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POSSIBILITIES OF USING 3D PRINTING TECHNOLOGY IN PRODUCTION OF AIRCRAFT COMPONENTS

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Abstract

The article provides the reader with a brief overview of the technology of industrial 3D printing used in the manufacturing process of aerospace technology. It includes analyses of the position of 3D printing in the aerospace industry and the forecast of its future development based on the marketing analysis of strengths / weaknesses, opportunities and threats. Many airlines and AMOs (Approved Maintenance Organizations) rely on externally supplied spare parts delivered over long distances. The whole process is expensive and time consuming and means a lost profit for the company. The performed SWOT analysis can therefore ultimately help the AMO manager to re-evaluate their production process in the light of the current innovative and progressive technology of industrial 3D printing.The aim of this work is to point out the existence of innovative 3D printing technology in aerospace production and to emphasize its preferences compared to conventional manufacturing techniques and procedures, thus providing a final perspective on the future of the 3D printing industry and its long-term sustainability

Keywords

3D printing, additive manufacturing, fly to by ratio, AMO

1. Introduction

Competitiveness is the driving force behind industrial innovation and technological advances, leading to more efficient production methods that take into account aspects of the ecological footprint, the urgency of timely production and savings achievement (Pecho et al., 2019). 3D printing meets all these criteria in its entirety, which is why it has found application in many areas of industry. 3D printing, often referred to as "additive manufacturing" (AM), has become, in addition to the medical industry, an integral part of the production processes of the automotive industry, architecture, marketing, food industry and the arts. However, the most obvious progress has undoubtedly brough to the world of aviation and space research. With increasing safety and performance requirements and requirements for air transport in general, there is a need to replace conventional technological practices and create new technology that will provide a comprehensive solution to environmental, technical and financial shortcomings. 3D printing by reducing aircraft weight, increasing the level of adaptation and overall construction efficiency poses new challenges for the further potential development of air transport (Kloski & Kloski, 2017).

2. 3D printing technology

The term "3D printing" as we know it today has a very deep history, dating back to the 1980s. 3D printing can be defined as "*the production process by which three-dimensional (3D) solid objects are created. It allows you to create physical 3D models of objects using a series of additive or layered support structures, where the layers are sequentially arranged to create a complete 3D object.*" (Kloski & Kloski, 2017). Each printed object is based on a 3D model (template) stored on the user's computer. Using the printer software, the model is imaginarily cut into hundreds to thousands of thin 2D layers and later transformed into a set of printer instructions. The whole production is an additive process. In practice, this means that the resulting product is created by precise application of individual layers of material on top of each other, which transfers from the 2D plane to 3D space (3D Printing.com).

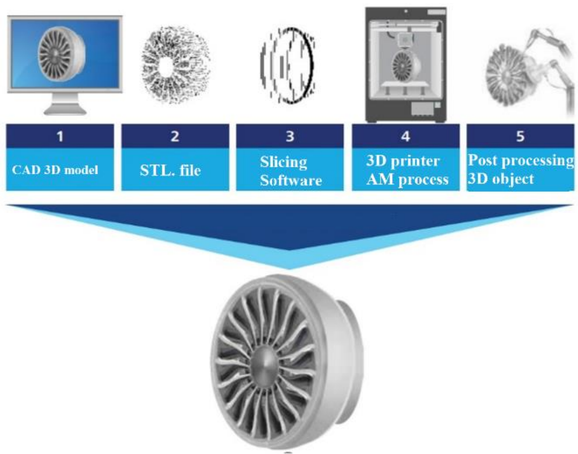

Figure 1: Principle of 3D printing technology. Source: COYKENDALL, (2014) edited by Authors.

3. SWOT analysis of industrial 3D printing technology applied for the aerospace engineering manufacturing purposes

The aim of the SWOT analysis is to evaluate the current state and future development of the researched object. In order to illustrate the position of 3D printing technology on the market following tables are used:

Table 1: Schematic representation of the strengths and weaknesses of 3D printing in aviation, as well as its opportunities and threats. Source: Authors.

