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Review Article

Additive Manufacturing for Aerospace from Inception to Certification

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Metal additive manufacturing (MAM) does not require any preface for its potential applications in various engineering and technological sectors. This article comprehensively discusses about the application of additive manufacturing technique specifically aerospace components. The structure of this article begins with an introduction to the current state-of-the-art MAM technologies with the aid of patent landscape analysis. Any manufacturing starts with understating of the manufacturing cycle, so herein, the aerospace manufacturing cycle has been discussed commencing from the design phase and followed by the process parameters selection. The immediate effect after printing is the selection of evaluation parameters, wherein the surface texture analysis of AM printed components is discussed. This paves to discuss about the specific alloys such as titanium alloy and Inconel alloys which are widely used in the aerospace industry. This analysis paves a path for the utilization of these materials to manufacture specific aerospace components which are also discussed. Thereby, the impact of MAM over the aerospace sector and the guidelines to decision making on the suitable variant of MAM has been discussed clearly with the help of earlier literatures. Finally, the qualification and certification procedure are discussed therein, leading to the conclusion about the future scope of MAM in the aerospace sector.

1. Introduction

For decades, the fundamental concept of additive manufacturing had already persisted. It is explained as the method of building three-dimensional components progressively therein through computer model data, layer–by–layer [1, 2]. The very first efforts related to additive manufacturing occurred during the late 1960s by American Battelle Memorial Institute [3], wherein research teams were using laser beams as well as photopolymers to construct solid artifacts in a liquid resin [4]. Developing the feasible marketable practice of SLA, stereolithography technology that took place during 1987 by Charles Hull as a patent holder is being introduced in the market which paves a path to develop the other variants, including FDM (fused deposition modeling), SLS (Selective Laser Sintering), EBM (Electron Beam Melting), and multijet printing, along with other variants that are being in usage today [5]. The initial applications of AMT (additive manufacturing technology) include the machine for Rapid Prototyping (RP) to develop the models and tools for another conventional machining, and eventually, it is effectively grown and reached the stage wherein the complete product developed is reached. Its potential does not stop at that point further accelerating to have a functional product development.

Even so, steadily for the past decade, AM had already made rapid technological breakthroughs as well as has become an increasingly popular method of the research design method. AM is already used in conjunction with conventional manufacturing (CM), such as subtractive manufacturing (SM), that either depends on material removal to create a final product, in niche sectors such as biomedical, aviation, as well as automotive [6]. It has contributed to an increase in the number of start-up companies specializing in Rapid Manufacturing (RM) of components [7, 8]. In the aerospace industry, AM is particularly prevalent in the construction of different individual aircraft components, accounting for 16.6% and 18.2% of the world manufacturing share of the market in 2016 and 2017, correspondingly [9, 10]. One of the primary causes for the same is the requirement for redesigning and part production with reasonable mass and savings in cost but not at the cost of mechanical characteristics of AM parts. A unique characteristic of the FDM used for the manufacture of aerospace parts is its rapid melting and solidification phases which results in faster cooling time and very fine grains when compared with the material characteristics of traditionally machined components. [11–15].

In accumulation, the easy-off processing of these fusion–based ATMs permits for good microstructural topographies such as topology texture along with the grain structure, to be managed through the manipulation over the processing parameters while at the manufacturing stage [16]. This freedom allows for not just the development of sophisticated attributes that would be impossible to machine or fabricate using conventional manufacturing methods, as well as the customizing of microstructures, that are crucial for the construction of high-performance aerospace applications that are frequently utilized in extreme environments, such as higher temperatures, adverse weather, and extended life cycles [17]. Moreover, the economic status of AM variants comprehensively favours the low-volume manufacture of parts for aerospace. A significant factor in the significant expense of manufacturing aerospace parts using existing subtractive manufacturing processes is about their high buy over fly ratio, which is characterized as that of the volume proportion of the main raw material to the finished product. This ratio varies among 10 : 1 as well as 15-20 : 1 in the aviation industry and therefore can reach 40 : 1 besides increasingly complicated part [10, 18].

Advantageous in terms of AM in creating nearly net-shaped products, the buy-over-fly ratio can indeed be significantly reduced and sometimes even close to 1 is to 1 [7]. With the advancement of intrinsic microstructures, increased input material utilization as well as associated material waste, faster processing times, and 3D printing technology is therefore no longer recognized as a prototyping alternative though as a direct production process capable of producing near net-shaped high-quality products [7]. This innovative additive manufacturing technology gives end users increased control over part specific requirements including incurred costs, geometric constraints, and mass [19]. Additionally, MAM's prosperous transformation in the aviation industry creates additional possibilities for sustainable development as well as accompanying supply chain frameworks in the long term. While also additive manufacturing is gaining traction throughout the medical, aerospace, and automotive sectors, it would still be regarded as an emerging technology. Due to the absence of defined procedures as well as certification for AM-developed components, the majority of recent AM utilization in the aviation industry has already been limited to nonmission-specific applications [20]. To tackle these issues, producers, as well as governmental aerospace bodies, are growingly collaborating to innovate novel benchmarks that are compatible with AM's actual abilities [21].

Besides, they were acknowledged by academic researchers and industrialists which specifically use AMT for the part production. Such acknowledgments may reduce the ambiguities and contradictions in various 3D printing technologies and terminologies [22]. Numerous standards have indeed been established to date concerning metal additive manufacturing in summary; these standards have included the ISO/ASTM52900-15 guidelines for AM nomenclature, the ASTM F3122-14 standard for evaluating the material characteristics of MAM parts, and the ASTM F3049-14 standard for categorization of powder metallurgy being used AM systems [1, 23]. Nevertheless, hardly very few guidelines, as well as certifications, have been created in the sense of metal additive manufacturing mostly in the aerospace sector; instances involve MSFC-STD-3716 for spacecraft hardware designed and manufactured using laser powder bed fusion metal additive manufacturing techniques and SAE AS9100 for quality management framework necessities in aerospace, aviation, and defensive system associations. Various attempts are thus expected to properly incorporate metal additive manufacturing standards and, more particularly, to fulfil the criteria of aerospace industries, which have been presently being spearheaded by National Aeronautics and Space Administration (NASA) [1, 23].

