Research Article

The Certification Steps for the Additively Manufactured Aviation-Grade Parts

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Abstract

The use of additive manufacturing (AM) has a lot of potential for manufacturing geometrically challenging parts, components, and even assemblies. To ensure the effective adoption of additive manufacturing by the aviation industry and to expedite the standardization process, a certification roadmap is essential. This study offers a thorough analysis of the issues facing the qualification and certification of additively made parts, components, and assemblies that could be used on commercial passenger air vehicles. It also provides information regarding the general standards of AM process. After outlining the principles of technical application for the AM process, the current status of the regulations, and rules created by national/international airworthiness authorities and communities are then summarized and analyzed in terms of the manufacturing of aviation-grade parts, components, and assemblies.

Keywords: *Additive Manufacturing (AM), Aviation Industry, Certification, Qualification*

1. Introduction

A commercial passenger aircraft -that is the subject of this proceeding- is a high-tech machine using multidisciplinary engineering sciences. These air vehicles are made of numerous complex systems and sub-systems to endure extraordinary working conditions [1]. A commercial passenger aircraft can only accept airworthy parts. The phrase "airworthy part" simply means that the component is "fit-to-fly" ensuring safety in the sky and on the ground. Obviously, for manufacturing an airborne part, it is required to own the facilities for precise manufacturing methods and meticulous tests [2, 3]. It can be easily claimed that, if a country has the capability of producing such a complex machine, it also has a high level of technological level [4].

There are many manufacturing methods used in the aviation industry. The aviation industry seems to be an ideal fit for additive manufacturing (AM), which enables the production of lighter parts with the same mechanical properties at a cheaper cost and in a shorter amount of time.

In this regard, the difference between qualification and certification should be underlined: The process of assessing a prototype design, a material, and a product while they are being developed or tested is known as qualification. Techniques, machinery, materials, parts, or even suppliers can be regarded as items. The primary purpose of certification is to satisfy a certifying authority or organization [5].

When it comes to qualifying additively manufactured components, airworthiness authorities will look to performance-based data. To confirm the stated criteria, the company producing the component must manufacture a specified number of test specimens -at least twice- in the same machine, demonstrating that the entire process is repeatable with demanded accuracy. The focus is not only on matching design parameters but also the repeatability. It is noteworthy that the test samples should match the minimum material feature requirements of the intended design.

In addition to qualifying the additive manufacturing machine, the supply chain process and the part should be qualified. In the aviation industry, the raw material is generally metallic powder in the additive manufacturing process [6]. The raw material chemistry, morphology, and size distribution must demonstrate that they are repeatable over layers. The heat treatment technique should also be proven to be re-applicable. At some point, the material qualities of the parts and components must be evaluated and demonstrated to be repeatable.

In the open literature, there are some studies on the qualification of additively manufactured airborne parts. Ze Chen and friends et al. [5] made a review study regarding qualification and certification for metal additive manufacturing. In the mentioned study, they described the additively manufactured metallic parts qualification studies. The difficulties are addressed, including those related to standards and protocols, materials, process repeatability and reliability, post-processing, data, and qualification and certification procedures. Saracyakupoglu et al. [7] made a study for defining the qualification process of additively manufactured parts with the perspective of weight reduction studies. In this study, mainly the carbon footprint impact of the AM parts was emphasized. In another study, Devarajan Balaji et al. [8] made a comparison study for metal additive manufacturing in the aviation industry. This manuscript goes into great detail on how additive manufacturing is used, specifically for aviation components. An aircraft engine company General Electric's in-situ inspection and quality control method was discussed as an example. At the end of this study, it was underlined that the maturity of the certification and qualification will need some remarkable time. The primary difference between the examined articles and this proceeding is the airworthiness requirements and airborne parts made utilizing AM technology and providing a roadmap.

2. Materials and Methods

The usage of traditional chip removal methods such as machining, lathing, grinding, etc. in the aviation sector dates back almost a century, and legacy production techniques continue to dominate aviation-grade manufacturing. Highly designed manufacturing processes are used to produce aviation-grade raw materials. Typically, these materials are not inexpensive. Waste and scrap are therefore highly significant. However, because traditional CNC machining procedures use subtractive methods, up to 98 percent of the material used may be wasted.

