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Review on Additive Manufacturing Process in Aircraft Industries

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Abstract: This paper explores the feasibility of implementing 3D printing technology for manufacturing seat buckles in the Airbus A380. While additive manufacturing has gained attention for its versatility, safety-critical components require rigorous testing and certification. Through a comprehensive review of literature and expert interviews, this study analyzes the viability of 3D printing for seat buckle production. The results indicate that traditional manufacturing methods, such as injection molding and forging, remain the preferred choices due to their established reliability and quality control procedures. The aviation industry places the utmost importance on safety and reliability, especially in the manufacturing of safety-critical components like seat buckles. This paper examines the potential integration of 3D printing technology into the production process of seat buckles for the Airbus A380, considering the stringent certification requirements and performance expectations. A literature review encompassing additive manufacturing techniques, aerospace certification processes, and current seat buckle manufacturing practices was conducted. Expert interviews were also conducted to gather insights from industry professionals with expertise in aerospace manufacturing. The analysis revealed that conventional manufacturing methods such as injection molding and forging are currently preferred for seat buckle production in the Airbus A380 and other aircraft parts. These methods have established reliability and quality control procedures, ensuring compliance with rigorous safety standards. Although 3D printing has found success in prototyping and non-critical components, its application in safety-critical components like seat buckles is limited. The decision to favor traditional manufacturing methods for seat buckle production in the Airbus A380 is driven by the need for extensively tested and certified components. Safety-critical parts undergo stringent testing to guarantee their performance under various operating conditions. While 3D printing offers design flexibility and reduced lead times, further research and development is necessary to ensure its viability in safety-critical applications. At present, 3D printing technology is not widely employed for manufacturing seat buckles in the Airbus A380. Traditional methods provide the required reliability and quality control procedures. However, ongoing advancements in additive manufacturing may present future opportunities for incorporating 3D printing technology into safety-critical applications within the aerospace industry. Further research and development are necessary to explore these possibilities.

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1. Introduction

With additive manufacturing, a component is built up in stages by material deposition using digital 3D design data. The use of this method is expanding in the aerospace manufacturing industry because of developments in 3D printing, which provides products made of many materials, including metals, polymers, and composites. Waste from raw materials could be significantly reduced thanks to the growing popularity of 3D printing. So, to lower the cost of ownership, cut labor costs, and boost operational availability for airplanes, additive manufacturing is being adopted. This could have a significant impact on the supply chain. When offering maintenance packages to airline operators to generate aftermarket revenue, manufacturers of aircraft and parts also occasionally serve as service providers **[4]**.

2. Additive Manufacturing Process in Aircraft Industry

The aviation sector extensively utilizes additive manufacturing across a spectrum of applications, ranging from the fabrication of simple items such as seat belt buckles to the intricate production of engine components. Additive manufacturing not only overcomes the limitations of conventional manufacturing techniques but is also considered cost-effective. Moreover, it stands out as the preferred option for facilitating rapid design iterations and modifications to interior aircraft parts. Original Equipment Manufacturers (OEMs), comprising prominent entities like Boeing, Airbus, GE Aviation, Lockheed Martin, BAE Systems, and Rolls-Royce Holdings, play pivotal roles as sellers in the aircraft industry. These entities oversee the production of aircraft and associated parts. Conversely, Maintenance, Repair, and Overhaul (MRO) companies function as service providers within the aviation sector. The clientele of this industry spans commercial airline operators and military agencies, both of which rely on OEMs and MROs to ensure the operational efficiency and safety of their aircraft fleets **[2]**.

3. Analysis of Price

The SAVING project, focused on aircraft optimization, has demonstrated the feasibility of redesigning seat buckles for additive manufacturing, potentially reducing weight by 55%. It is estimated that implementing optimized designs for all seat buckles on the Airbus A380 could lead to a total weight reduction of 73 kg, translating to approximately 3.3 million liters of fuel savings over the aircraft's operational lifespan. In the commercial aviation context, every kilogram of weight reduction corresponds to approximately US$ 3000 in fuel savings annually, accompanied by a proportional decrease in carbon emissions **[3]**.

Identification of components amenable to modification and fabrication via additive manufacturing suggests a potential 6.4% decrease in fuel consumption. The significance of weight reduction is underscored by findings indicating that every 100 kg of weight loss over a 30-year service life equates to fuel savings ranging from 13.4 to 20.0 TJ. Notably, NASA's assessment indicates a 4.9% reduction in fuel consumption and an 8.3% decrease in NOx emissions with additive manufacturing adoption. These improvements are driven by material selection and geometrical optimization, areas where conventional manufacturing techniques often face limitations in achieving intricate geometries.

