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# Eklemeli Olarak Üretilen Uçar Parçalar Üzerine Kapsamlı Bir Literatür Araştırması

**Tamer SARAÇYAKUPOĞLU[1]**

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## Öz

Eklemeli Üretim (EÜ) teknolojisi, uzay, havacılık ve tıp gibi niş endüstriyel sektörlerde hem metal hem de plastik parçaların üretimi için oyunun kurallarını değiştiren bir teknoloji olarak ünlenmektedir. Geleneksel olarak üretilen, Inconel tipi malzemeler olarak adlandırılan Ni esaslı alaşımlar, çok uzun zamandır yukarıda bahsedilen endüstrilerde yaygın olarak kullanılmaktadır. Ancak artık teknik olarak EÜ uygulamaları için bu alaşımlar kullanılabilmektedir. Bu durum, EÜ'nün daha sık kullanılacağı anlamına gelmektedir. Bununla birlikte, malzeme görüntüsünün, eklemeli olarak üretilen parçalarda mikroyapısal anizotropiyi nasıl etkilediği henüz açıklık kazanmamıştır. Örneğin, belirli bir tribolojik durumda, hareketli temas zayıflığına maruz kaldığında, anizotropi mekanik özellikleri ve termal özellikleri etkileyebilmektedir. Yaygın olarak kullanılan bir EÜ teknolojisi olan toz yatağı bazlı üretim süreci, diğer EÜ tekniklerine kıyasla daha pürüzlü bir yüzey sağlamaktadır. Havacılık endüstrisinde EÜ tekniklerinin kombinasyonel olarak kullanımı, artan yüzey kalitesi ve mekanik özelliklere sahip olmanın önündeki engelleri şekilde aşabilecektir. Bu kapsamda; bu makale, havacılık endüstrisindeki en yeni EÜ araştırmalarını incelerken, diğer taraftan kısıtlamaların da altını çizmektedir.

**Anahtar Kelimeler:** Eklemeli üretim, Havacılık endüstrisi, Ağırlık Azaltma

**JEL Sınıflandırma:** O32, O33.

# A Comprehensive Literature Research of the Additively Manufactured Airborne Parts

## Abstract

Additive Manufacturing (AM) technology has been gaining a reputation as a game-changer for the production of both metal and plastic parts in the niche industrial sectors such as aerospace, aviation, and medical. Conventionally manufactured, Ni-based alloys called Inconel type materials have been widely used in the mentioned industries for a very long time. But they are now technically available for AM applications. It means that AM will be more frequently used. However, it is not clear yet how the material display influences microstructural anisotropy in the additively manufactured parts. For example, in a certain tribological situation, when exposed to moveable contact weakness, anisotropy might influence mechanical characteristics and thermal features. The powder-bed-based manufacturing process that is a widely used AM technology provides a slightly rough surface compared to other AM techniques. The combination of AM techniques in the aviation industry could gracefully overcome the barriers to having increased surface quality and mechanical features. In this manner; this paper explores the cutting-edge AM studies in the aviation industry while underlining their constraints.

**Key Words:** Additive manufacturing, Aviation industry, Weight Reduction

**JEL Classification:** O32, O33.

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## GİRİŞ

## 1. Introduction

AM has been developing a wide range of business utilitarian applications since its inception at the initial stage. Specifically, metal AM is currently part of the aviation business to assemble and fix different segments for commercial and military aircraft, just like space vehicles. Aerospace makers have been using add-on substance manufacturing frameworks since AM's inception in the '80s. However, in the past few years, rapid advances in AM innovation have led to a multiplication of the use of innovation in aeronautical. In the past, AM had a special function in aerospace manufacturing as an innovation for prototyping. In any event, as the ongoing improvements suggest, AM quickly becomes a key innovation that will generate revenue across the aviation chain gracefully. Common aviation applications are intricate engine parts, auxiliary units, and new components. AM empowers the creation of such parts at a lower weight and substantially lower life-cycle costs.

In the open literature, there are studies regarding additively manufactured airworthy and aerospace-grade parts. For example, Byron Blakey-Milner et al [1] made an investigation about the metal materials additive manufacturing process used in aerospace. In general, this study provides information about lattice structures that requires topological optimization. In another study, Adam Pajonk, et al [2] made a research study on multi-material structures that are very primitive in the aviation industry. In this study, it was claimed that mixing two or more materials are restricted to only sharp interfaces between the respective materials. On the other hand, Rajat Kawalkar et al [3] made a standardization study of the additively manufactured parts. Albeit this study concentrates on the certification issue which is vital in the aviation industry, the authors mainly focused on the International Organization for Standardization (ISO), American Society for Testing and Materials (ASTM), and Support Action for Standardization in Additive Manufacturing (SASAM) organizations. Considering the above-mentioned studies and other studies in open literature; it was observed that the investigations are generally related to studies that include information either aerospace or multi-materials or certification organizations.

It has been observed that there is a gap between the current literature and this because of perspective. Mainly, the gap between this study and the inspected papers is focusing on the airworthy and airborne parts which are produced using AM technology.

AM has been essential for the creation of airplanes for quite a long time, but its work has been largely limited to non-critical parts, such as ventilation work and internal segments, or to engine sections for which the loads included are warm rather than mechanical. Early use of AM, innovation incorporates Rapid Prototyping (RP) of machine equipment and RP to help the continuous improvement of the item by granting physical item approval to model models. In any case, over the last decade, AM has seen rapid advances in mechanical capability and has been progressively used as a type of direct assembly. In special ventures, for example, the aviation, biomedical, and car businesses, AM is currently utilized connected at the hip with Conventional Manufacturing (CM), e.g., Subtractive Manufacturing (SM), which depends on the evacuation of material to deliver a result. These SM processes are generally called chip-away manufacturing techniques. In comparison to conventional assembling approaches, AM is an assembling cycle whose usage has been primarily determined by its potential to allow for moderately unregulated schedule customization while containing fewer cycle imperatives. Most moves toward component configuration, as is customary, accept an isotropic material for ease of use and the development of partial definitions using a number of traditional techniques including carving, projecting, or subtractive machining. AM as a cycle isolates itself from these usual strategies because it includes an extended adaptability measure of the plan while choosing the form and calculation of the ideal part.

Further, the addition of cycle substance capacities, including the use of AM features in a material with a different microstructure, takes into account the use of a created substratum. This makes it possible to produce custom-examined materials by AM and presents the possibility of products with customized microstructures that are intended to be implemented. AM as a cycle isolates itself from those conventional technologies by taking in the form and the algorithm of an ideal part by including an expanded measure of planning adaptability.