Nonetheless, those same defined standards seem to be extremely beneficial to decision-makers as well as the 3D printing community in general and also have served as fundamental guidelines for developing additional aerospace-specific standards along with guidelines. Numerous works have been published that review on state-of-the-art metal 3D printing in a comprehensive way. For instance, Frazier [24] analyzed the diverse metal additive manufacturing classifications and concentrated on the material research, methodologies, company, and environmental challenges associated with MAM. Beyer [25] discussed the potential significance of mass acceptance of additive manufacturing, significantly about creating the required mind-frame between many engineers and producers to fully utilize the benefits of AM throughout a variety of industrial uses,

Table 1: Landscape analysis of MAM in aerospace [30].

S. no	Country	No of patents	Major applicants	No of patents	Year-wise count	No of patents
1	USA	42	The Boeing Company	5	2013	1
2	PCT*	23	California institute of tech.	4	2014	1
3	China	13	The curators of the University of Missouri	4	2015	1
4	EPO**	6	Ebullient LLC	3	2016	6
5	UK	4	HRL laboratories LLC	3	2017	13
6	India	4	Lincoln global Inc.	3	2018	14
7	Australia	1	Mat solutions ltd.	3	2019	26
8			Nanocore tech.	3	2020	22
9			Shanghai aerospace equipment manufacturer co ltd.	3	2021	9
10			United tech co.	3		

including medical, engineering, consumer products, aerospace, and automotive industries. Additionally, Seifi et al. [26, 27] had also concentrated their attention on creating guidelines to aid in the credential and certification of metal additive manufacturing, particularly concerning material, microstructure, and mechanical properties. Additionally, additional investigators examined the application and enormous prospects of metal additive manufacturing in aerospace engineering. For instance, Uriondo et al. [22] described the utilization of metal additive manufacturing and material modeling in the manufacturing and as repair of aerospace components, emphasizing the critical role of regulatory frameworks, airworthiness, and air transport safety in accomplishing such two goals. In this way, Liu et al. [17] have emphasized the specific core competence of nonmetal and metal AM production along with repair of aerospace components and the upcoming trends of prospective AM technology in the business along with the academic perspective of the aerospace industries. Kinsella [28] explains that while metal additive production techniques may still not entirely substitute the conventional manufacturing techniques for manufacturing aviation components, those that may provide a reduction in costs as well as the manufacturing capability for creative features leveraging super-alloys, of that kind as dual-alloy accumulation as well as FGM - Functional Graded Materials, for such USAF - United States Air Force as well as DoD - Department of Defense. Additionally, Nickels [29] stated that perhaps the unresolved challenges of functional integration, geometric freedom, energy consumption, waste reduction, and machine constraints might well slow metal additive manufacturing's adoption for large-scale manufacturing in the aviation industry.

The MAM gained better acceleration in various domains, and specifically, the aerospace industry owing to its costlier metal parts is being predominantly used. So, it is necessary to understand clearly the entire process starting from MAM initial stage up to the product certification stage, based on this article, walkthrough is structured. The progress of the MAM can be revealed by the understand growth curve over the years, at least data of the decade owing to the expiration of Selective Laser Sintering (SLS) patent during 2014. The SLS is one of the pioneers in the MAM technique in the AM variant, in place of searching the broad database wherein converging is harder. In the existing literature, patent databases are considered to be the latest and get updated every minute along with that consolidation related to specific domains is easier than other article clusters. So, the patent landscape analysis is taken as a core identity to understand the growth profile of the MAM variant of AM specifically in the aerospace domain.

The following Table 1 reveals 3 factors that are country, major players, and year versus a corresponding number of patents filed. The inference revealed out the USA is the dominating country in this variant of AM, might be owing to the fact they want to reduce the import of final finished products, and in lieu they can import only raw materials. So, they accelerate the product development within their country leads to reducing the manufacturing cost and time. The major player in this technology is "The Boeing Company" occupying the top of the table. The country of origin of Boeing is the USA, where remarkable industry in the aerospace can be found, considering the growth year was quite good numbers during the last 5 years that is in double digit. All these data depict that this MAM variant of AM has a good scope shortly at least for a decade. AM technique provides greater flexibility in manufacturing opens up a better forum for metal components to be manufactured. The total count is 93 as per the record for the keyword EN_ALL: ("Metal Additive Manufacturing" "Aerospace"). The analysis is made by selecting the option "Single-family member," which means that the same patent filed in multiple countries is considered as one patent.

Every 3D printing technique has its own unique set of material properties, treatment processes, as well as abilities. Nonetheless, the majority of them operate on a point-by-point basis and can use powdered material as more than just a raw resource. Industries such as Solidica in the United States manufacture components using an ultrasonic accumulation methodology [31]. Only Laser Metal Deposition (LMD), Selective Laser Melting (SLS), and Electron Beam Melting (EBM), as well as Wire Arc Additive Manufacturing (WAAM), have been regarded and explained in summary even if they are currently perceived as the four additive manufacturing processes another very acceptable towards the aviation industry, since they are capable of producing nearly completely high-density parts without the use of post-processing (near to 99.9 percentage of density) while comparing over the conventional technique corresponding to their mechanical and electrochemical characteristics [32, 33].