Strengths	**Weaknesses**
• component weight reduction • production of spare parts • improved development cycles • design consolidation • reducing costs and buy-to-fly ratios • ecological aspect of production	• expensive technology • the need for a skilled workforce • small production volume • limited dimensions of printed products • rising unemployment
Opportunities	**Threats**
• long-term reduction of the share of air transport in CO_2 production • increasing level of air transport safety • cost reduction • 4D print	• demonstrable negative impact on human health • the arrival of new competitive technology on the market

3.1. Analysis of Strengths

3.1.1. Component weight reduction

Weight is one of the most important indicators in the aviation industry (Table 2) because, lighterequals cheaper and in connection with air transport especially. 3D printing of aircraft components with more efficient geometry, grid structure or topological optimization undoubtedly helps to reduce the weight of parts. An ideal and at the same time groundbreaking example of reducing the weight of an aircraft component is the hinge of the engine nacelle, whose purpose is to hold the engine cover when it is opened.

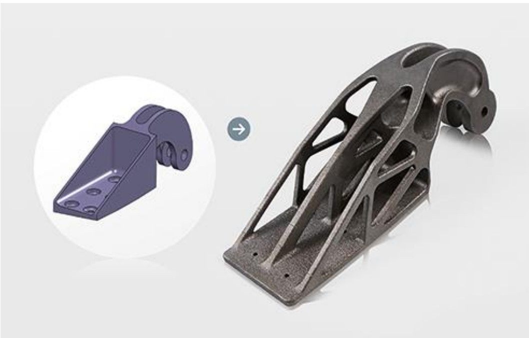

Figure 2: Demonstration of the original component and its current design. Source: TCT Magazine (2014).

By adding a 3D printing factor to the production of this component, it significantly reduced the proportion of waste from secondary machining, thus reducing titanium consumption by 25% (Iljaszewicz et al., 2021). The overall weight of the components was reduced by 35-55%, thus reducing the weight of the aircraft by approximately 10 kg. Ultimately, removing only 1kg of each aircraft with a capacity of 600+ could save up to 90,000 litres of fuel per year and prevent the release of up to 230 tons of CO_2 into the atmosphere (Leandri, 2015).

3.1.2. Production of spare parts

In the process of maintenance of aircraft, it is very important to ensure the availability of spare parts in order to minimize time lost in maintenance time, because whenever the aircraft does not fly, it loses money. It is crucial for airlines in the maintenance area to reduce the delivery time of spare components. By incorporating additive manufacturing into the work process, it is possible to rapidly reduce stock quantities and produce smaller volumes on request with a catalogue of parts that have been designed for the additive manufacturing process.(LENDRI, 2015) The Royal Netherlands Air Force is a perfect example. Its fleet includes various types of helicopters, fighters and cargo planes (Apaches to NH90s and F16s). These machines have a large number of unique parts that are not easy to work with. The Royal Netherlands Air Force therefore began printing its own tools on 3D printers. For example, when transporting jet engines, some openings need to be covered with special covers. Procurement of these parts is expensive and has long delivery times. In contrast, printing them on the Ultimaker 3D printer takes only about two hours (Additive- X, n.d.).

3.1.3. Improved development cycles

One of the many benefits of 3D printing is based on eliminating unnecessary assembly steps. It enables faster prototyping, conceptual design without additional tools, and provides rapid testing methods (Bugaj et al., 2019).

3.1.4. Design Consolidation

The benefit is to eliminate the need to join or assemble several parts of a given component together by welding or in any other way that potentially reduces reliability and durability (Galieriková et al., 2018). It is possible to produce complex spare parts using additive production technology.

3.1.5. Reducing costs and buy-to-fly ratios

Very expensive or hard-to-reach materials, such as titanium (Ti6Al4V) or Inconel 718 superalloy, are mostly used for the production of aircraft, and therefore their efficient use is important. The Buy-to-Fly indicator is an indicator of the efficient use of materials. *„The buy-to-fly ratio refers to the weight of the raw material purchased, compared to the weight of the final part."(Materialise).* At present, this indicator averages around 10:1. Involving the 3D printing technology as a production process, airlines have a high probability of achieving the ideal value of this parameter of 1:1, which means 100% efficient use of working material. Minimizing the weight of the raw material needed to produce a particular component, regardless of industry or application, will always have a positive impact on cost savings. The less a company needs to buy in order to produce a particular part, the higher the potential profit.