Furthermore, AM features are used in a produced substrate with a contrasting microstructure, such as the material is built in layer-by-layer philosophy. The aviation business chain is obviously the most volatile and longest relative to various businesses. An aircraft consists of several complex segments and subcomponents, and a multilayered assembly system is often used in the thought of the concept of the organization. This design requires concerted efforts to ensure smooth service in the managers' gracefully chain since any flexible connection hick-up will interrupt the new aircraft. Aircraft companies routinely keep higher levels of stocks to allow for dynamic fluid chain agreements and the need for quicker management frameworks. Globally, stock expenditures are estimated to be in the range of USD 50 billion. Various solutions have been researched and used in the aviation industry, including estimating the interest of the part, employing algorithms to predict upkeep requirements and part failures, and expediting the graceful chain arrangements. Despite this, the high exchange prices and the costs of deferred airplane overhauling only made these measures partially practical. By applying the lean assembly approaches, the manufacturers have been working tirelessly to streamline the planning and production processes, as well as reduce waste and production lead times. Products and services have also been developed using cutting-edge robotization, computer-generated designs, and assembly. This study provides information about the complete analysis of the potential roles of AM in the airplane flexible chain and stock systems, as well as the existing state of usage and related quality assurance and normalization issues.

The aviation industry has its own features. On the other hand, as a novel technology, the additive manufacturing has its own restrictions and features as well. In this concept, this study particularly has channeled into the additively manufactured airborne parts.

## 2. Material and Method

Since AM has a variety of applications, making an overall review is nearly impossible. For this reason, the application in the aviation industry has been selected. Also, the applications in the aerospace and aviation industry were investigated in terms of AM studies. This section also discusses the different techniques categorized under additive metal and nonmetal technologies. Barclift et al [4] proposed a strategy for assessing AM building costs through a strong 3D business demonstration program. Using the Application Programming Interface (API), part length and surface detail are challenged from the CAD model and utilized to generate inner and outside support structures as strong body characteristics. Customers have chances to utilize the data to calculate production time, feedstock conditions, and improve parts for AM construction as they prepare for the CAD scheme, as well as track the parts' manufacturing course.

### 2.1. The methods of AM

In Kannan and Rajendran et al [5], the various exploration parts of the AM are discussed at the premises of two expansive zones, such as the assembly plant and the boundary control cycle. The field of AM has taken the assembly to the next level where the creation and improvement of the item are made easier. Investigations are made on the scattered exploration articles and the examination holes have finally been found to give a future degree in the field of metal AM. As illustrated in Figure 1, the process parameters are primarily connected to the laser features, scan parameters, powder specifications, and temperature levels.

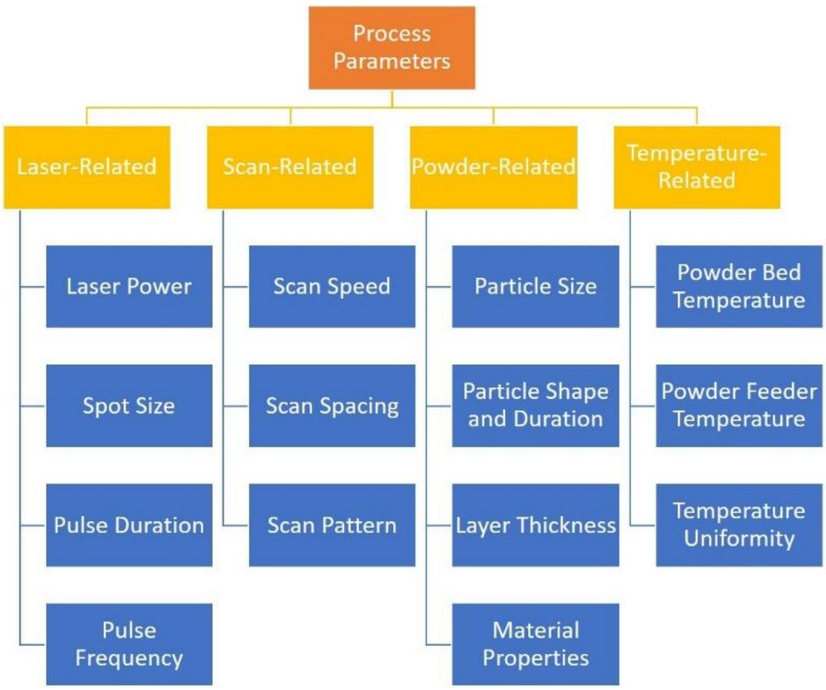


**Figure 1.** Process parameters for SLM process (The figure was re-illustrated based on the information [5])

Leal et al [6] used direct metal laser manufacturing to pick one of the launched variants at a conclusion. Among the metal AM procedures mentioned, the powder bed combination test, the fifth class on the ASTM F42 and ISO/TC 261 continuous guidelines—the Direct Metal Laser Sintering (DMLS)-technology claimed by EOS GmbH—was chosen. A planned approach for cell structures to be built utilizing AM techniques is created by Opgenoord and Wilcox et al [7], primarily for such early stages of the plan. This planning philosophy uses flexible cross-section processes to design the geography of the cell structure, after which the cell structure's swaggers are independently streamlined to decrease the issue's dimensionality. Allevi et al [8] used the achievability to learn about the possibilities of using the Thermoelastic Stress Analysis (TSA) on an additively assembled titanium-based composite aeronautical section. A study of the cycle was performed on the printed segment together at the earliest reference stage, both to think about the dimensional deviations between it and the CAD component and to analyze the real segment using the Finite Element Method (FEM). Klahn, Omidvarkarjan and Meboldt et al [9] showed the weight-saving capability of Selective Laser Melting (SLM) and fill it as a technology demonstrator featuring the potential of this youthful creative technology. What really had any effect are strategies for composing the work process and overcoming limitations, e.g. early assurance of part direction depending on the ideal plan. Durakovic et al [10] explored patterns, issues, and difficulties in the AM plan, including related costs, alternatives for the plan, and quality considerations. It has been discovered that AM is in its early stages, that there is a lack of understanding of the cycle, technique, procedures, apparatus used in the plan for AM measures, while quality and capacity measurements are constantly improving. Rawal, Brantley, and Karabudak et al [11] described the use of a few EBM-prepared Ti6Al4V sections on the Juno rocket. At first, a three-dimensional (3D) CAD model of each section drawing was created to incorporate a marginal abundance of surface layers for smooth surface finishing. Numerous parts were assembled in an accessible chamber size at the same time. A starter cost and advantage investigation were also carried out to evaluate the value of the use of the AM for future segments of the shuttle. In another study, Lakshmi and Arumaikkannu et al [12] concentrated on the impact of the different boundaries on the different levels tentatively. The segments were planned and manufactured in accordance with the ASTM principles in this work. Investigations were planned on the basis of Taguchi's trial plan. The L27 Orthogonal Taguchi configuration cluster was used. In order to determine the criticality and commitment of each factor to elasticity, the difference investigation (ANOVA) was carried out.