There have been numerous classification schemes for these techniques. Those certain techniques were categorized according to the method by which the resource was available. On this same, yet another side, powder bed integration processing technologies include one or maybe more high-temperature resources for melting the powder, a technique for directing the fusion of the particles to a specific area within each layer, as well as a mechanism for prespreading a seamless layer of powder. MD procedures, from the other side, disintegrate the substance as it has been laid down. SLM and LMD both make use of a high-power laser. EBM, on the other hand, employs an electron beam wherein, WAAM uses plasma arc. Laser-based technology has advanced significantly over the years [34, 35], with smaller intensive areas and increased laser power, as well as wavelengths that are more tuned to the absorption characteristics of metal powder [36, 37]. At present, in every additive manufacturing technique, the laser is utilized in all the variants, therein, they use fiber lasers as a substitute over the carbon dioxide and Nd: YAG lasers. The subsequent sector offers some specific characteristics of LMD, SLM, and EBM through which the ability of an AMT to manufacture high performance parts through laser energy can be fabricated through particle embodiment on the surface [38]. Such embodiments can be made through a coaxial powder feeding system via nozzle and can be synchronized with the laser scanning [39, 40]. They can also be materialized through the tailoring of processing conditions, rate of deposition, scanning method, and materials. As a final point, it is indeed critical to keep in mind that the nomenclature used to describe LMD, SLM, and EBM techniques tend to vary between various organizations.

Additive manufacturing (AM) has the prospects to significantly reduce production time as well as the cost, particularly for aviation parts manufactured of expensive titanium alloys. It is looking to attract widespread interest owing to its outstanding capacity to establish complex components, including fine microstructure, better surface quality, and excellent properties. Significant work has indeed been accomplished in recent decades, which includes fabricating facility development, manufacturing technology development, and specification development. It summarizes the advancement and the status of AM technology and the underlying conditions and the potential applications on civilian aviation in this section. Only with constant ought to reduce the overall weight of airplane, as well as the expense of production titanium alloy parts, involvement in nontraditional 3D printing has increased, whether for a significant portion or tiny portion fabrication. It is assumed that 3D printing technology will provide a strategic vision for something like the production specialized field, including its radically different concept of fast evolution compared to traditional disposal forming, as well as pressured forming, to particularly emphasize the investigation as well as utilization in the aviation industry. At almost the same moment, the advancement of process innovation encourages the emancipation of structural engineering notion and growth. All these mutual advancements will have a considerable impact on long-term aviation production technologies [41]. Let us move forward with the article that MAM has a scope, so it has to be understood from the manufacturing cycle till the certificate of metal products.

2. Manufacturing Cycle—MAM in Aerospace

3D Printing has been at the cutting edge of innovative production technology yet does have the same prospects to transform producing by radically altering design and endeavor belief systems. A concise evaluation of existing metal additive manufacturing procedures, producible materials, associated defects, and evaluation techniques (destructive and nondestructive) is described. Specifically, the AM structural optimization techniques are investigated, along with their associated risks and restrictions. Eventually, a research report from the aviation sector is introduced, along with several case studies. Figure 1 depicts the straightforward production cycle for additively manufactured metal components. The additive manufacturing market is rapidly expanding, and numerous AM machine providers have been accessible. While the mechanical and physical properties of something like the subsequent parts are occasionally superior to those of the started to bring contemporaries, reproducibility as well as standardization continues to be a challenge. Microstructural imperfections from either the resources or the procedures seem to be the consequence of the questionable reproducibility, and their characterization can always be accomplished using a variety of methods. To increase the growth of additive manufacturing, the technology cycle must be rethought. Although many instruments are already obtainable for its segments (design optimization and process simulation), this still simply lacks unification and competence. Additionally, the incorporation of production restrictions into design techniques is still very much in infant stages, even though other methods and techniques have also been reported. Strength analysis is a very important challenging issue caused by a variety of manifestations such as anisotropy, porosity, and residual stress. Numerous cost-effective examples exist in the aviation sector, where expense, as well as weight savings, has been validated. Due to the widespread acceptance of its prospects, endeavor requests are indeed being started opening to fund its further growth (namely, ESA Initiatives). Notwithstanding, their application would be limited to difficult components (concerning the material composition, shape, and/or weight) [42].

2.1. Parameters Selection for Invar 36 Processing. Owing to its poor correlation of thermodynamic enlargement, Invar 36 (I36) might have acquired tremendous prominence in a variety of industrial sectors, which include the aerospace industry. The goal of this article is to provide a summary of the study necessities in metal 3D printing. A comprehensive investigation of the effect of processing variables on the reliability of the components manufactured is introduced. This research is helpful for such additive manufacturing