2.1. Additive Manufacturing

Engineers have modified the way they design a part to prevent waste, moving from the traditional practice of "subtracting material" to the cutting-edge method of adding material layer-by-layer to create the parts, especially the complicated ones. In addition to eliminating material waste, cutting down on manufacturing consumables like coolant and cutters open up possibilities for weight loss and topological improvement [8]. As shown in Figure 1. a CAD model is a set of data that can constantly be refined. The CAD model is typically converted to Standard Triangle Language (STL) format for the part to be created using the additive manufacturing technique. The CAD model is transformed into the most optimal structure using regular triangles using the ".STL" format. The STL file's data is then divided into layers.

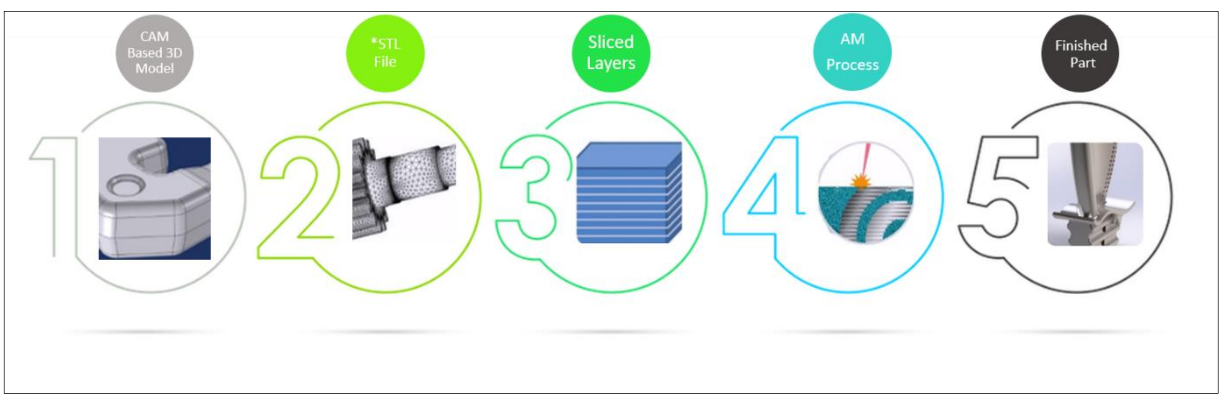

Figure 1. The Steps of the Additive Manufacturing Process (The figure was re-illustrated based on the information [9])

This process is known as slicing. The goal is based on the additive manufacturing principle, which creates manufacturing in a layerwise manner. After slicing, the item is prepared for processing on the additive manufacturing machine.

Depending on the mechanical features, in general, it is a single-machine process but in some cases, post-process such as Hot Isostatic Press (HIP) may be required for having the end-part. HIP compresses materials while simultaneously applying high temperatures of several hundred to 2000 °C and isostatic pressures of several tens to 200MPa.

2.2. Product Organization Approval (Part 21-G) and Design Organization Approval (Part 21-J)

The International Civil Aviation Organization (ICAO), an agency of the United Nations (UN), supervises the well-structured and well-regulated aviation industry [10]. Not only for aircraft part manufacturing but also maintenance activities and personnel training, ICAO also regulates the civil aviation industry. There are different regional governing agencies, as depicted in Figure 2. including the European Aviation Safety Agency (EASA), which has its origins in Europe, and the Federal Aviation Administration (FAA), which was established in the United States. Country Airworthiness Authorities (CAA) have the responsibility of compliance with the airworthiness regulations.

