the most important features of DMLS technology is the ability to produce extremely complex metal parts, with fine details and tight dimensional tolerances, without the need to manufacture dedicated tools or molds [5]. DMLS also allows the creation of topologically optimized structures, thus reducing the weight of the parts without compromising mechanical strength. The resulting parts have a very high density, close to that of conventional cast or forged materials, which makes them suitable for safety-critical applications. Another great feature of this process is the drastic reduction in production time for prototypes or small series of components, compared to traditional manufacturing methods. In addition, the diversity of materials available for DMLS (aluminum alloys, titanium, stainless steel, nickel, etc.) significantly expands the area of applicability of this technology.

Despite all its obvious advantages, DMLS technology also has a number of limitations. The main disadvantage is the high costs associated with the purchase of printing equipment and the consumables used (special metal powders with strictly controlled characteristics) [5]. In addition, the sintering process requires controlled ambient conditions (such as inert nitrogen or argon atmosphere) to prevent oxidation of the materials, which implies additional investments in infrastructure. Also, most parts obtained by DMLS require post-processing operations, such as support removal, heat treatments, grinding or finishing machining to meet the strict requirements of industrial applications. The size limitations of the build volume and the relatively low manufacturing speed for large objects are other obstacles to the wide-scale adoption of DMLS in mass production.

3. FREQUENTLY USED MATERIALS IN 3D PRINTING

Materials used in 3D printing in the aerospace sector vary considerably, covering a wide range of properties and performances, from standard general-purpose polymers to advanced metal alloys specifically designed for critical applications. The choice of material is determined by factors such as mechanical strength requirements, specific weight, high temperature resistance, chemical compatibility, durability and production costs. Thermoplastic polymers, such as PLA, PETG and ABS, are often used for prototyping, non-structural parts and applications where low cost and ease of processing are a priority. On the other hand, in structural applications or in components intended for use in extreme environments, such as those found in aviation and space exploration, metallic materials such as AlSi10Mg or titanium alloys are preferred, due to their superior mechanical and thermal resistance characteristics [1][5].

The following Table 1 summarizes the main mechanical characteristics of some of the most commonly used materials in 3D printing for the aerospace industry, highlighting the typical ranges of yield strength, tensile strength, ultimate elongation and longitudinal modulus.

These data are essential in the selection process of the right material for the specific application, as they directly influence the structural performance and life cycle of the manufactured components.

Table 1. Mechanical properties of typical 3D printing materials [2][3][5]

Material	Yield Allowable Stress [MPa]	Failure Allowable Stress [MPa]	Maximal Elongation [%]	Longitudinal Elasticity Modulus E [GPa]
PLA	60-70	65-75	4-10	3.5-4.0
PETG	45-55	50-60	20-30	2.0-2.2
ABS	40-50	45-55	10-30	1.8-2.5
Nylon (PA12)	50-75	70-90	50-100	1.5-2.5
AlSi10Mg (DMLS)	230-350	270-310	3-5	70.0

Table 1 highlights the superior mechanical performance of metallic materials (e.g. AlSi10Mg), compared to polymer materials commonly used in FDM printing. Especially for drones, the weight/strength ratio becomes essential, making materials like Nylon or PETG extremely valuable due to their flexibility.

PLA (Polylactic Acid) is one of the most widely used materials in 3D printing due to its affordability and ease of use. Derived from renewable resources such as corn starch or sugarcane, PLA is biodegradable and emits fewer toxic particles during the printing process. Its mechanical properties, with a yield stress of 60–70 MPa and a tensile strength of 65–75 MPa, make it suitable for non-structural applications and lightweight components. However, PLA has low thermal resistance and high brittleness, limiting its use in conditions of mechanical stress or high temperatures [2].

PETG (Polyethylene Terephthalate Glycol-modified) represents an excellent compromise between durability, flexibility and ease of processing. It exhibits higher impact resistance and a maximum elongation of 20–30%, making it ideal for parts that require some flexibility without compromising strength. Higher printing temperatures compared to PLA, combined with good interlayer adhesion, make PETG a popular material in applications where superior mechanical strength and increased durability are required, such as drone housings or components exposed to moderate stress [3].

ABS (Acrylonitrile Butadiene Styrene) is a traditional material in the plastics processing industry, widely used in the manufacture of electronic housings, automotive parts and toys. In 3D printing, ABS offers a good combination of impact resistance and dimensional stability, with an allowable yield stress of 40–50 MPa and a tensile strength of 45–55 MPa. However, printing with ABS requires controlled ambient temperature conditions to prevent warping, and the emissions of ultrafine particles and VOCs during processing require the use of adequate ventilation systems [4].