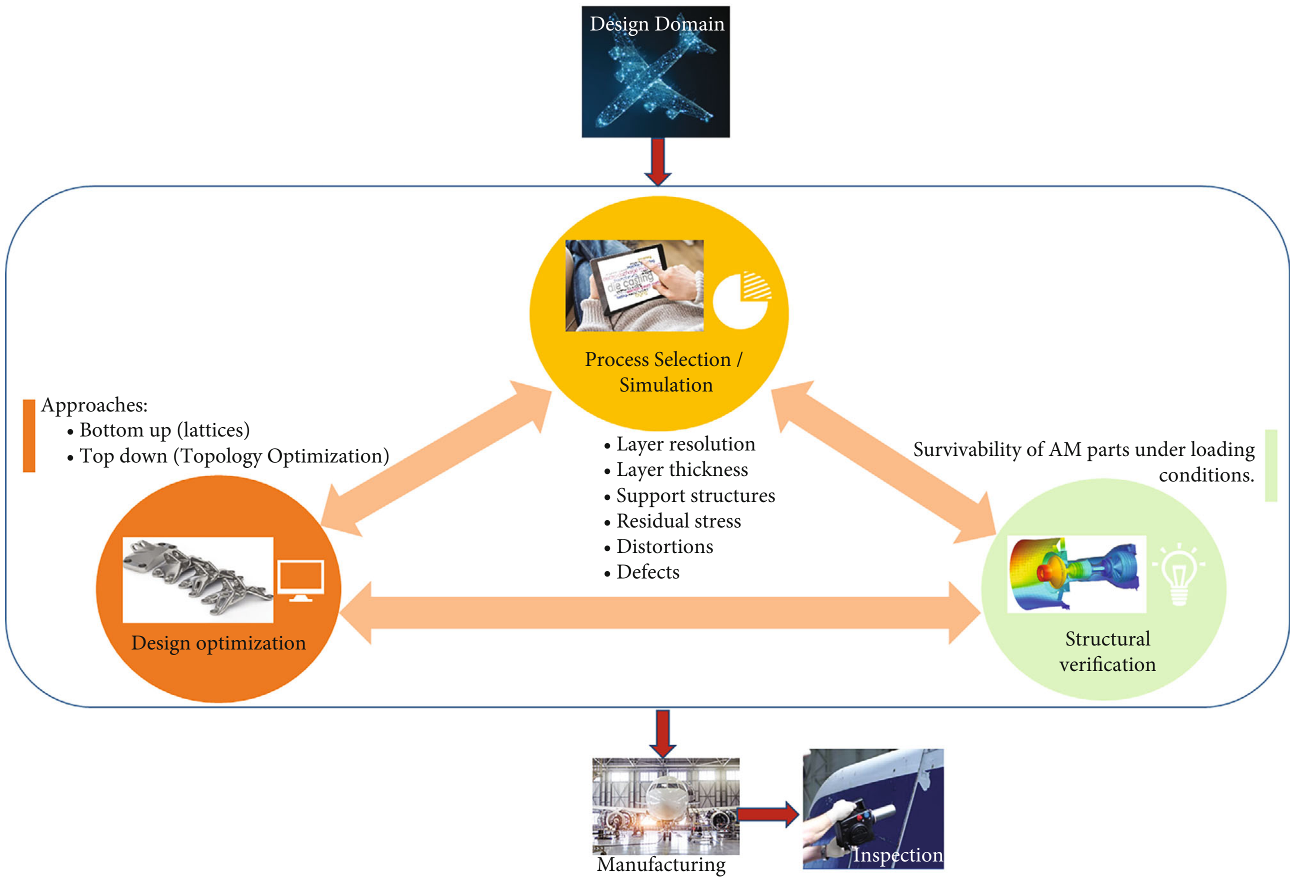


Figure 1: Manufacturing cycle.

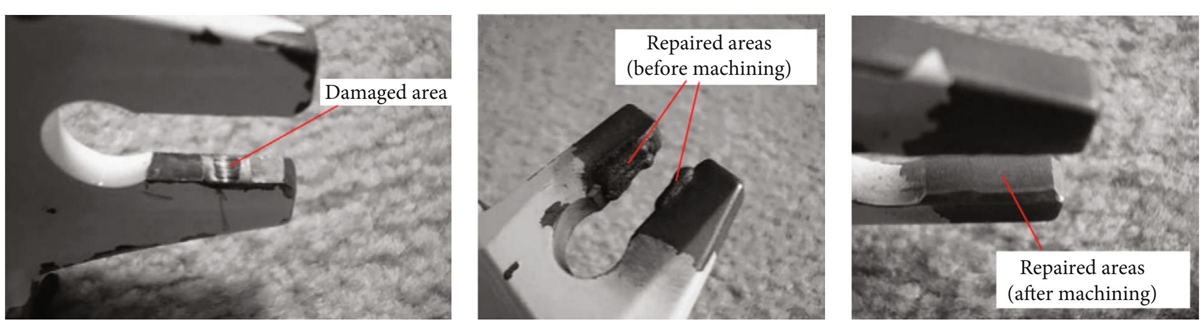


Figure 2: Repairing using direct energy deposition method [45].

company's long-term development. The purpose of this article is to determine the processing variables necessary for fabricating dense components from I36 (UNS K93600) just using the selective laser melting method. Using only SLM equipment, an organization of cubes has been manufactured utilizing processing variables from I36 particles. Researchers evaluated the density, microstructures, and surface features among those cubes. Data gathering procedures were used to generate obtained data. The article discusses the effect of process variables upon this density of the components manufactured and establishes and suggests collections of SLM production variables for manufacturing high-density Invar 36 parts and structural features. Invar 36 is well-known in the aviation sector for some of its minimal coefficients of thermodynamic development. It could be used in a variety of implementations requiring a high degree of strength properties. This comprehensive study conducts a thorough analysis of the effect of SLM processing conditions upon the density of components manufactured from I36.

For all of this research, the maraging steel 18Ni (300) is often been using factors that can explain a benchmark. The research reveals also that the density of something like the laser energy does indeed have a significant effect somewhat on the density of either the components manufactured. The density enhances proportionately to this same energy density till the reaches a certain point affiliated to melting.