3.1.6. Ecological aspect of production

3D printing is becoming more environmentally friendly production compared to traditional production processes. Through the implementation of 3D printing technology into the production and maintenance processes of airlines, the share of air transport in CO_2 production is indirectly reduced.

Table 2: Assessment of identified strengths. Source: Authors.

	Efficiency <1-5>	Weight (0-1)	Calculated Value	Maximal value
Component weight reduction	5	0,2	1	1
Production of spare parts	4	0,10	0,4	0,5
Improved development cycles	4	0,10	0,4	0,5
Design consolidation	5	0,2	1	1
Reducing costs and buy-to-fly ratios	5	0,2	1	1
Ecological aspect of production	5	0,2	1	1
SUM	**-**	**1,00**	**4,8**	**5**

3.2. Analysis of Weaknesses

3.2.1. Expensive technology

The implementation of additive manufacturing as a production technology in connection with aircraft maintenance requires a certain financial initial investment. Smaller companies can't afford 3D printers for metal alloys. They thus rely on traditional production methods and technologies.

3.2.2. The need for a skilled workforce

This is not a shortcoming of 3D printing itself, but the fact that every 3D printing is preceded by 3D modelling. IT technology is an integral part of 3D printing, as all printed products are in fact materialized digital designs created using modeling software. The 3D printer will not be able to handle the wrong 3D model and will print it incorrectly. This wastes material, energy, time and money. At best, it doesn't even print such a model. Therefore, the models must always be thoroughly checked, or their control or the entire modeling left to professionals. Behind each component is a dedicated team of engineers and technicians and that is why skilled workforce is really necessary (Table 3).

3.2.3. Small production volume and limited dimensions of printed products

Depending on the quality and size of the printers as well as the material and printing technology that used, printing can take several hours or even days to process. In the case of electron beam printers (EBM), the printing process itself takes place in vacuum chambers. To some extent, such a size of the printed product is limited. For larger models, which the 3D printer is not able to print in one piece, it is necessary to print divided parts of the whole one by one and then join them.

3.2.4. Rising unemployment

Any application of automation, innovative technology means an increased unemployment rate. The machine replaces the human factor and replaces several original jobs. The structure of the economy is thus changing with changes in labour demand due to the introduction of new machines, time-saving technology and improved production methods.

Table 3: Assessment of identified weaknesses. Source: Authors.

	Efficiency <1-5>	Weight (0-1)	Calculated Value	Maximal value
Expensive technology	5	0,55	2,75	2,75
The need for a skilled workforce	3	0,1	0,3	0,5
Small production volume and limited dimensions of printed products	4	0,20	0,8	1
Rising unemployment	0	0,15	0	0,75
SUM	**-**	**1,00**	**3,85**	**5**

3.3. Analysis of Opportunities

The opportunities of additive production technology in air transport consist of the persistence of the achieved positive results of 3D printing as a production process, with the assumption of further progress. The high potential of 3D printing can be expected in a term of long-term CO_2 reduction due to aviation operations and increasing aviation safety (Tab 4). However, the ambition of 3D printing goes much further. The primary goal remains to rapidly reduce the costs related to the material and energy security of the printing process. The absolute culmination of 3D printing in the aviation industry is the premise of the application of 4D printing, which, compared to its predecessor, is supplemented by the so-called smart materials. These are capable of changes or other properties that are triggered by an external energy source such as a change in temperature, humidity or pressure. The 4D printing technology could also be used in the military aviation or space sector.

Table 4: Assessment of identified opportunities. Source: Authors.