In Seabra et al [13] the overall improvement measure, from enhancement to planning, development, and testing, tended to be used. At first, the geography of the airplane section was enhanced to be created using SLM methods. The Topology Optimization (TO) arrangement has been deciphered and intended for AM. During the comprehension and configuration measure, the planning technique was designed to encourage and make the TO plan more accurate and to prepare it for the AM. Following the creation of the advanced part, metrological and mechanical tests were carried out in order to approve the last plan and the Computer analysis. Gebisa and Lemu et al [14] focused on the topologically enhanced plan approach for the additive produced by a contextual analysis of the lightweight plan of the stream motor segments. The examination result shows that geography enhancement is an incredible plan method to reduce the heaviness of an item while keeping up with the needs of the plan if AM is considered. In order to carry out AM innovations in the field of practical components, the innovation of materials propellers and improvement of the plan are considered key areas of flow research. Liu et al [15] discussed the new opportunities and advantages of AM advances in aircraft applications. It not only assumes the function of rapid prototyping innovation for saving capital and time during the improvement period of the item, but it can also be received for quick tooling, direct assembly of the part, and fixing in aeronautical trade. Given the current state of affairs, AM has rapidly emerged as a crucial breakthrough that will gracefully produce sales through the aviation chain. In Levatti et al [16] a contextual Analysis was introduced as a system linked to the hypothesis on which the streamlining programming is based. The entrenched approach is used to improve the parts of any gadget under load. The importance of considering anisotropy in loads, algorithms, and properties is discussed and clarified just as a working procedure is proposed. Brusa, Raffaella, and Ossola [17] presented the mathematical display of the mathematically unpredictable basic section for aviation applications, which has been re-planned through topological advancement and delivered in Ti6Al4V using AM methods. The action plan presented here needed to turn to an appropriate model of the constitutive properties of the material by tackling the enormous number of porosity / low thickness regions identified by a tomographic examination of the mechanical segment. Brandt et al [18] presented and discussed a portion of ideas and discoveries related to the design, manufacture, and assessment of high-quality aviation components from the Ti6Al4V combination created by the RMIT University's, Advanced Manufacturing Precinct department. As will be mentioned later detail, the Ti6Al4V alloy is one of the most widely used materials for the assembly of aeronautical segments due to its low thickness, high-quality, high-quality, high-quality machinery. The Ti6Al4V SLM parts show comparative or better physical and mechanical properties than the other common materials, without using any post-handling techniques. In Figure 2, the AM optimization methodology was examined based on a flowchart as it is demonstrated.

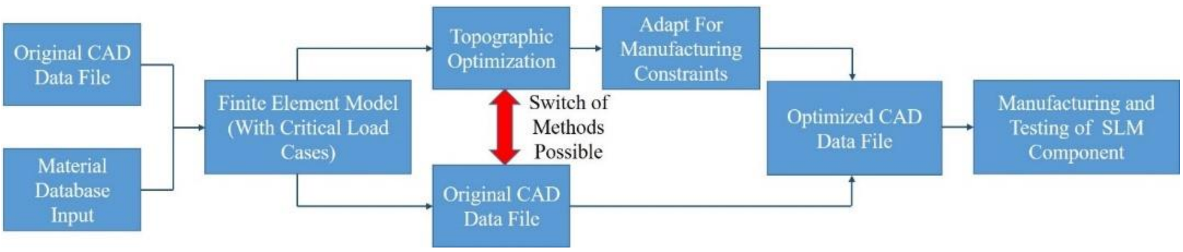


**Figure 2**. Generic AM optimization methodology (The figure was re-illustrated based on the information [18])

Tomlin and Meyer et al [19] highlighted the potential for improvement of smaller parts over the entire aircraft, despite the fact that these potential weight reserve funds are spread across a large number of parts. Thoughts for misuse of these potential weight investment funds include creating groups of comparative parts, all utilizing varieties of similar geography, thus increasing the cost of advancement between parts. For a particular type of part, plans could be made on a procedural basis. Orme et al [20] described and presented a comprehensive approach to space and aircraft parts of the cycle stream. The cycle stream incorporates geography advancement of the design of the segment, the AM plan contemplations (e.g. support of evacuation of the structure, removal of the powder, and minimization of the remaining concerns through the help structure plan and part plan), the manufacture of antiques and in-measure testing coupons, and last check at both coupon and segment levels. Additively manufactured metal parts in conjunction with the update of the parts that have positive cost-saving effects. In fact, if the segment shape is changed into misuse AM opportunities, an incredible decrease in costs can be achieved. The Design for Manufacturing (DFM) strategy is driven by the creator's production cycle to simplify the development cycle, to combine phases, misuse creation possibilities, and reduce the production cost. DFM is a strategy that uses the creator to produce products. Thus, to achieve the points of DFM the most significant rule is to plan for simplicity of production and creation, which could be distinctive relying upon the assembling cycle embraced.

## 2.2. The Applications in the Aviation Industry

Typical aerospace applications are confusing engine components, basic and new components. The production of AM allows such parts to be created at a lower weight and reduces the cost of the life cycle fundamentally.