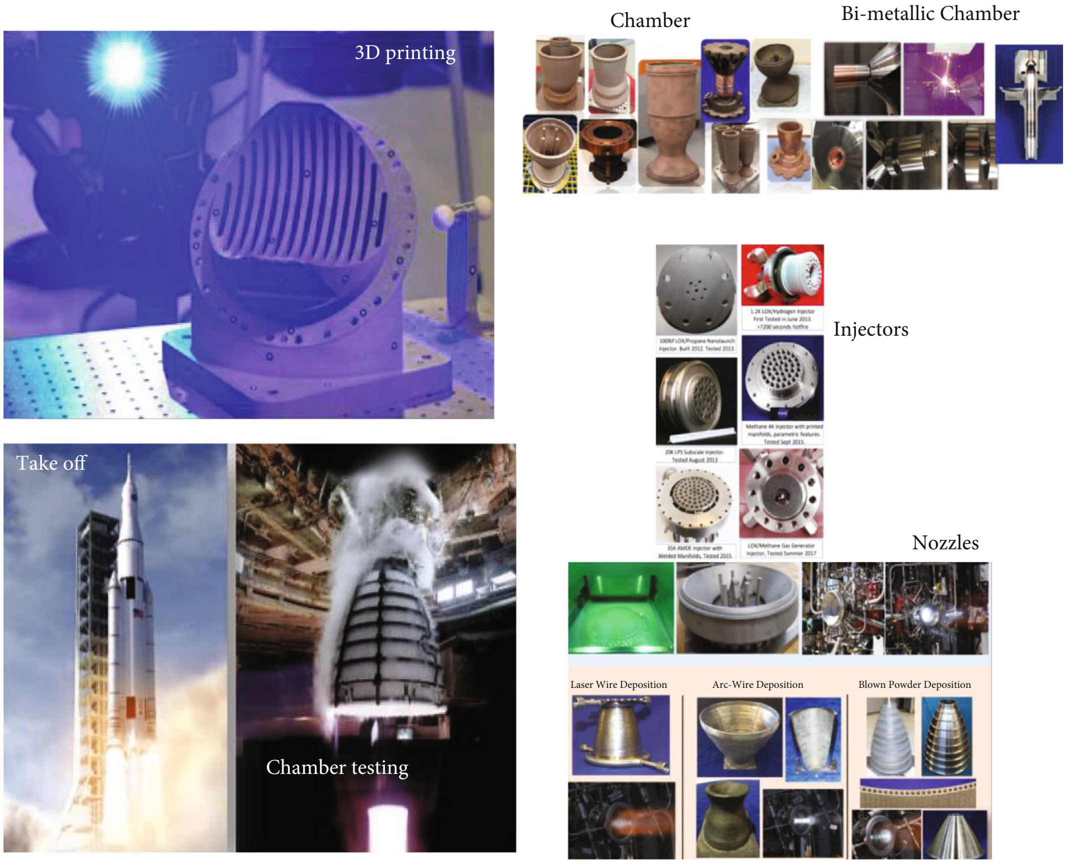
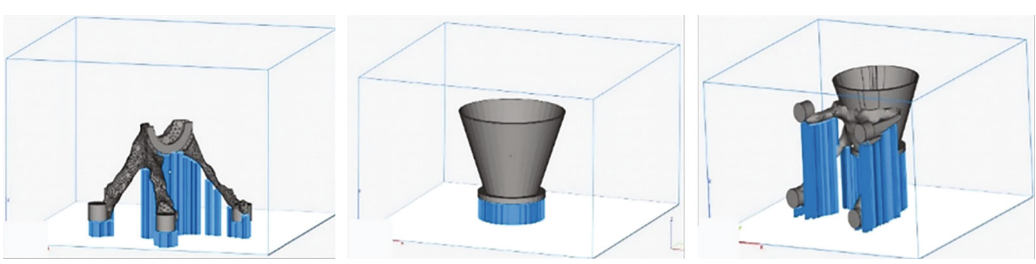


Figure 3: Engine parts are 3D printed [53]. (Courtesy: NASA).



(a) (b) (c)

Figure 4: Antenna manufactured as 3 parts with topology optimized [54].

Following that, this same part is probably quality degrades as a result of thermal stresses and stimulated residual stresses. The assessment determined that I36 requires a sequence of SLM processing variables capable of generating roughly 60 to 75 J/mm^3 of laser energy density to disintegrate completely (maraging steel requires approximately 67.5 J/mm^3). Even though I36 seems to have a relatively low thermal conductivity compared to maraging steel, it does have an elevated energy density due to its relatively high thermal decomposition point. Thus, I36 requires a high amount of laser energy to melt completely. The proposed energy density variation may have an effect on other factors, such as component density and microstructure. Among those same variables are percent elongation, tensile strength, hardness and residual stress. As a result, additional tests are required to analyze additional confounding variables. These experiments could perhaps establish the optimal range of laser energy densities necessary to completely melt I36 without impairing its efficiency [43].

3. Optimization and Characterization of Surface Texture

The discipline of additive manufacturing (AM) is accelerating its growth, to novel printing technologies and alterations to existing techniques being introduced daily. Powder bed

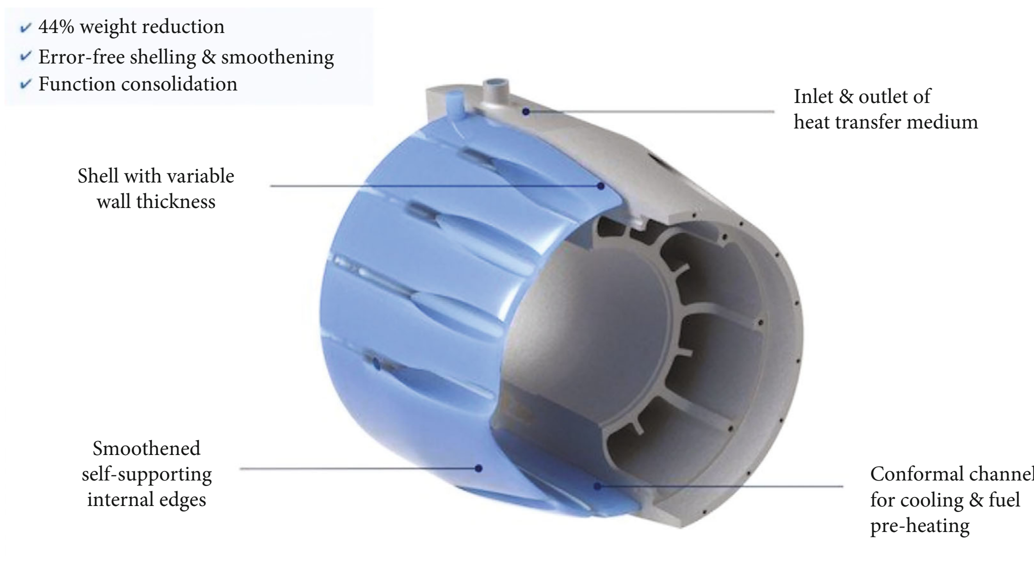


Figure 5: Optimized housing [55]