	Efficiency <1-5>	Weight (0-1)	Calculated Value	Maximal value
Long-term reduction of the share of air transport in CO_2 production	5	0,3	1,5	1,5
Increasing level of air transport safety	4	0,3	1,2	1,5
Cost reduction	3	0,25	0,75	1,25
4D printing	5	0,15	0,75	0,75
SUM	**-**	**1,00**	**4,2**	**5**

4. Analysis of Threats

The only factors that can theoretically endanger the high position of 3D technology in the aerospace industry are the findings of a negative effect on the health of workers who are physically involved in the printing process. So far, no negative effects of this technology on the health impact of the workers involved have been demonstrated. The only risk of 3D printing is the arrival of competitive technology on the market. In the foreseeable future, however, the only hypothetical competitor is the 4D printing technology (Table 5). It is basically just an improved modification of 3D printing, and therefore cannot be understood as its direct threat.

Table 5: Assessment of identified threats. Source: Authors.

	Efficiency <1-5>	Weight (0-1)	Calculated Value	Maximal value
Demonstrable negative impact on human health	1	0,7	0,7	3.5
The arrival of new competitive technology on the market	0	0,3	0	1,5
SUM	-	**1,00**	**0,7**	**5**

5. Evaluation of the SWOT analysis

$$\sum S - \sum W = 4,8 - 3,85 = 0,95 \quad (1)$$

$$\sum O - \sum T = 4,2 - 0,7 = 3,5 \quad (2)$$

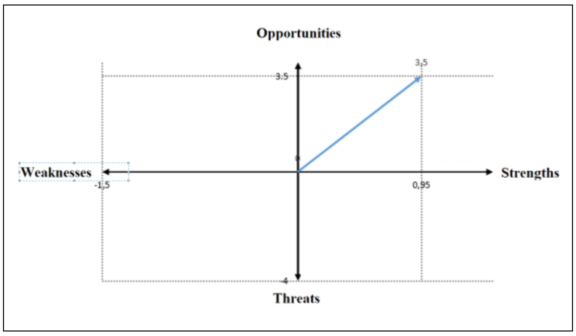

Figure 3: The result of the SWOT analysis. Source: Authors.

The result of the SWOT analysis (Figure 3) placed 3D printing technology in aviation in the quarter of the offensive strategy, which means that the technology makes sufficient use of its strengths and also has a high potential for development and further wider application in the aviation industry (Figure 4). 3D printing as such has an ideal position to become the number one choice, whether in the field of production or maintenance services of airlines.

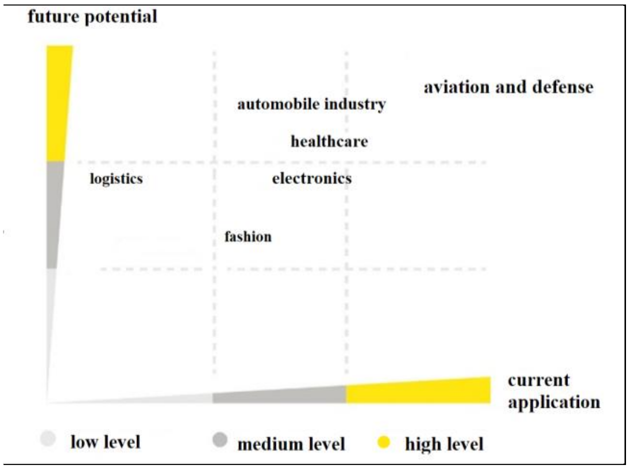

Figure 4: Current application and potential of 3D printing in industry. Source: Authors.

6. Expected future appearance of space industry involving 3D printing technology

It is aeronautics and space research that have become the driving force behind the development of 3D printing technology, which has taken on a new dimension in the possibilities of worldwide travel and space research. Over the next few years (forecast time interval 2020-2026) it is estimated that 3D printing in the aerospace and defense (military) market will register an annual compound growth rate of more than 20% (Figure 4). The Compound Annual Growth Rate (CAGR) is an indicator that describes the rate at which an investment would grow if it grew at the same rate each year and the profit reinvested at the end of each year. A key aspect of the rapid growth of industrial aviation 3D printing is the additional permission of the Federal Aviation Administration (FAA) as well as the European Aviation Safety Agency (EASA) to use more 3D printed parts for commercial jet airliners. The largest increase is projected for the North American region, as can be seen in the forecast below (Figure 5) (Mordorintelligence.com, n.d.).