AM may be employed for weight and stream improvement, sound decrease, close to net part substitution, and decrease in part for aircraft applications such as sections, ducting, and safety belt clasps. Direct Digital Manufacturing (DDM) innovation is one that producers have imagined for quite a long time, yet as recently as late become a reality. AM, creation advances that up to this point have been consigned to quick prototyping applications, have gone into the assembling domain. The utilization of AM creation methods is the thing that recognizes DDM from the other traditional assembling procedures, and it is from DDM innovations that one-of-a-kind chances and preferences emerge. The concisely conveyed process time causes time-to-showcase reductions and also protects the time transport if difficulties arise a moment ago. Two components lead to a move away from the term fast assembly. Numerous regular cycles have started using the term 'fast assembling' in order to show the movement whether it reinforces additive manufacturing technology. Secondly, DDM provides much more than an acceleration of the assembly cycle. An emphasis on "fast" can promptly supervise the different focus points throughout the assembly cycle. DDM is nothing other than a fundamental change of existing cycle assembly strategies. The DDM opens the door to businesses in different ways to recognize critical advantages. The situation is extreme and usually changes manufacturing. At present, the use of DDM for explicit requirements to achieve objectives that are already unreachable is an acceptable cycle for fancy people and reform organizations. DDM speaks to circumstances for these organizations. It brings new dangers to other people. For example, large, well-established groups have another source of competitiveness. The small start has an appliance that supports new business sectors with new products and is significantly less dangerous. Actually, the company pool in which field-tested strategies depend and new action plans are based on DDM's special focus points has a huge number of inventive uses of DDM. These business visionaries have an appliance that can make organizations new and serious dangers. Rapid prototyping "points to the various added-substance manufacturing techniques used to quickly generate the example parts – indeed the added tooling has started here. Rapid tooling is another innovation that speeds up the production of items. This theme shows how you can profit by quick assembling methods. When cycles for fast tooling were drawn up, organizations that produced molds using conventional techniques (such as aluminum or steel processing) began to speed up these approaches. The term "fast tooling" was inevitably used for every device which could be quickly assembled, incorporated into it those produced with more usual techniques. A few organizations can turn a metal form around in a couple of days to seven days. Clearly, the most troubling and longest-standing chain of aircraft corporations is the graceful chain. The aircraft consists of multiple refined segments and subcomponents, and a multi-layered assembly system is often used when dreaming of the market concept. This configuration involves an increased commitment on the board gracefully and the expectation for the supply to maintain a seamless operation since any fluid tie-ups will disrupt the last aircraft collection. Given the erratic graceful layout of the chain and the need for quick support control frameworks, aviation industries also maintain more stock levels. The overall manufacturing costs around the world are measured at about 21 Billion USD in 2020 [21].

A section is created layer by layer from directly advanced 3D information without improvement, projection, or workmanship. After completion of the plan for a section, the assembly can start immediately. The lead time is currently estimated in hours and minutes, rather than months, weeks, or days, for the first articles of finished items. After the CAD information has been provided, the assembly can start since the tooling is not delayed. The organization can send CAD information in the form of a * STL document, instead of 6 to 12 weeks to complete the tooling development and plan process, and start creating [22]. In Figure 3, the CAD model (as an initiator) and the following steps of AM process are shown in consecutive steps.

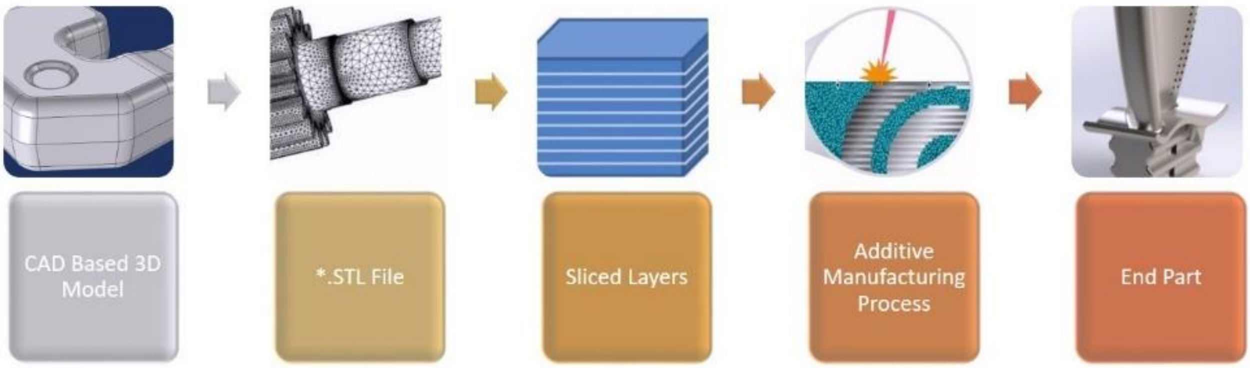


**Figure 3.** The Steps of the Additive Manufacturing Process (The figure was re-illustrated based on the information [22])

The challenge to decrease stock volumes and different strategies have always been steady, for example, to estimate the shared interest, using formulas to estimate service circumstances and partial suspicious deaths, and upgrading the graceful chain designs have been considered and actualized in the airplane business. Nonetheless, these steps were only marginally powerful in terms of high currency rates and modification of delayed aircraft rates. The factories have constantly endeavored to update the plans and designs and decrease waste and manufacturing lead times by using lean assembly. With the use of state-of-the-art digitalization, computers have helped organize and assemble items and services. In this study, more development in AM is taking place. A detailed audit of the possible AM jobs will flexibly conduct chain and inventory framework within the aircraft and will be inserted into this paper the actual utilization status and associated quality confirmation and normalization problems.

In this manner, Cozzani et al [23] compared the impact of the 4-section framework, with the help of the 3D Finite Element methodology, including Alexander, Roth, Maxillary Transverse Bio-Adaptation (MBT). In all of the 100, 200, 300, 400 grams of withdrawal power, the MBT framework had the most extreme root and the incisal edge development. In all withdrawal powers, the Alexander frame had the lowest peak and incidents. Kamal and Rizza et al [24] gave the viewers an exhaustive overview of the main considerations of whether an aviation item should be manufactured utilizing AM and the significance of the interconnection of part and cycle. Several kinds of AM measures can be used to create metal parts for AM as an assembling technique. The laser powder bed framework and the coordinated energy test frameworks are the two most normal AM frameworks used at present. In Froes, Boyer, and Dutta et al [25] the aerospace material was usually a metal composite, although it had additionally consisted of polymer-based materials, either created for or through their use for aviation purposes for noticeable quality. Automobile uses often require significant implementation, quality, or heat obstacles, even to the cost of large-scale production or customary production costs. Others are chosen for their reliability, especially for their protection against weariness stacking in this safety-cognizing area. The turbofan engine used for F-35 aircraft (F135) has many additively manufactured parts as shown in Figure 4 It is noteworthy that, some critical parts are used in the High-Pressure Turbine (HPT) and Low-Pressure Turbine (LPT) of the F135 engine. These parts are generally subjected to extremely high temperature (~ 1400-1500 0C) and pressure (~ 20-40 Atm)