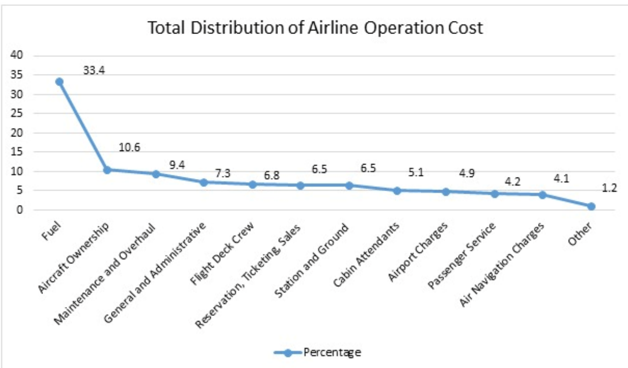

Figure-1 Telemetry Data Preprocessing and Feature Extraction [3]

In Fig. 1, depicting airline operational costs, fuel consumption emerges as the primary cost component, accounting for 33.4% of operational expenses. Aircraft ownership follows at 10.6%, significantly lower than fuel costs. Considering the energy-intensive processes associated with fuel, including extraction, processing, distribution, and storage, reducing fuel prices would directly impact travel affordability. For instance, a commercial fleet exceeding 600 aircraft could save approximately 11,000 gallons of fuel annually by reducing weight by one pound.

Furthermore, weight reduction yields tangible environmental benefits, with each kilogram shed resulting in reduced carbon emissions. For aircraft like the Boeing 747-400 and Airbus A330-300, a 1 kg weight reduction correlates with reductions of 0.94 kg and 0.475 kg of carbon emissions, respectively. Additionally, every kilogram of carbon emissions reduced saves up to 0.3 kg of aviation fuel. Boeing's research demonstrates that fuel efficiency improvements, driven by weight reduction, enable aircraft like the Boeing 777-300 to outperform counterparts like the Boeing 767-300, with added benefits of increased passenger capacity.

4. Seat Buckles in AIRBUS 380

Figure-2 Seat Buckle Manufactured through 3D Printing [3]

Another study discovered that by simply redesigning the seat belts on the Airbus A380, weight could be decreased by 55% within the scope of the SAVING project, an initiative spearheaded by Airbus. Should all 853 seat belts of the Airbus A380 be fabricated using additive manufacturing techniques, an approximate weight reduction of 72.5 kg could be realized. Project SAVING aims to achieve a total of "3.3 million liters of fuel savings" over the operational lifespan of the Airbus A380 **[5, 11]**.

5. Rapid Tooling and Repairing

The utilization of additive manufacturing techniques for the fabrication of quick tooling applications, such as jigs, fixtures, mandrels, surrogates, dies, and molds, within the aerospace sector, presents significant opportunities. These tools typically undergo functional testing rather than the more rigorous qualification and certification processes associated with flight components. Moreover, due to the low quantities required, particularly in the aircraft industry, low-volume additive manufacturing production of tools proves to be cost-effective. Both Airbus and Boeing incorporate quick tooling into their manufacturing processes, with expandable plastic tools being particularly suitable for applications where single-use tools suffice, thus enhancing ergonomic benefits with their lighter weight **[5-6]**.

Another area of advancement lies in the creation of master molds or patterns for investment casting, capable of generating intricate geometries for patterns, dies, and molds. The rapid casting process, especially when paired with investment casting utilizing sacrificial and single-use patterns, holds promise for small-batch production, offering significant benefits for aviation maintenance and manufacturing operations, where rapid turnaround times are essential.

Studies exemplify the swift design and manufacture of tools through rapid tooling approaches, resulting in reduced overall manufacturing lead times. For instance, Rokicki et al. employed computer-aided design and quick tooling techniques to fabricate an aircraft turbine blade with internal cooling channels, demonstrating the potential of additive manufacturing in producing complex components efficiently. Similarly, Wu et al. explored hollow turbine blade production using investment casting and stereolithography resin patterns, showcasing the feasibility of utilizing additive manufacturing for turbine blade fabrication **[6-8]**.

Additionally, Fette et al. utilized selective laser melting to produce metal molds with conformal heating channels for the rapid production of fiber-reinforced plastic (FRP) aircraft components, highlighting the enhanced design freedom and shortened production lead times afforded by additive manufacturing. The application of large area maskless photopolymerization technique by Das et al. resulted in ceramic molds with internal cores for casting equiaxed and single crystal aerofoils, further illustrating the time and cost savings achievable through additive manufacturing.