Nylon (Polyamide), known for its strength and flexibility, is frequently used for functional components in the aerospace industry. With a tensile strength of 70 to 90 MPa and a maximum elongation of up to 100%, this material is ideal for parts that must withstand cyclic loads and repeated impacts. Nylon also has good chemical and abrasion resistance, but is sensitive to moisture absorption from the air, which can affect the printing performance and mechanical properties of the parts [3].

AlSi10Mg (Aluminum-Silicon-Magnesium Alloy) is a metal alloy widely used in 3D printing using direct laser sintering (DMLS) technologies due to its excellent weight-to-mechanical strength ratio. With a yield stress of 230–250 MPa and a tensile strength of 270–310 MPa, this material is suitable for the manufacture of demanding structural parts in the aerospace industry. In addition to its impressive mechanical properties, AlSi10Mg also offers good corrosion resistance, making it ideal for harsh environments or long-term exposure to atmospheric agents. Post-processing, such as heat treatments and mechanical finishing, is often required to optimize the final properties of the printed components [5].

4. PROCESS PARAMETERS FOR COMMON MATERIALS (FDM)

Processing conditions are critical to obtaining quality parts, especially in the industrial context, where precision and reliability are essential. In the aerospace field, especially in the manufacture of drone parts, where each component must meet strict performance and safety requirements, printing parameters play a fundamental role. Temperature, print speed, and cooling settings are just a few of the factors that can directly influence the success of a project.

The following table shows the temperatures required for the correct extrusion and printing of the main thermoplastic materials used in the FDM (Fused Deposition Modeling) process. These materials, such as ABS, PLA, PEEK or Nylon, are chosen according to the specific requirements of the parts to be manufactured. For example, materials such as PEEK, with high thermal resistance, are frequently used for drone components that are exposed to high temperatures or high mechanical loads, while ABS is preferred for components that require a combination of rigidity and low impact.

In addition, it is important that the printing temperature is precisely controlled to avoid part deformation or poor adhesion between material layers. Also, the extrusion speed and cooling conditions must be adjusted according to the material used to prevent the accumulation of internal stresses that could compromise the integrity of the final part. These fine adjustments are essential, especially when working with advanced materials used in the aerospace industry, which have strict requirements in terms of strength, durability and weight of parts.

In this context, choosing the right material and optimizing process parameters are essential to ensure the reliability of parts under the extreme operating conditions encountered in aeronautics, from exposure to strong vibrations to extreme temperature fluctuations that can occur during flight. In addition, surface quality and dimensional accuracy are essential to ensure the correct assembly of components, as well as to guarantee efficient operation and safe operations in the extreme environments in which drones are used.

The Table 2 below shows the essential processing parameters for 3D printing using FDM (Fused Deposition Modeling) technology. These parameters, including extrusion and printing temperatures for various thermoplastic materials, are critical for achieving high-quality components. In the context of the aerospace industry, they directly influence the performance of the manufactured parts, especially for drone applications, where reliability and precision are essential.

Table 2. Processing parameters for FDM printing [2][6]

Material	Nozzle Temperature (°C)	Print Bed Temperature (°C)	Recommended Ambient Temperature (°C)
PLA	190–220	0–60	>15
PETG	220–250	70–90	>20
ABS	230–260	90–110	>25 (closed case required)

Table 2 shows that ABS has stricter temperature requirements than PLA or PETG, and also requires a closed housing to prevent delamination of the layers. This technological requirement adds additional costs to the printing process.

5. EMISSIONS AND IMPACT ON HEALTH

During the 3D printing process, especially when thermoplastic materials such as ABS, PLA or PEEK are used, ultrafine particles and volatile organic compounds (VOCs) can be formed and released into the air. These emissions can be harmful to human health, especially in enclosed or poorly ventilated environments, and have been associated with respiratory irritation, adverse effects on the nervous system and, in extreme cases, risks of cancer or other chronic conditions.

Ultrafine particles are very small particles (typically less than 100 nanometers) that can penetrate deep into the lungs and enter the bloodstream, with the potential to cause lung inflammation and other respiratory problems. Volatile organic compounds (VOCs) include chemicals that can be released into the air as vapors or gases, and prolonged exposure to them can lead to symptoms such as headaches, dizziness, eye and skin irritation, and in severe cases, liver or kidney damage.