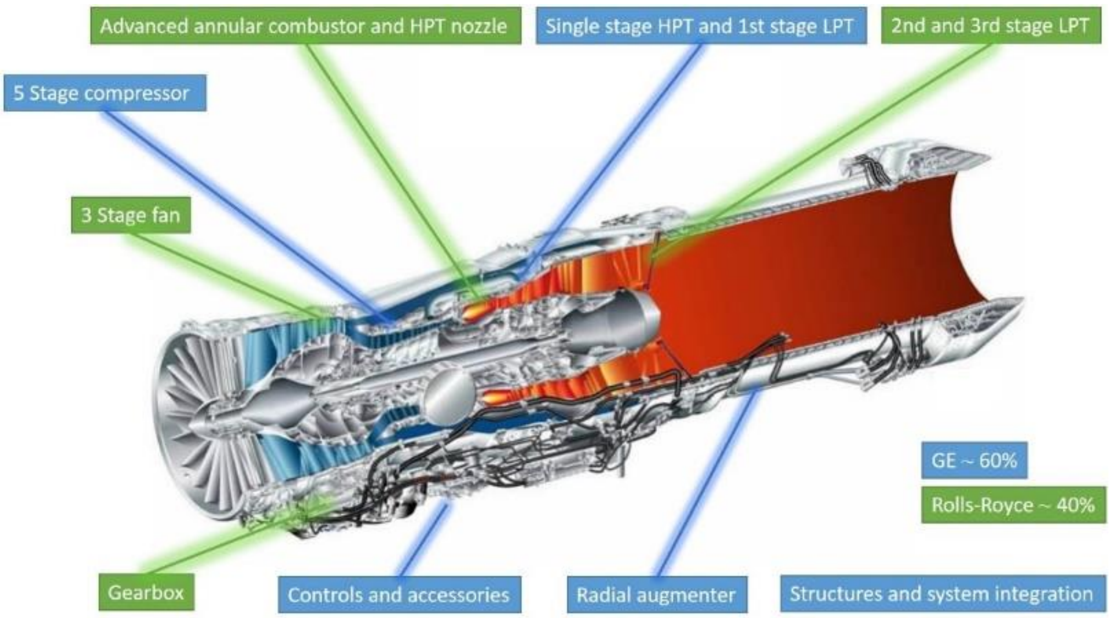


**Figure 4.** The F-35 Lightning's Propulsion System's Additiely Mamufactured Parts (The figure was re-illustrated based on the information [25])

In Minet et al [26] focused cubic gem structure, also called the gamma (topic) phase, is the basic component of these combinations. At room temperature, the composite iron and cobalt-base typically have a Body-Centering Cubic Structure (BCC), but nickel rises can also retain the austenite Face-Centered Cubic (FCC) structure. Nickel-based superalloys are unavailable for the most difficult uses, such as gas stream sections in land-based and vehicle gas turbines, though they outperform other superalloy types. The conventional way of dealing with a metal component is subtractive machining from a cast or a fabricated ticket to a final form or a metal cast in the close by a net form which is finally machined to resist in Withers et al [27]. Castings generally contain residual porosity and, depending on thickness, varied mechanical qualities over the cross-segment due to the variable cooling rate through the projecting cross-sectional area. In Yang et al [28] the specific cycle nature of the AM measure had risen to a large group of favorable circumstances over the usual cycles. From an application point of view, AM offers high degrees of customization and customization with little effect on assembling intricacy and cost as tools and related cost components do not exist for AM measures. In the pilot run and low-volume discovery environment, material waste, time, and material-related costs, the stock is substantially reduced. Atzeni and Salmi [29] dealt with the assessment of the volume of production for which the AM procedures are serious as for the traditional cycles for the production of end-usable metal parts. For this reason, a correlation between two distinct advances in metal part creation, the usual high-pressure projection and the immediate metal laser sintering add-on substance method, is concluded with a consideration of both the mathematical perspectives of AM and the monetary perspective. Mellor, Hao, and Zhang et al [30] focused on the execution cycle of AM and is driven by the absence of socio-specialized studies. It tends to require existing and potential future AM venture managers to have a use structure to control their efforts to receive this new and potentially difficult technology class to deliver high-value items and create new business openings. Huang et al. [31] calculated the net improvements in the life cycle of critical energy and ozone-depleting compounds associated with AM developments in lightweight metallic processing equipment in 2050 to provide insight into the environmental advantages of switching from Conventional Manufacturing (CM) to AM in the US aviation industry. Frameworks for displaying the structure are introduced, with coordinated building rules, environmental lifecycle information, aircraft armada stock, and fuel use models in various AM selection situations. Uriondo, Esperon-Miguez, and Perinpanayagam et al [32] reviewed ongoing upgrades in the add-on substance-making advances, zeroing in those that could possibly create and fix metal parts for the avionics business. Electron liquefying, in particular, laser dissolving and other metal test measures, e.g., wire and circular segment AM, are considered to be the best contender to carry out this test.

Govdeli, Wong and Kayacan et al [33] acquired vital data on the creation of low-cost and lightweight Unmanned Aerial Vehicles (UAV)s. By researching the focal points and detriments that the AM innovation brings along on the plan and assembling measures, a definite investigation is completed from the aeronautical designing perspective.

The aero-engine fuel nozzle which is used in LEAP engines is shown in Figure 5 as a sample of the additively manufactured airborne part. The mentioned nozzle had been produced by

20 parts before it was made using AM technology. After the Manufacturing technique was converted from legacy methods to AM in a single machine it weighed 25% less and was 5 times durable than the traditionally manufactured predecessors [34]).

**Figure 5.** Additively Manufactured LEAP Engine Fuel Nozzle (An open-source image was used based on the information [34])

### 2.3. The Materials Used in the AM Process

Yakout, Elbestawi, and Veldhuis et al [35] provided a review of key developments in the manufacture of metal AM. It focuses on the impact of significant cycle boundaries on the microstructure and mechanical properties of the subsequent part. Some materials are considered, including aeronautical combinations, such as titanium (TiAl6V4 'UNS R56400'), aluminium (AlSi10Mg 'UNS A03600'), iron and nickel-based composites (treated steel 316L 'UNS S31603'), Inconel 718 'UNS N07718' and invar 36 FeNi36 'UNS K93600'). Uhlmann et al [36] focused on the capability of a superior titanium compound, as well as on the examination of the streamlined cycle boundaries and the location of the structures delivered in the SLM machine. Post-handling results, applied to TiAl6V4 parts, generated by SLM, show a gigantic potential in the progress of surface quality. Ghadge et al [37] assessed the effect of AM use on aircraft Supply Chain (SC) organizations. AM and traditional assembling save part stock control frameworks are considered and looked at, uncovering bits of knowledge in SC performance. The study provides strong evidence of the solution to the basic service choices of the SC re-plan, powered by another and difficult scientific advancement. Cutting edge SC and coordination will replace the current interest in satisfying material objects with AM machines. Gisario et al [38] reviewed the ongoing updates on AM innovations, material issues, post-cycles, and plan angles, particularly in the avionics business. In addition, the AM cycle is examined on a monthly basis, including different cost models, saving part digitization, and environmental consequences. In this study, the part consolidation was detailly investigated. As it is shown in Figure 6, for gaining a redesigned structure, it is necessary to make a part consolidation on basis of process constraints and design specifications.