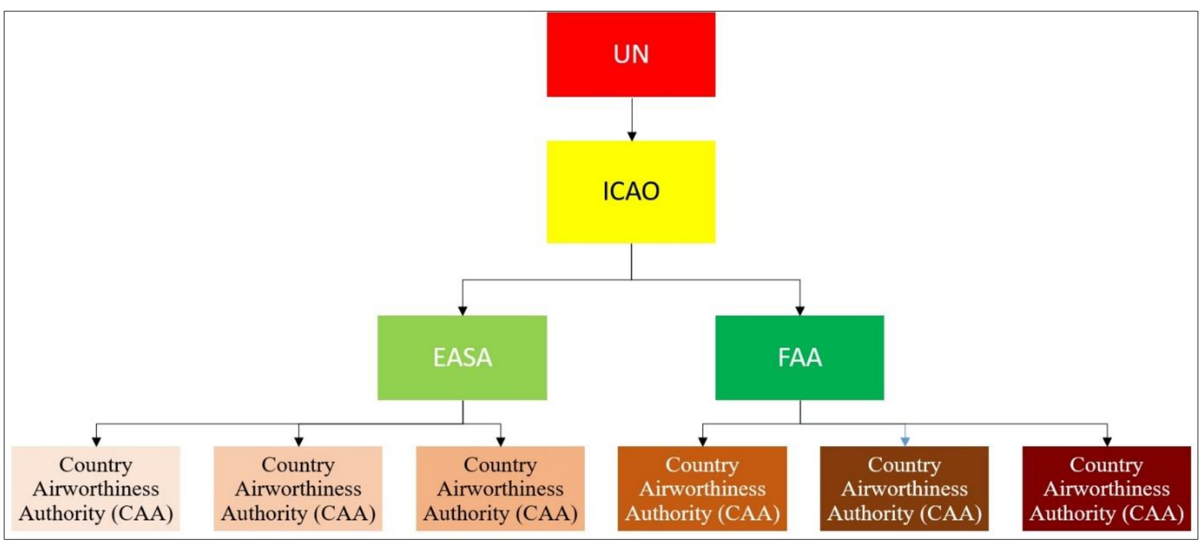

Figure 2. The Hierarchical Depiction of Airworthiness Authorities (The figure was re-illustrated based on the information [11])

The ability to take part in the production of aircraft, aircraft parts, or aircraft components and to produce airworthy parts is defined as Aviation- Grade. In aviation terminology, the terms "Airworthy part", "Airborne part", "Ready-to-take-off part", "Flight-ready part", and "Flight-grade part" also may be encountered for defining an aviation-grade part or component. The manufacturer of an "airborne part" must obtain Production Organization Approval (POA) and be granted a Type Certificate (TC), which verifies its airworthiness, to ensure that the aviation-grade part corresponds to approved design data and is capable of operating safely. The finished product is not permitted to be installed or used on any aircraft without this certificate. As shown in Figure 3. a "POA Candidate Company" undergoes many different audits in terms of human resources, facility requirements, and flow of documentation.

Figure 3. The Fields to be Audited by the Relevant Aviation Authority in the Part 21-J, Part 21-G Accreditation Process (The figure was re-illustrated based on the information [9, 12])

As can be seen in Figure 3, CAA or international airworthiness authorities execute comprehensive and meticulous audits. At first sight, it may be a time-consuming activity. But when public safety is considered these audits are crucial and should be executed meticulously.

It should be noted that because AM technologies are now in the early stages of development, they need more thorough qualification and certification assessments. AM will eventually replace chip-away technologies, The current challenges, such as the effectiveness of mass production, surface roughness, and the need for post-processing, will eventually be resolved. These problems are merely technical ones that may take some time to solve.

In these regulations, the rules of the process from the design of the part or component to the assembly of the part or the component on a commercial passenger aircraft are clearly described.

2.3. Bettering and Besting the Additive Manufacturing Process in Terms of Compliance with POA Requirements

The company procedures generally shape the manufacturing process. But compliance with the airworthiness regulations supersedes the company procedures. For bettering a process, novel technologies should be implemented while considering they might be a dangerous issue because of immaturity. In the aviation industry, there are many examples of incidents that happen because of immature technological implementations. Many cases of disruptive innovation included mishaps right after adoption. Many cases of disruptive innovation included incidents right after adoption. When executed recklessly, as was the case in the Boeing 737 Max crashes, these unique implementations pose a risk to flight safety. Two Boeing 737-Max commercial passenger airplanes crashed on October 29, 2018, and March 10, 2019, resulting in 346 fatalities [13, 14]).

After many attempts are applied the besting stage may be thought of as reached. As a novel technology for additive manufacturing both bettering and besting stages are provided in Figure 4. As can be seen, both stages have some sub-steps that should be implemented.