To reduce these risks, it is important that 3D printing processes are conducted in a well-ventilated environment and that users wear appropriate protective equipment, such as respirators. The use of safer materials or air filtration treatments can also help minimize exposure to these emissions. Comparative data on emissions from different types of materials used in 3D printing is presented in the following Table 3, providing a clear picture of the potential health impacts depending on the materials and processing conditions used.

Table 3. Emissions of particulate matter and volatile organic compounds from FDM printing [7]

Material	UFP emissions (particles/cm³)	VOC level (ppm)	Health risk
PLA	2×10^5	<0.1	Low
PETG	4×10^5	0.2	Medium
ABS	2×10^6	1.0	High

As shown in Table 3, ABS generates significantly higher levels of harmful emissions compared to PLA or PETG, requiring additional ventilation measures or the use of HEPA-filtered print booths.

6. APPLICATIONS IN THE AEROSPACE INDUSTRY AND AERIAL DRONES

In the aeronautics and drone industry, 3D printing / additive manufacturing has extensive applications, such as:

- manufacturing body components and aerodynamic elements for commercial drones: 3D printing allows the creation of lightweight and highly precise components, essential for the aerodynamic performance of commercial drones. Elements such as the fuselage, rotor arms and aerodynamic panels can be manufactured quickly and efficiently, reducing the costs and time required for the production of traditional parts. The materials used, such as carbon or metal alloys, allow for structures with low weight but high mechanical strength, contributing to greater autonomy of drones.
- making supports for sensors, actuators and transmission systems: Due to the diversity of materials available for 3D printing, it allows the creation of customized

supports for a wide range of sensors (e.g. GPS, video cameras, proximity sensors) and actuators. These supports must be precise, lightweight, and able to withstand the vibrations and environmental conditions specific to drone flights. 3D printing facilitates the rapid adaptation of the design of these supports according to the specific needs of each type of drone.

- building functional prototypes for testing ergonomics or aerodynamic performance: 3D printing plays a key role in rapid prototyping, allowing for the functional testing of new concepts and design improvements before mass production. Prototypes can be made from various materials that simulate the behavior of components in real flight conditions, providing rapid feedback on the ergonomics, user interfaces, stability, and aerodynamic performance of the drone. These prototypes are often essential for evaluating the performance of a design before it is implemented in series production.
- production of lightweight structural elements in experimental aircraft: 3D printing plays a significant role in the development and production of lightweight structural components for experimental aircraft, which are tested to evaluate new technologies and concepts in aviation. The manufacture of complex parts, such as beam structures or wing support elements, can be done quickly and precisely, significantly reducing the overall weight of the aircraft and thus increasing its efficiency and performance. 3D printing also allows the creation of shapes and geometries impossible to obtain using traditional methods, offering the possibility of structural optimization based on strength and performance analyses.

Companies such as Airbus and Boeing use DMLS to manufacture ultra-light, topologically optimized structural metal components to reduce aircraft weight and fuel consumption [5]. These companies benefit from DMLS's ability to produce complex parts with optimized geometry that cannot be achieved by traditional manufacturing methods. The parts manufactured in this way are significantly lighter, which contributes to reducing aircraft fuel consumption, thereby increasing operational efficiency. In parallel, for rapid prototyping and less demanding applications, materials such as PLA, PETG, and ABS are used for test components, housings, supports, and other non-structural parts. PLA is often used for initial prototypes due to its ease of printing and low cost, PETG is ideal for applications requiring impact resistance and flexibility, and ABS is used for parts requiring higher mechanical strength and stability at higher temperatures, often being preferred for prototypes that simulate real operating conditions in functional tests of drones and experimental aircraft.

7. COST COMPARISON BETWEEN CONVENTIONAL METHODS AND 3D PRINTING

Cost is a critical factor in the adoption of additive manufacturing technologies, especially in industries with high performance requirements, such as the aerospace and drone industries. Although 3D printing offers significant advantages in terms of rapid customization, design efficiency and reduced production times, initial costs can be a significant barrier to the widespread adoption of this technology. Compared to conventional manufacturing methods, 3D printing allows for a significant reduction in the number of manufacturing steps, but the costs of materials and equipment can be higher, depending on the complexity of the parts and the technologies used.

To better understand the impact of costs in the manufacturing process, it is essential to compare the expenses associated with producing a functional prototype using conventional methods and 3D printing.