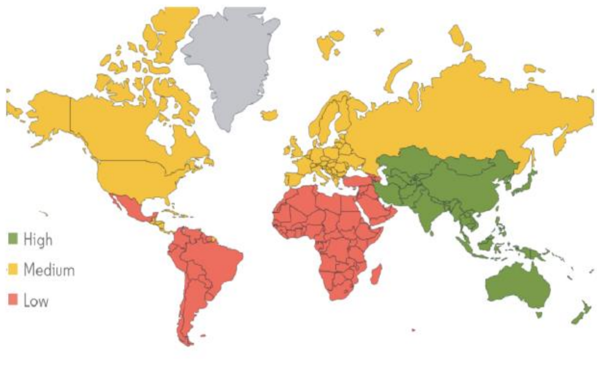

Figure 5: 3D printing in Aerospace and defence Market (2020-2025). Source: Mordorintelligence.com.

The increase in this area is largely due to the companies that operate in this area and have a dominant position in the market. These are companies such as GE (General Electric), Pratt & Whitney or Boeing Company, which clearly excel not only in the activity of additive manufacturing but also its necessary equipment (Figure 5).

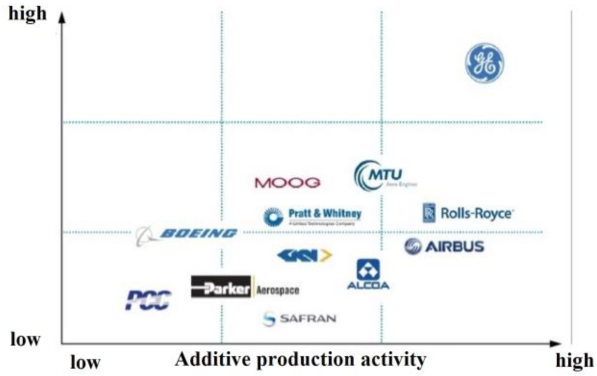

Figure 6: Activity map of selected companies. Source: Langerfeld (2013).

Many airlines and AMO (Approved maintenance organisations) s rely on externally supplied spare parts imported over long distances. The whole process is expensive, time consuming and represents a lost profit for the company. With 3D printing, it is easy to manufacture some parts saving time and money. The prices of 3D printers are falling and will continue to fall due to the greater number of companies using this technology, so a rapid decline in "outsourced" products can be expected. Areas where 3D printing should grow more progressively should be unmanned aerial vehicles (Figure 6) and experimental aircraft, as they require a lower degree of regulatory control.

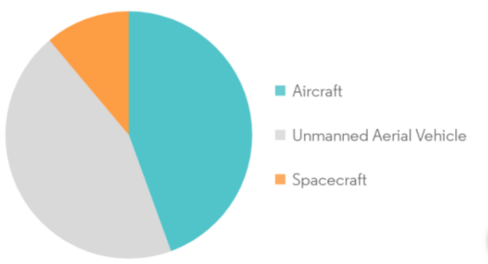

Figure 7: 3D printing in Aerospace by application in aircraft, UAV, and spacecraft segment. Source: Mordorintelligence.com.

7. Conclusion

Based on the performed SWOT analysis and subsequent analysis of statistics related to the integration of additive production as part of the production process in aviation industry, it can be concluded that the current position of AM is more than favourable. For its benefits, it is currently an unquestionably unrivalled method of aircraft production and maintenance. It provides flexibility in creating aircraft components of very complex geometries that are sometimes impossible to create by conventional technology processes. AM rapidly reduces the weight of components, while in no way degrading the mechanical properties of the material and maintaining the level of safety in full. From an ecological point of view, the post-processing process generates a minimum amount of waste, which is to some extent reusable in selected AM technologies. These are usually cases of powder-based systems where unconsumed powder can be used repeatedly.