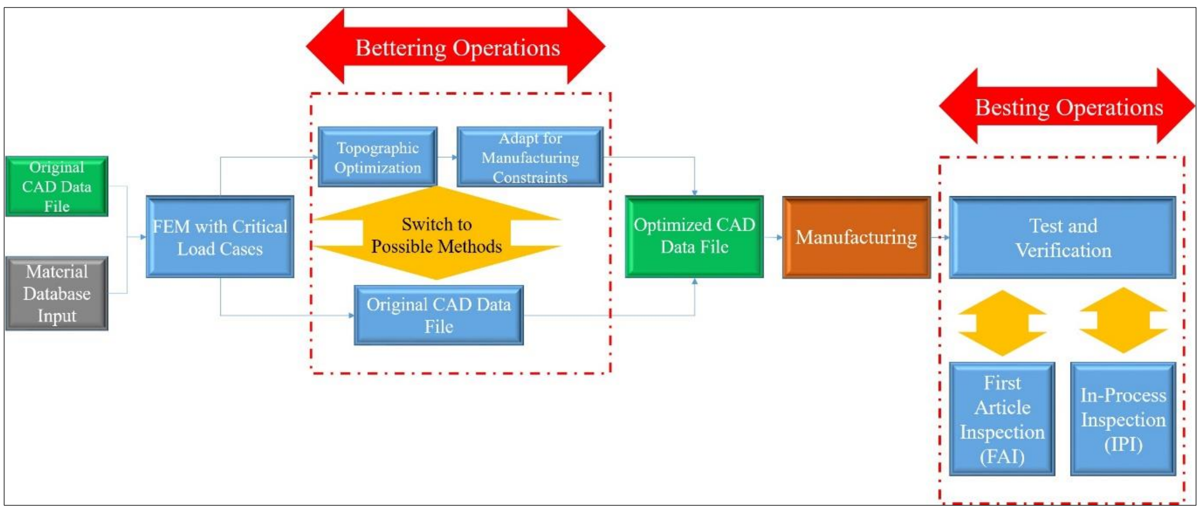

Figure 4. The Bettering and besting Operations In Terms of Compliance with POA Requirements (The figure was re-illustrated based on the information [9, 12])

One of the famous bettering studies is Topology Optimization (TO). TO of the airworthy parts used in airplanes is an excellent application since it allows for greater design freedom than traditional manufacturing methods. As an illustration, the GE engine nozzle which is shown in Figure 5.a. is 25% lighter after AM application. The mentioned airborne nozzle was made by combining 20 parts into one, manufactured in a single machine. Figure 5. b. depicts how European Aeronautic Defence and Space Company (EADS) revised the nacelle hinge brackets of the Airbus A320 in different research with the help of AM and TO studies. The weight of the brackets was reduced by up to 64% while maintaining satisfactory mechanical properties.

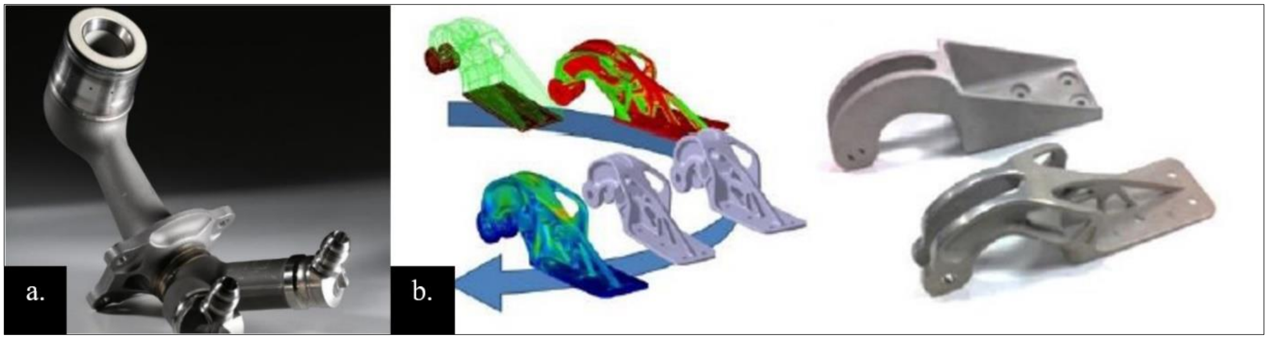

Figure 5.a. Additively Manufactured LEAP Engine Fuel Nozzle, Figure 5. b. The figure TO and AM Application of Airbus A320 Nacelle Hinge Bracket (Based on the information [15])

3. DISCUSSIONS AND CONCLUSIONS

As a result; the company procedures, Part 21 regulation, and manufacturing standards should be followed in harmony for having an additively manufactured aviation-grade part. In this concept, the flow and the roadmap given in Figure 6. may be usable for companies that intend to manufacture aviation-grade parts and/or components.