This allows for a detailed assessment of the costs per unit and highlights the potential savings or challenges that may arise when deciding to use additive technologies, especially for medium-sized prototypes, which are commonly found in industries such as aerospace and drone development.

Table 4 compares the average costs for manufacturing a medium-sized functional prototype (1–2 kg) using conventional methods and 3D printing. This comparison provides a clear view of the costs involved in both processes, facilitating informed decisions regarding the most efficient production method for various applications.

Table 4. Average manufacturing costs for a medium-sized functional prototype [2],[6]

Manufacturing method	Setup Cost (€)	Material Cost (€)	Estimated Total Cost (€)	Delivery Time (weeks)
CNC Machining (Milling)	1000–1500	200–400	1200–1900	2-4
Rapid Casting	3000–5000	100–300	3100–5300	3-6
3D Printing FDM/SLS/DMLS	100–300	150–500	250–800	<1

3D printing dramatically reduces both initial production costs and lead times. In addition, the flexibility to modify designs without the need to create new molds provides an undeniable advantage in the rapid prototyping and testing phases.

8. FUTURE TRENDS IN 3D PRINTING FOR THE AEROSPACE AND DRONE INDUSTRY

Additive manufacturing technologies are in continuous evolution, and their future is shaped around major trends that promise to revolutionize the aerospace industry and beyond. These trends reflect the rapid advances in 3D printing technologies and the development of innovative materials and processes that will allow the creation of much higher-performance, lighter and more durable components. In this context, three key directions stand out: advanced materials, post-processing automation and 3D printing in zero gravity conditions.

8.1 Advanced Materials. A major direction of evolution in 3D printing is the development of advanced materials, essential for increasing the performance of manufactured components. New alloys and composites are optimized to cope with the extreme conditions in the aerospace industry, especially in terms of high temperatures and intense mechanical stresses.

- **Nickel-based superalloys.** These materials are essential for the production of components intended to operate in extreme temperature environments, such as aircraft turbines. Nickel-based superalloys are used for parts subjected to high temperatures and mechanical stress, with exceptional thermal stability. In combination with 3D printing, these superalloys can be modeled with high precision and topologically optimized, contributing to more efficient aircraft turbines with lower weight and improved performance [10].

- **Carbon fiber composites.** These materials are already used in many applications, but by using 3D printing, much more complex and lighter structures with superior performance can be created. Carbon fiber composites are particularly suitable for the production of ultra-light drones and small satellite structures such as CubeSats. These structures benefit from remarkable impact resistance, low weight and design flexibility that would not be possible with traditional manufacturing methods.

3D printing allows the creation of complex structures that help reduce the cost and production time of aeronautical and space components [11].

8.2 Processing Automation. Post-processing automation is another emerging direction in additive manufacturing, with a significant impact on the efficiency and accuracy of the production process. Post-processing steps, which include part cleaning, surface finishing, and quality inspection, can be automated to reduce manufacturing time and improve part quality consistency.

- Automated support cleaning. After printing 3D parts, it is sometimes necessary to remove supports used to support complex geometry during the manufacturing process. Automating this step can save time and reduce the risk of human error, providing a fast and accurate solution for the cleaning process, which is essential in obtaining high-quality final parts.

- Robotic surface finishing. Robotic surface finishing of 3D printed parts will allow for smooth and precise surfaces, preparing the parts for precision applications. These methods will include automated grinding and the application of high-quality finishes, thereby reducing the need for manual intervention and ensuring that manufactured parts meet the stringent standards of the aerospace industry.

- Automated part quality inspection using machine vision. Machine vision-based automated inspection technologies are already being used to monitor the quality of parts manufactured through 3D printing. These systems can detect minor defects, such as cracks or surface irregularities, providing a quick and accurate assessment of the quality of each part, which ensures high-precision production, essential in critical areas such as aeronautics and the drone industry [12].

8.3 3D Printing in Zero Gravity. Another promising area for additive manufacturing technologies is 3D printing in zero gravity, an area in which NASA and ESA (the European Space Agency) are investing significantly. 3D printing in zero gravity opens up enormous opportunities for the production of components directly in space, saving resources and reducing the need to transport materials and parts from Earth.

- Manufacturing spare parts directly on the International Space Station (ISS). 3D printing in space allows astronauts to produce spare parts directly in microgravity, which is essential for maintaining the functionality of the International Space Station. This can reduce the dependence on frequent transport of parts from Earth and ensure that astronauts have quick access to the necessary components in case of malfunctions.