To translate the position of additive manufacturing into the language of numbers, the values clearly speak in favour of 3D printing as the most efficient technological choice of production (average values): total cost savings in the range of 30-50%, maximum waste after post-processing 10%, time saving up to 64%, component weight reduction 30-65%. However, the most important indicator of all the above is the buy-to-fly ratio, which reached an incredible 1:1.

The statistics and analyses clearly identify AM as a leader in aerospace technology, and the position is expected to be as positive in the next 5 years. Despite the fact that the expected progress in North America is more pronounced due to the geographical situation of the leaders of the aviation industry, Europe will not remain stagnant. The growing use of AM in the maintenance may also lead to some degree of economic progression. However, many AM and aerospace experts agree that real and full use of the potential of 3D printing, which can add another dimension to the world, is still ahead of us.

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References

3D Printing.com. n.d. What is 3D Printing?. [online] Available at: <https://3dprinting.com/what-is-3d-printing/> [Accessed 6 September 2021].

Additive- X. n.d. 3D Printing Aircraft Tools, Fixtures, and Prototypes with Royal Netherlands Air Force and Ultimaker. [online] Available at: <https://www.additive-x.com/blog/3d-printing-aircraft-tools-fixtures-and-prototypes-with-royal-netherlands-air-force-and-ultimaker/> [Accessed 9 October 2021].

Bugaj, M., Urminský, T., Rostáš, J., Pecho, P. 2019. Aircraft maintenance reserves - New approach to optimization. Transportation Research Procedia, 2019, 43, pp. 31–40.

Coykendall, J, 2014. 3D opportunity for aerospace and defense. [online] Deloitte Insights. Available at: <https://www2.deloitte.com/us/en/insights/focus/3d-opportunity/additive-manufacturing-3d-opportunity-in-aerospace.html> [Accessed 12 September 2021].

Galierikova, A., Materna, M., Sosedova, J. 2018. Analysis of risks in aviation. Transport Means - Proceedings of the International Conference, 2018, 2018-October, pp. 1427–1431.

Iljaszewicz, P., Lusiak, T., Pastuszak, A., Novak, A. 2020. Aerodynamic analysis of the aircraft model made with the 3D printing method. Transportation Research Procedia, 2020, 51, pp. 118–133.

Kloski, L. - kloski, N. 2017. Začínáme s 3D tiskem. 1. vyd. Brno: Computer Press, 2017. s. 216. ISBN 978-80-251-4876-1

Langefeld, B. 2013. Additive Manufacturing. Roland Berger (2013) [online]. Available at: <https://www.rolandberger.com/de/Publications/Addi

tive-Manufacturing.html> [Accessed 3 September 2021].

Leandri, A. 2015. 7 3D Printing Pluses for Aerospace - 3D Printing Industry. [online] 3D Printing Industry. Available at: <https://3dprintingindustry.com/news/7-key-improvements-3d-printing-brings-to-the-aerospace-industry-49823/> [Accessed 7 September 2021].

Materialise. n.d. Whitepaper: Buy-to-Fly Ratio, Cutting Costs with Metal 3D Printing. [online] Available at: <https://www.materialise.com/en/manufacturing/whitepaper-buy-to-fly-ratio-cutting-costs-metal-3d-printing> [Accessed 12 September 2021].

Mordorintelligence.com n.d. 3D Printing in Aerospace and Defense Market | 2021 - 26 | Industry Share, Size, Growth - Mordor Intelligence. [online] Available at: <https://www.mordorintelligence.com/industry-reports/3d-printing-in-aerospace-and-defense-market> [Accessed 3 September 2021].

Pecho, P., Ažaltovič, V., Kandera, B., Bugaj, M. 2019. Introduction study of design and layout of UAVs 3D printed wings in relation to optimal lightweight and load distribution. Transportation Research Procedia, 2019, 40, pp. 861–868.

TCT Magazine. 2014. EOS and Airbus Group Innovations join forces on study for 3D printing in aerospace. [online] Available at: <https://www.tctmagazine.com/additive-manufacturing-3d-printing-news/eos-and-airbus-group-innovations-join-forces-on-study-for-3d/> [Accessed 1 September 2021].