Figure 6: RF antenna [56]

fusion (PBF) needs to stand out among the numerous additive manufacturing (AM) technology solutions as the primary methodology for fabricating metallic parts for aircraft components. This article will discuss this same texture and modeling of metal part surfaces manufactured by PBF. Although the exterior texture among those parts is extremely complex and unique, it is necessary to understand their distinctive character to accurately characterize those. This section covers the best practices for determining the surface texture of PBF-built parts depending on the printed module's surface properties, optimizing the surface textures even during the construction phase and utilizing various surface modification methodologies (postprocessing) to achieve smooth surfaces. For the aviation sector, additive manufacturing is an advisable method for producing sophisticated configurations with optimized weight reductions and economic viability. Nevertheless, the printing technology produces a considerable amount of surface roughness. Those certain surfaces seem to be extremely challenging to characterize and analyze. There has been a sequence of procedures that could be taken as the best techniques to ensure that surface roughness values have been reported adequately in the publications. Nonetheless, this outer layer can be optimized using a variety of surface modification methods; however, sacrificial metal should always be incorporated into the component to facilitate a surface smooth finish.

A surface treatment methodology's ability to remove surface stress growers including such notches and incompletely melted granules seems to be extremely coveted for outstanding mechanical efficiency. Numerous surface finishing techniques have been shown to significantly enhance the mechanical effectiveness of additively manufactured components. Nevertheless, the body of knowledge on this subject is extremely unpredictable, of research findings utilizing a variety of distinct fatigue tests on some kind of variety of distinctive materials for a variety of varying alloys with a wide assortment of various surface modification procedures. Additionally, the surface finish assessments disclosed in the publications are hard to comprehend leading to a shortage of sufficient data to assign a purposeful value toward the disclosed surface roughness criterion. Additionally, there may be an evident lack of available standardized data that provides an even more complete picture of the influence of surface modification on parts' mechanical characteristics [44].

4. Impact of MAM in Aerospace

MAM has progressed itself from early life in investigation towards the manufacturing of a diverse array of commercial

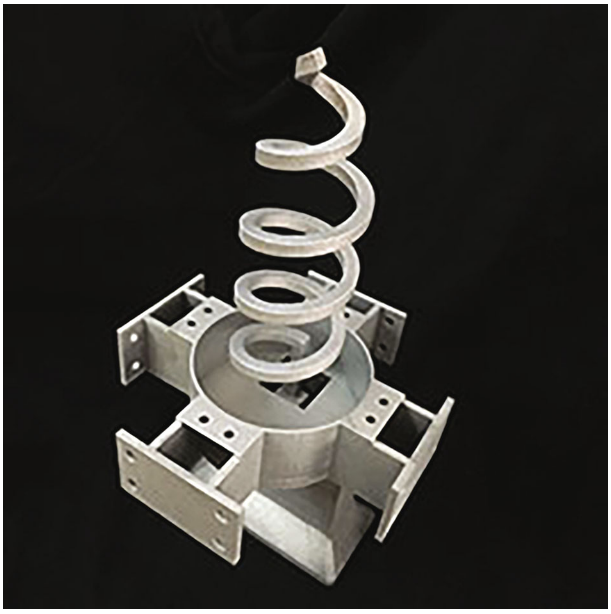


Figure 7: Antenna with feed [57]

application areas. Metal additive manufacturing is particularly famous in the aviation industrial sector at the moment for manufacturing and also repairing numerous parts for commercial and military airplanes and also external spacecrafts. To begin, the categories of additive manufacturing technologies some of which are frequently often used in fabricating metallic components. Whereupon, the transformation of metal additive manufacturing throughout the aviation sector is discussed, from designing to fabrication rocket engines as well as internal structures. Additionally, current unresolved issues preventing metal additive manufacturing from having entered widespread adoption in the aviation sector are explored, including standardization, sustainability, qualification, and also supply chain development.

Figure 2 reveals the repairing of a component using direct energy deposition additive manufacturing method. As MAM progresses to emerge, the aviation sector is preparing to ensure its success. While concerns about part certification, as well as sustainable development, persist, considerable advancement is anticipated in the coming years as governing agencies and business professionals collaborate to demonstrate guidelines and competencies for metal additive manufacturing. Major benefits of additive manufacturing, especially its design adaptability and a low waste of materials, had already resulted in the assimilation of metal AM in and out of numerous aviation producers' ongoing and prospective manufacturing lines. Looking at the latest manufacturing great successes, it has become clear that metal additive manufacturing will possess a lengthy influence somewhat on the aviation sector, laying the groundwork during the succeeding generation for designing products [45].

4.1. Design for Aerospace MAM. Our conversation will cover best practices for determining the surface texture of PBF-built parts depending on the printed module's surface properties, optimizing the surface textures even during the construction phase and utilizing various surface modification methodologies (postprocessing) to achieve smooth surfaces. [46].

5. Aerospace Alloys

In the case of considering aerospace material, the list is very long, and in the survey, only a few alloys taken not on no specific options are chosen for the selection of the following alloys. One of the alloys used in aerospace is Inconel 625, while attempting for WAAM technique, and it reveals very fine columnar equiaxed grain formation and has no sign of secondary dendrites. So, this material shows the required strength which could be adopted for the aerospace industry [47]. Other than this alloy, titanium and nickel alloy is discussed.

5.1. Ti-6Al-4V. All microstructure simulation tools demonstrate the critical nature of developing an integrated and generalized concept for the MAM methodology as a feature of melt pool topography and resulting microstructure. To accomplish an exact simulation, establishing databases, respectively, and recognizing phenomena are the optimal methods for filling on some discrepancies at the moment. Additionally, it is critical to understand developing model because all anticipated outcome does not result in innovative perspectives. When simulating crystalline structure throughout MAM, it is preferable to create methods that contain essential guidelines or concept parts from whom the quite complicated crystalline structure, as well as texture, could indeed establish on their own. Alternatively, these same simulation models are just not suggestive and are mere representations of existing knowledge [48].