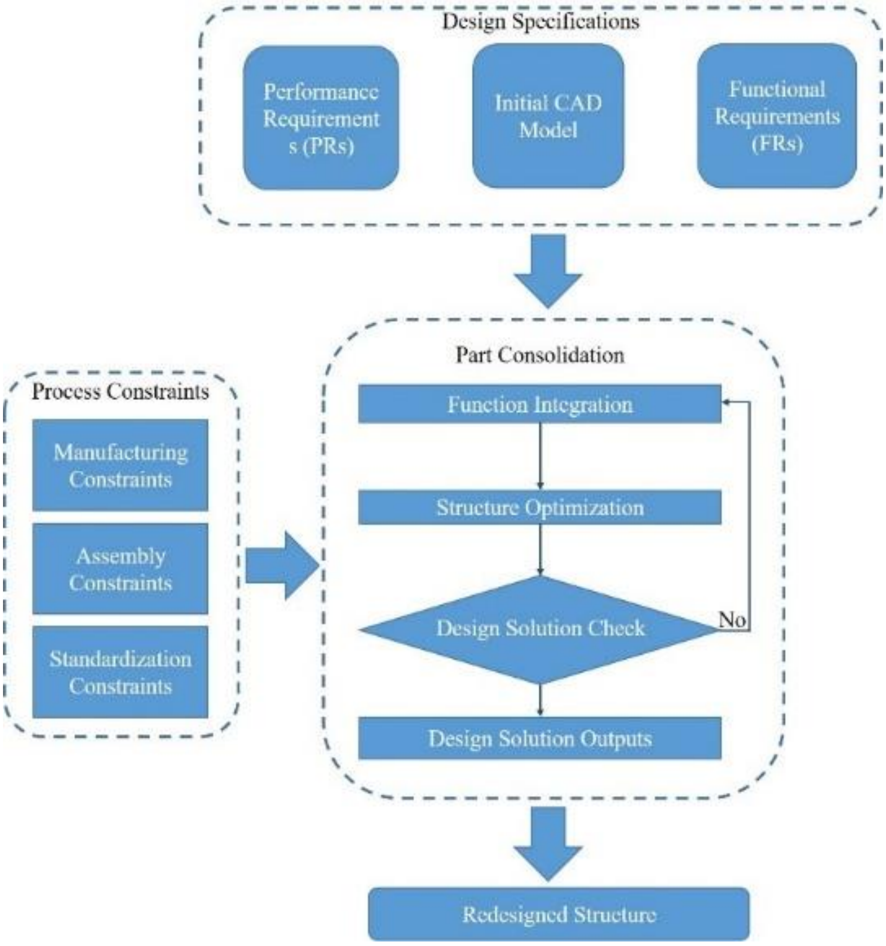


**Figure 6.** Methodology for part consolidation (The figure was re-illustrated based on the information [38])

Barroqueiro et al [39] reviewed the disasters, improvement devices, and imperatives of AM building cycles in order to assess its current stage and distinguish its needs. The first section discusses existing metal AM steps and categorizes them for clarification, referring to their core characteristics and the components that can be processed. Moreover, at present accessible computational plan apparatuses are recorded and the principal impediments, from the assembling perspective, are reviewed. Joshi and Sheik et al [40] look at the supply of well-known 3D printing steps in the aviation industry.  The researchers look at how 3D printing is being used in various organizations and associations around the world. Experimentation in the field of extraterrestrial printing is also illustrated. Yusuf, Cutler, and Gao et al [41], the groups of AM developments that are widely used to produce metallic parts were defined by the researchers. The progression of metal AM in the airplane industry from prototyping to the assembly of impetus structures and simple parts is also illustrated. Thompson et al [42] presented the significant changes, limitations, and financial contemplations for Design for Additive Manufacturing. It investigates issues identified with plans and updates for immediate and backhanded AM creation. It additionally features key mechanical applications, traces future difficulties, and distinguishes promising bearings for research and the abuse of AM's maximum capacity in the industry. Plocher and Panesar [43] focused on auxiliary enhancement in AM with specific accentuation on DfAM. As most chips away at lightweight methodologies depend on isotropic material suppositions, strengthened materials and the cycle prompted anisotropy brought about by the manufacture in a layer-by-layer design or infill design (for example configuration approaches customized for anisotropy), are not evaluated. Infills are along these lines exclusively talked about with regards to grids. Harikrishnan et al [44] measured the deformation of the triggered bracket slot at different twist points. The opening distortion was available in traditional stainless steel (SS) sections of 0.018" and 0.022" with scientifically relevant archwires that reached the turning stage. The “Top Slot Deformation “(TSD) was higher than the “Middle Slot Deformation” (MSD) and “Bottom Slot Deformation” (BSD) in all the section archwire mixes. It is presumed that there is just flexible distortion of section openings up to 300 points of contorting and clinicians could keep up inside these force cutoff points to dodge plastic twisting prompting inappropriate teeth position. Vijayan and Geetha et al [45] focused on valuable and valuable research on the part that can be seen throughout the suspension frame without affecting the presentation and nature. The existing rear-air section model is more costly and heavier. Countless contentions are recalled regarding appreciation as a powerful appliance to refine the current item plan with pressurization and resultant removal to the purpose of the new item plan. In Liao and Liao et al [46] the lightweight improvement technique was proposed. With the compound structure strategy with improvement cycle, the plan boundaries of the upgraded hydro-generator lower section model are controlled. The biggest normal pressure and the most extreme lower section relocation are in the allowable value via a lightweight improvement plan, modular examination shows that the dynamic attributes of the streamlined structure likewise meet the necessities, with the capability of material further used.