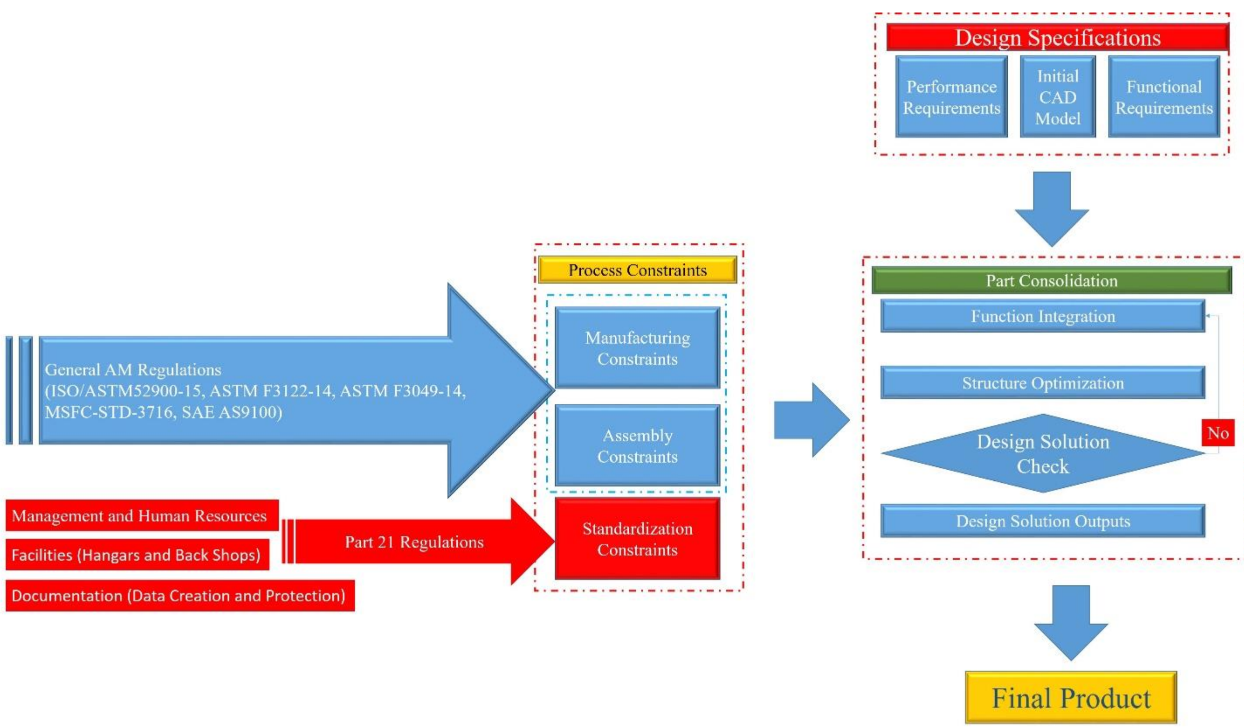

Figure 6. Roadmap for Qualification of the Additively Manufactured Aviation-Grade Parts (The figure was re-illustrated based on the information [6,7,8])

As it was mentioned before aviation-grade raw materials are expensive. For figuring out a part's cost efficiency the "buy-to-fly-ratio" definition is an identifier. The "buy-to-fly ratio" can be described as, "the weight of the raw material divided by the weight of the final product". The buy-to-fly ratio for components made by additive manufacturing can be as low as 1:1. This ratio varies between 10:1 and 15-20:1 for traditional manufacturing systems, and it can even reach 40:1 for highly complicated components. The buy-to-fly ratio can be significantly decreased and even brought close to 1:1 thanks to AM's advantage of generating items that are almost net-shaped. In addition, compared to standard machining processes, scraps can be as low as 10%, parts' costs can be reduced up to 50%, time to market can be cut by 64%, and component weight can be reduced up to 64% [16].

In this regard, while having advantages of using additive manufacturing technology, the product organization approval procedure's requirements should be implemented in the whole production process. A cost-effective AM aviation-grade part production has a unique application methodology. Part 21 requirements are the influencers of the process. On the other hand, every company has its own company procedure based on the company culture. The "ISO/ASTM52900-15" standard for standard AM terminology, the "ASTM F3122-14" standard for measuring the mechanical properties of metal AM parts, and the "ASTM F3049-14" standard for characterization of metal powders used in AM processes are just a few of the standards related to metal AM that have been developed so far though. Only a few standards and requirements, such as "MSFC-STD-3716" regarding space flight hardware made using laser powder bed fusion (L-PBF) metal AM processes and "SAE AS9100" regarding the specifications for quality management systems in aviation, space, and defense organizations, have been established in the context of the built environment of metal AM within the aviation industry [17].

4. RESULTS

For POA-approved companies, the regulations directed by either CAA or international airworthiness authorities such as FAA, EASA, etc. should be followed. For the product (it can be part or assembly) the company procedures should be followed.

As a result; the company procedures, Part 21 regulation, and manufacturing standards should be followed in harmony for having an additively manufactured aviation-grade part. In this concept, the flow given in Figure 6. will be the most likely and usable roadmap for the companies that intend to manufacture aviation-grade parts and/or components.

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