By utilizing additive manufacturing, researchers were prepared to create a versatile dimensional nanopositioning deformation to increase mechanical deformation and bandwidth encapsulated within a simple design. To begin, it characterized the material characteristics of EBM-printed Ti-6Al-4V bridges and especially compare them to the others of bulk metal bridges. Researchers discovered that, due to the porosity over surfaces, the printed bridges behaved like a smooth surface with such an estimated mean Young's modulus of 41 Giga Pascal since less than the uppermost dimensions were considered [49].

Various process specifications could be researched utilizing Ti6Al4V diamond-like formations and demonstrated heretofore unidentified data about the microstructure and mechanical characteristics of cellular structures. To begin, in the aspects of process parameters, lateral fasteners should indeed be avoided, except if the orientation of something like the force applied would be recognized and can be adequately substantiated by any of the other stiffeners. Furthermore, heat treatment methods had the same influence on all constructing orientations. It is recommended that the results, as well as conclusions from any of the actual work, be considered when developing additive manufacturing processes for metallic cellular structures for aviation applications [50].

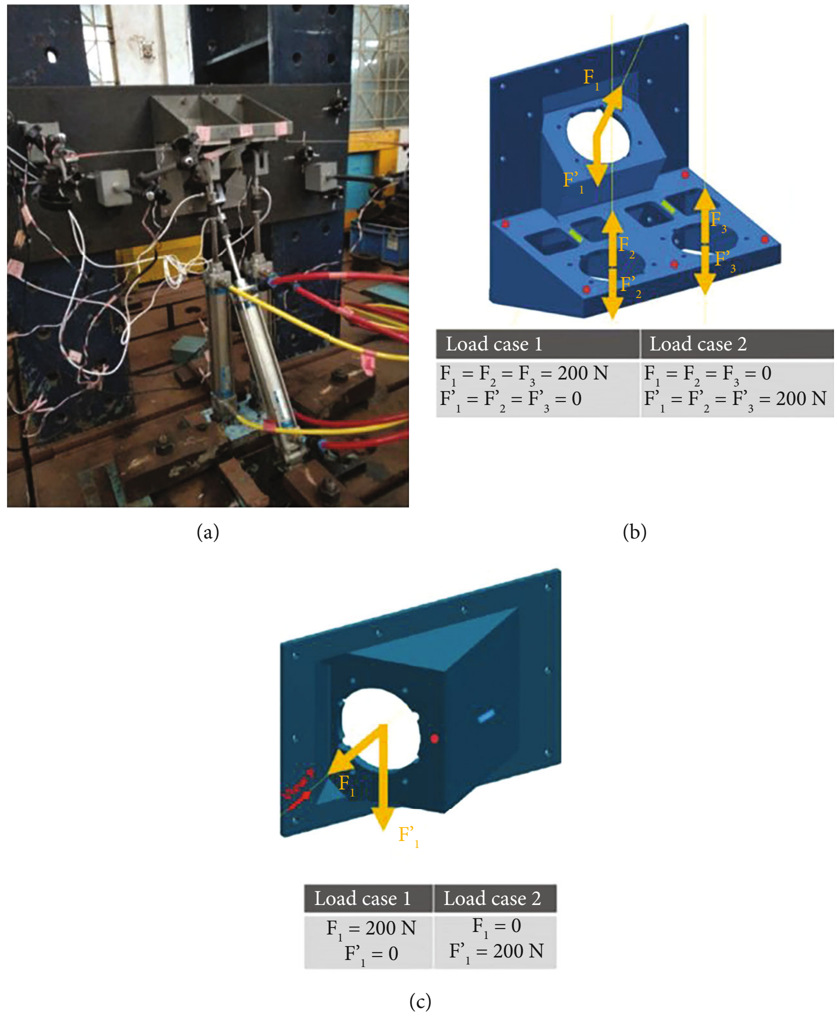


FIGURE 8: Brackets [58].

5.2. Inconel 718. Inconel 718 seems to be an extensively utilized alloy in metal additive manufacturing due to its broad scope of implementations in aerospace, gas turbines, and other high-temperature structural parts. Owing to its capacity to control microstructure, mechanical characteristics, and maintain high accuracy, the DED methodology had already been extensively used for aviation parts restoration. The findings manufactured while collaborating with DED on aviation parts repair were analyzed to determine the difficulties experienced throughout the methodology. Numerous issues have always been evidenced, including the appearance of micropores at the component's edges and alteration inside the microstructure to increase diffusion height. As more than just a result, the research concentrated on demonstrating the DED process's utility in repairing metallic aviation parts and recognizing the obstacles associated with the component's geometric shapes and metallurgical characteristics [51].

6. Aerospace Components

6.1. Flap Lever. Weight enhancement and cost savings on build to fly ratio, fuel costs, and time-to-market, combined with the convenience of personalization via additive manufacturing, could very well offer one such product an advantage. The generic remarks of numerous constraints and their potential implementation to an important system aviation part (flap lever) might very well pave the way for more practical deployment of crucial aviation components to comparable design purposes [52].

6.2. Rocket Engine Parts. Impactful hot-fire going to test of even a full-scale additive manufacturing component that will be airlifted on NASA's (SLS (Space Launch System)) RS-25 Pogo Z-Baffle—reduced sophistication from 127 to 4 welds by utilizing an established DFAM [53]. Figure 3 shows the 3D-printed aerospace engine parts.

6.3. Satellite Antenna. Figure 4 compares the support structures created whenever the horn, as well as antenna bracket, has always been printed separately here to support structures produced even before their interfaces were indeed combined. Material utilization information for building parts and fabrication structural components could be estimated using software specific to the AM machine's equipment set.