Besides, Emmelmann, Herzog, and Kranz et al [47] gave a review of the most essential plan rules for Laser Additive Manufacturing (LAM) and portrays item functionalities that misuse the mathematical opportunity of LAM. The potential for new methodologies in item configuration is colossal. However, on the grounds that the oddity of LAM, information on its plan limitations are just minor. Against this foundation, this section introduced the most fundamental plan decisions that ought to be viewed when planning parts for LAM and summed up it in a smaller diagram. Oyesola et al [48] aimed to build up a cost model got from a "Period Driven Activity Based Costing" approach for the mechanical joining of the Hybrid framework to increment the monetary intensity of profoundly Maintenance, Repair, And Overhaul (MRO) administrations in the aeronautic trade. Henceforth, a kind cost definition strategy was examined through the scientific procedure in cost building models to make measures. Nazir et al [49] aimed to give a thorough audit of the different cross-section morphologies, plan, and the AM of the cell structures. In addition, the main characteristics of the additively assembled structure, as well as its uses and challenges, are discussed. The directed audit has established the crucial impediments and gaps in the current writing, as well as the areas that need further analysis in the cell layout plan, improvement, attributes, implementations, and AM. Ahn et al [50] reviewed the Direct Metal Additive Manufacturing

(DMAM) measures and their manageable applications for green innovation. Standards and qualities of the DMAM measures were explored. The cutting edge and significant issues identified with supportable utilizations of DMAM measures were talked about. At last, huge chances and future examination issues of the DMAM cycle were talked about from the perspective of the improvement of maintainability. Poyraz and Kushan [51] presented fundamental standards for AM assembling and configuration issues to use the strategy appropriately for the flying industry. Moreover, it benchmarks and examines plans made for airplane and impetus segments. At long last, the points of interest and impediments used during the plan for AM were featured, and research needs were accentuated. Senck et al [52] studied the specific parts and in-measured test coupons at several spatial goals in the range of 105 and 1,25 m isometric voxel sizes in a multi-scale manner to deal with the possibility of reducing pore size appropriations. There is no way to partition existing pores into minimum spatial objectives. Reduced particle sizes, on the other hand, result in a 1.53 percent increase in overall porosity.

In another study, Schwarz et al [53] an aircraft entryway pivot gathering by Gulfstream Aerospace was broken down after a built-up measure called for "Design Manufacturing and Assembly" (DMA). The pivot was then upgraded to be made additive, which is currently unprecedented for load-bearing parts in the industry. It was noted that the Design for Manufacturing (DFM) rules were insufficient to apply to the new innovation of AM. This was basically due to AM's one-of-a-kind and extraordinary ability to assemble. Additive Layer Manufacturing (ALM) has gone far from its organization's early stages, 30 years ago. In modern applications, a widely available ALM measurement produces components on a powder bed layer by laser or electron bar methods, in particular, dissolving powder particles. In general, ALM is challenging the conventional difficulties between scale and extension which win in two ways. Initially, the capital required for economies of scale is reduced. A solo printer can manufacture a number of complex components with variable designs. Consequently, it is not expected at this point that enormous, concentrates-processing plants with mechanical production systems (boundaries for assembly to an area are reduced). Secondly, the range of plans produced by a capital measure is expanded. Unpredictability, changes in the creation, and adaptations are therefore less expensive.

A brief survey on surface imagery and examination was explained by Diaz et al [54] utilizing AM surface features, as an illustration, to better grasp the approved processes for selecting the cut-off channel in order to identify the best feasible spatial wavelength. Contact and non-contact profilometers are the two main types of advancements available on the market for creating a surface profile. In Koester et al [55], it was explained that additive assembling, as opposed to subtractive and developmental assembling methods, is a fast-growing technology that involves the integration of materials to create parts from 3D model content, as usual layer by layer. The capacity for the rapid construction of complex segments with minimal material waste is ready to affect many enterprises. In Hassila, Harlin, and Wiklunda et al [56], the Inconel 625 created using Laser-Based Powder Bed Fusion (PBF-LB) was evaluated in a moving contact fatigue test. Test coupons (Ø10 mm) have been created using various shape bearings and sweeping techniques, resulting in fluctuating microstructures and textures. A round and hollow example is mounted in a moving contact exhaustion test between two Ø 140 mm metal rollers, arranged through a spring. After testing, contact tracks are examined using a Scanning Electron Microscope (SEM) and Electron Backscatter Diffraction (EBSD) to detect cracks. Microstructure and anisotropy cracks have been broken down. In Singha, Ramakrishna, and Singh et al [57], the most widely used AM procedures for biomedical applications have been investigated. Uncommon consideration has been paid on Fused Deposition Modelling (FDM) based AM procedure as it is conservative, naturally cordial, and versatile to the adaptable fiber material. From the current survey, it needs to conclude that with the rise of AM advances, clinical services have sufficiently developed to handle basic medical problems quickly and absolutely. However, the constraint of almost every business AM procedure is that their unbending decision to handle material is still unraveled. Considering multi-standard dynamic tools, Zaman et al [58] proposed a non-exclusive choice system that will not only deliver a large number of traded AM materials, cycles, and machines but will also work as a rule for creators to gain solid traction in the AM business by providing commonsense arrangements containing configuration situated and practical material-machine combinations from a current information base of 38 prestigious AM sellers on the planet.

Williams and Butler-Jones et al [59] proposed a structure to adjust existing principles for use with space assets by distinguishing explicit hazards and key components for part quality, determining part criticality and recording material, measuring controls, environmental conditions, and other relevant elements. Relatively strict documentation and danger ID can improve the work and progress of appropriation of the additional substance that is produced for related tasks of space assets, decreasing the cost of the mission and accelerating the extra-planetary industrialization movement incredibly. Schiller et al [60] explored AM's aircraft applications services, while still facing huge numbers of difficulties. Manufacturing is a non-known but very good person using AM strategy. Any airline company that does not focus on AM openings is analyzing that its position is immensely favorable. While costs are a driving force, many applications view the decrease in cost investment funds, as well as in points of concern achieved in terms of usefulness and long-term Return of Investment (ROI). Shapiro et al [61] focused mainly on the lower estimated materials (e.g. preparations, metal, etc.).The disposal of joints through the intense blend of many components in combination with planned improvement methodologies may lead to the development of remarkable or natural parts that cannot be developed for a similar expenditure by using normal preparation strategies. The design streamlines can lead to remarkable or natural components. Singamneni et al [62] created a risk-sharing association. The obligation of the manufacturer of the aircraft is to supervise the last assembling of the aircraft and to ensure that it proceeds in accordance with the standards. The end clients request planes or segments from airplane makers or part suppliers. Recent considerations show that a more expressive and professional, flexible chain organization can be created by combining the AM that is manufactured with the aircraft business.