- Building structural elements on the Moon or Mars using local resources. Another important goal is to use the resources available on the Moon or Mars to produce the structures needed to build bases or research stations on these celestial bodies. By using local materials and 3D printing technologies, space agencies can build essential structural elements for space exploration and colonization, reducing the need to transport materials from Earth and facilitating the construction of sustainable infrastructure in space [13].

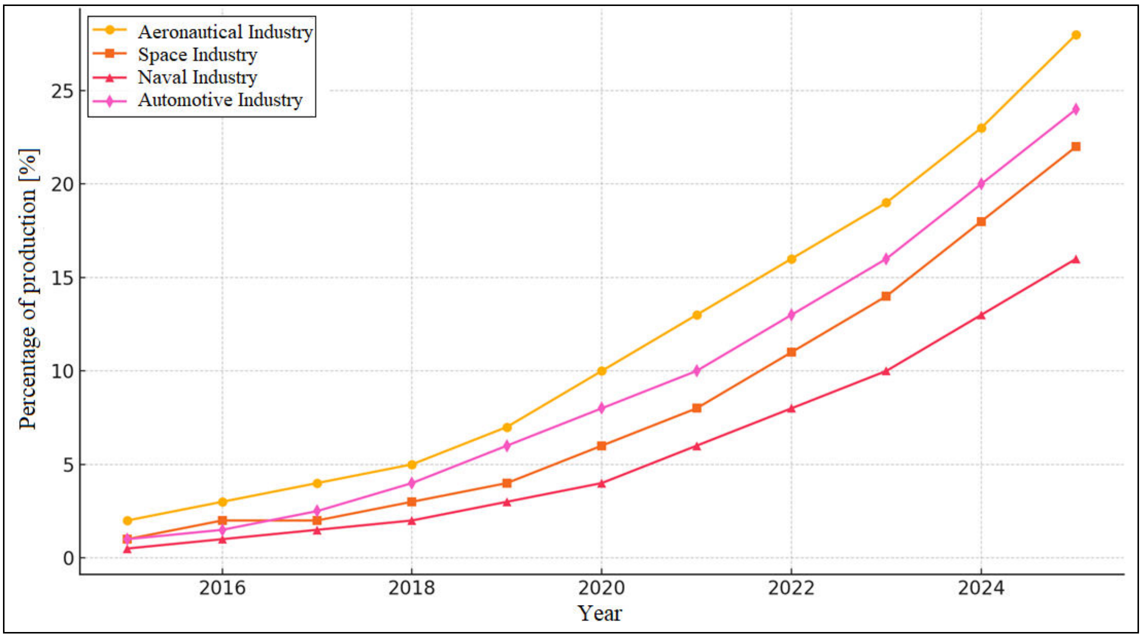
These trends point to a promising future for additive manufacturing, with innovative applications in the aerospace sector, but also in other fields, where 3D printing technologies will profoundly transform production processes, increasing efficiency, reducing costs and opening up new possibilities in the exploration and use of space resources.

3. THE EVOLUTION OF THE 3D PRINTING MARKET IN THE AEROSPACE FIELD

As technologies evolve, 3D printing is becoming more integrated into mass production processes, not just prototyping.

3D printing is expected to continue to grow in industries such as aerospace, automotive, marine and space. Innovations in composite materials, advanced metals and topology optimization software solutions will make these processes faster, cheaper and more sustainable.

The Fig. 1 chart illustrates the growth of 3D printing in global manufacturing for four industry sectors between 2015 and 2025, based on available data from [14].



* Year 2025 is estimated based on the trends.

FIG. 1 Evolution of the share of 3D printing in global industrial production (2015-2025)

This chart highlights the trends in the adoption of 3D printing technologies, with accelerated growth in the aerospace and space sectors, followed by the automotive industry. The marine industry is seeing slower adoption, but interest is growing, especially for on-demand spare parts and optimized structures.

CONCLUSIONS

3D printing has become an indispensable technology in the aerospace industry and in the development of modern drones. It allows: significant reduction of component weight, design freedom unmatched by traditional technologies, reduction of prototyping and small-scale production costs, creation of topologically optimized structures, impossible to achieve using classical methods.

By integrating advanced additive manufacturing technologies, aeronautical companies and drone manufacturers increase their competitiveness and contribute to the development of more sustainable solutions for the air transport of the future.

It is expected that, in the next 10–15 years, 3D printing will become the standard method for the production of customized aerospace components and for the in-situ fabrication of elements required for space missions.

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