In the realm of aircraft Maintenance, Repair, and Overhaul (MRO), the sporadic need for small quantities of standard parts presents challenges. However, additive manufacturing offers a solution by enabling MROs to produce or repair parts on demand. Studies have demonstrated significant cost and time savings in MRO operations through the utilization of additive manufacturing techniques. For example, Franuhofer ILT successfully repaired Inconel 718 turbine casing and compressor seal using laser metal deposition (LMD) and selective laser melting (SLM), with subsequent certification from Rolls-Royce Deutschland. Notably, Rolls-Royce estimates that additive manufacturing can reduce production time by 30% **[6-9]**.

Various innovations, such as hybrid manufacturing methods for repairing dies and cores, geometrically adaptive toolpath laser processing for accurate repairs, and direct laser deposition for turbine blade repairs, further underscore the viability and potential of additive manufacturing in aviation MRO operations. These advancements not only enhance mechanical and material characteristics but also contribute to significant energy and carbon savings, reflecting the growing interest and adoption of additive manufacturing in the aviation industry..

6. Buy-To-Fly Ratio

In the aerospace industry, the term "buy-to-fly ratio" denotes the disparity in weight between the final product of a component and its original raw material. Conventional manufacturing techniques typically yield buy-to-fly ratios ranging from 15 to 20. According to ICF International, the global annual total material consumption in the aircraft sector, encompassing both manufacturing and maintenance, exceeded 680,000 tons in 2014 alone, with a consistent upward trend.

Given the exorbitant cost of aerospace materials, aviation industries face persistent pressure to minimize waste and adopt near-net shaping techniques. Additive manufacturing (AM) emerges as a compelling solution, boasting buy-to-fly ratios as low as 1:1. For instance, in the case of the Lockheed Martin engine bleed air leak detector bracket, produced using electron beam melting method, the buy-to-fly ratio is reduced to 1:1, compared to the 33:1 ratio achievable through traditional methods. This reduction translates to a remarkable 50% savings in the cost of the titanium alloy **[9, 11]**.

7. Discussions

In summary, the pivotal attributes of additive manufacturing, including design flexibility, part integration, enhanced material utilization, customization, shortened lead times for small-batch production, and notably, improved supply chain structures, address the core concerns and challenges within the aircraft industry. Major aircraft Original Equipment Manufacturers (OEMs) are now acknowledging the potential of these new technologies and incorporating them into various stages of the aircraft production process.

However, the reproducibility, anisotropy, and relative immaturity of additive manufacturing (AM) technologies present inherent challenges. Surface finish, a critical factor impacting fatigue life, stands out as a major concern. Additionally, limitations on build size further impede the widespread adoption of this technology. These and other factors complicate the certification process for parts manufactured using additive manufacturing techniques, posing obstacles for aviation authorities.

8. Conclusion

This study underscores the paramount importance of weight reduction initiatives within the aviation sector. By leveraging additive manufacturing (AM) techniques, significant weight reductions can be achieved in aircraft production. Given its ability to fabricate lighter components with commensurate mechanical properties at reduced costs compared to traditional machining methods, additive manufacturing proves to be an optimal solution for the aviation industry. As demand for air travel escalates, the aviation industry faces heightened competition. Embracing additive manufacturing technologies offers a strategic advantage by enabling weight reduction in aircraft, consequently diminishing fuel consumption and reducing carbon emissions. With the undeniable benefits afforded by additive manufacturing processes, the prevalence of such components within the aviation sector is poised to increase substantially.

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10. Biography

Subalakshmi V, a standout student in the Electrical and Electronics Engineering Department at Kumaraguru College of Technology, she is renowned for her prowess in aerospace engineering. Her research interests lie at the intersection of these fields, focusing on advancing techniques and applications in both Additive Manufacturing and Power Electronics. Her dedication to academic excellence has been recognized through prestigious awards, including the Mahatma Gandhi Scholarship, which she received consecutively for two years from her institution. With a passion for research and a drive for excellence, she continues to contribute significantly to the advancement of Electrical and Electronics Engineering, making her a valuable asset to the academic and professional community. Additionally, as an active member of the Events and Management team in SEDS-KCT, she showcases her leadership skills and commitment to innovation.

Vasanth S, a student from the Electrical and Electronics Engineering Department at Kumaraguru College of Technology, Coimbatore, he developed a keen interest in space and science, leading him to pursue aerospace engineering. His research focused on recent technologies for essential safety equipment using additive manufacturing, resulting in a paper titled "Review on Additive Manufacturing Process in Aircraft Industries."As a recipient of the Mahatma Gandhi Merit Scholarship for the academic year 2021-2022, he has consistently excelled in academics. Additionally, he actively contributes as a member of the SEDS Kumaraguru club, specifically as part of the media team. His areas of expertise include Power Systems and Electrical Machines, and he aspires to create socio-impactful products that promote green energy and contribute to societal well-being.

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12. Conflict of Interest and Funding

The author declare no competing conflict of interest, and no external funding was received to support this study.