Kok et al [63] described a wide range of metals AM developments as well as reviews of literature on microstructure anisotropy and heterogeneity, as well as mechanical properties of metallic AM parts. It should be highlighted that either the outstanding microstructural highlights or the assembly gaps contributed to the anisotropy and variability of the metal

AM pieces. Finally, we present closing remarks on the best-in-class research on this topic, as well as potential reactions to the anisotropy beat and heterogeneity of AM metal parts. Laureijs et al [64] showed that, regardless of the simplicity of the engine section, when considering the part update for AM and related lifetime fuel investment funds of the additive section, the additive part and configuration is less expensive than the one designed for a wide range of situations, including higher volumes of 2,000 to 12,000 sections per year. Additionally, the chances of lowering costs include getting material costs down without trading off quality, delivering vertical shapes in proportion to even forms, and expanding measure control in order to empower reduced testing. Herzog et al [65] described the unforeseeable link between AM processes, microstructure, and metal properties. It clarifies the basics of Laser Beam Melting, Electron Beam Melting, and Laser Metal Deposition and presents economically accessible materials for different cycles. From this point on, microstructures for the additive steel, aluminum, and titanium mills are introduced. Uncommon consideration is given to AM's explicit grain structures, which come about because of the complex warm cycle and high cooling rates. Werken et al [66] examined the work that has been carried out in this rapidly developing territory to date. In particular, the impact of fiber fortification on the structure and mechanical properties of 3D printed parts is explored within the writing group. The upper limits for the malleable properties of carbon fiber composites are hypothetically assessed and contrasted and tentatively estimated. A possible combination of industry 4.0 advancements with aeronautical support was proposed by Ceruti et al [67]. New developments such as “Augmented Reality” and “Additive Manufacturing” can provide a better approach to complete support activities in the context of a conventional approach. Additive assembling can help to maintain a strategic distance from huge storage tanks and cut the calculated chain: a section can be manufactured in metals such as aluminum or titanium due to the availability of a reasonable AM machine and powder. Besides, high-tech technologies such as Abrasive Water Jet (AWJ) cutting is used in the aviation industry [68].

### 2.4. The Future Prospect of AM

In the future, the hybrid machines combined with AWJ and AM will be used for having net-shaped airborne parts. Martin et al [69] provided an extensive survey of 3D printing processes in terms of the fundamental techniques used, materials used, their current status, and applications in different industries. In terms of strategy, Fused Deposition Modeling (FDM) is one of the most widely recognized 3D printing advances due to its ease, effortlessness, and rapid processing.

As it was mentioned before, the use of AM technologies has become increasingly widespread for almost 30 years. The studies approve that the AM technology augments the weight reduction researches in the aviation field. Weight reduction is an effective way for decreasing the carbon footprint [70]. Sustainability is another important asset for the usage of the AM in the aviation industry. According to Huang et al. AM is anticipated to grow as a main fabricating technology in a future sustainable society [71].

## 3. Results

A comparative analysis is prepared based on the objectives, applications, results obtained, and the scope for further research obtained from existing literary works. Some remarkable studies are provided in Table 1 in terms of different industries such as medical, aerospace, and aviation

**Table 1.** Quantitative literature on AM processes and applications

| Study | Objective | Applications | Results | Scope |
|---|---|---|---|---|
| 6 | To make a comparison between thermoelastic stress analysis and theoretical results of additively manufactured aerospace brackets | Aerospace brackets | The mechanical behavior of the Additively Manufactured brackets was examined. In the conclusion, manufacturing of the aerospace brackets using AM technique was found feasible. | Generating the CAD models based on reverse engineering techniques can be helpful for manufacturing the aerospace brackets using AM techniques. |
| 11 | To provide information on handling lighter aircraft parts with the studies of Topology Optimization (TO) and Selective Laser Melting (SLM). | A sample aircraft part. | The TO was successfully implemented to the aircraft sample part. At the end of the study, the material volume decreased by 54% and the 28% weight reduction was gained. | Using TO and AM studies on an aircraft part can result in decreasing the material volume and weight. |
| 21 | To provide a brief review of the key factors while manufacturing an aerospace product using AM. | Industry design tools | AM makes accurate predictions representing the microstructure of a part. | It suggests the up gradation of traditional notions for improving AM part fabrication. |
| 26 | To evaluate the production volume for AM techniques. | Commercial aircraft industry | AM is found to be adequate for small to medium-batch productions of end-usable metal products. | The assembly cost needs to be reduced for further studies. |
| 28 | To calculate the overall changes in life-cycle energy and greenhouse gas Emissions in association with AM technologies. | Light machine aircraft manufacturin g industry | It briefs the role of AM to ensure long-term usage of energy. | Improvement needs to be incorporated in the use phases to save energy. |
| 41 | To make a Research of AM Techniques for producing Unmanned Aerial Vehicles (UAV). | Unmanned Aerial Vehicles | The study provides information about the usage of AM technologies for producing UAVs. The challenges such as reinforcement areas have been highlighted. | The increase in the demand for UAV manufacturing will be a leverage of AM usage. |

| | | | | |
|---|---|---|---|---|
| 52 | To evaluate Inconel 625 produced using PBF-LB in a rolling contact fatigue test. | AM built cylinder and the conventionally build cylinder | Initially, a constant vibration level was observed followed by slowly growing increasing vibration levels. | The small damage sites need to be reduced. |
| 53 | To review a few of the largely used AM techniques for biomedical applications. | Biomedical industry | It reviewed the different techniques needed for producing metal powders, polymer/composite feedstock, and ceramics filaments for various AM techniques. | It further develops parts in combination with magnetic and non-magnetic properties to support applications of electronics and electrical. |

## 4. Conclusion

Conclusionally, the findings gained from this study are given as follows;

- AM technologies are effectively used in high-tech fields such as the aviation and aerospace industries.
- The AM process reduces time and expenditure from the planning stage to assembly. Besides, this technology also provides cost-effective solutions for tools such as fixtures and holders which are required during conventional manufacturing processes. Tooling delays, which normally take some time for a job unwanted since these delays are costly. The actual state of the use of the additional material in the aviation industry is determined by the open literature. The valuable jobs applied to substances that make progress can be played in the stock and the structures of the aircraft company are nicely explained.
- In any event, the monetary advantage, the efficiency of plans, survey, testing, and assembly and cycle improvements are much more significant than the shirking of the tools. As far as time is concerned, a further AM advantage is that the creation begins immediately when the part configuration is provided.
- The basic benefits of additional components and the ordinary necessities of different types of aircraft sections are planned for the methodological classification. The areas of implementation are clustered according to the basic benefits, which are illustrated in depth by models that rely on applications. The advantages and instances of the aberrant utilization of AM inside the airplane area are featured. There are distinguished consistency statements and certifying barriers that hamper further AM progresses. The progress in enhancing AM standards is evaluated, and different instructions are characterized by a wheel diagram at different points in the production specifically of AM technologies.

Eventually, this review shows that the manufacture of AM has an enormous challenge in the aviation industry, which can be fully understood when developing new technologies guidelines are fully established. Besides airworthiness issues should be applied when an additively manufactured part is installed to an air vehicle.

## Conflict

*The author has no conflicts of interest to declare.*

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