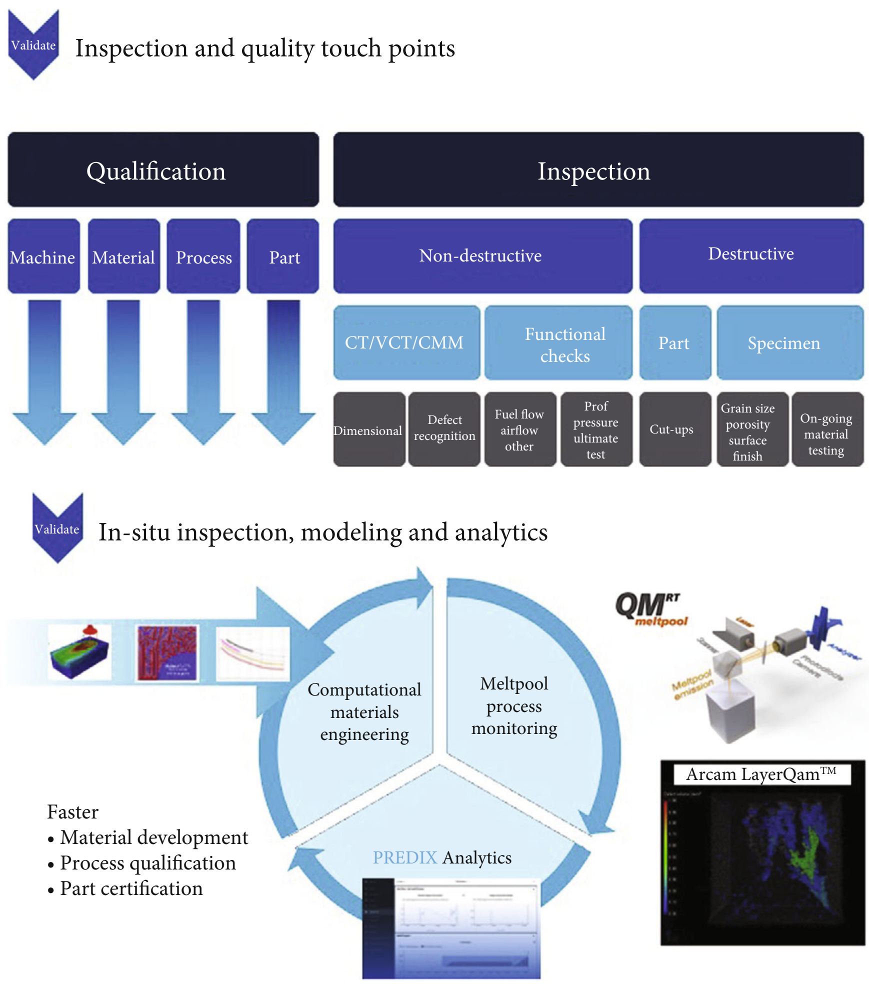


Figure 9: Certification cycle by GE [59].

Figures 4(a) and 4(b) illustrate the bracket and horn produced separately, with the required support structures indicated in blue. The horn and bracket are shown in Figure 4(c); within that configuration, the part has been positioned in the AM equipment of this same horn polishing prerequisites, as its reliability seemed to be crucial for the antenna's core function. As a result, a significant portion of assistance must have been engendered during the bracket's production process, influencing the quantity of material available for consumption, and, consequently, the weight starts changing feature [54].

6.4. Turbogenerator Casing. Enriquez, Chief Executive of KW MicroPower, begins to question just why someone might require to recognize any of it other than the 44 percent weight savings. This same newly configured housing of microturbine generator incorporates a conformal cooling channel established through differential shelling and automated smoothing. Figure 5 reveals the optimized housing [55].

6.5. RF Feed Antenna. The part seems to be an antenna based on RF feed something that was installed on the GSAT-19 telecommunication satellite, which was launched by India's largest launch vehicle forever, is GSLV Mk III D1 (Geosynchronous Satellite Launch Vehicle). Figure 6 represents the RF feed antenna [56].

6.6. Antenna Integrated Helix Feed. The "Antenna Incorporated Helix Feed" would be a component of a transmit antennas scheme that amplifies radio frequency signals. RF waves have always been typically carried by helical geometric shapes, and an electron beam has always been allowed to pass axial direction and segmentation-based helical configuration. There at the edge of the helical configuration, the RF wave and the electron beam converge, actually resulting inside of that this amplified RF wave. In summary, helical geometries do seem to be difficult to fabricate using traditional manufacturing methodologies without experiencing significant errors or waste. Anyway, to Additive Manufacturing's freedom, helical frameworks also seem to be difficult to fabricate. Wipro 3D skilfully realized the "Antenna Incorporated Helix Feed" by leveraging its specialized powder bed method know-how. Figure 7 represents the antenna integrated helix feed [57].

Table 2: Major variants of MAM for aerospace.

S. no	Technique	Parameters	Scale factor*	Reference
1	L-PBF	Part complexity	10	[60]
		Accuracy	10	[61]
		Surface finish	9	[62, 63]
		Overall cost savings	2.5	[64, 65]
		Material utilization	3	[64, 65]
		Efficiency	5	[66]
		Postprocessing requirements	3	[67, 68]
		Mechanical properties	5	[69, 70]
		Platform flexibility	2	[71, 72]
		Maximum volume available	5	[73, 74]
		Building rates	2	[60]
		Defects	9	[75]
		Contamination risk	8	[76]
		Safety—prone to fire	9	[77]
		Energy consumption	5	[78]
		Dimensional accuracy	10	[63]
		Build speed for Ti6Al4V	10	[78]
		Maximum build volume	6	[78]
		Minimum layer thickness	10	[63, 79]
		Good surface roughness	10	[62]
		Overall cost	8	[80]
		Machinery cost	7	[81]
		Raw material cost	9	[82]
		Operational cost	8	[83]
		Maintenance cost	8	[84]
		Markforged; metal X (gen 2) 300 × 220 × 180 mm	—	[85]
		Renishaw; RenAM 500 M– 250 mm × 250 mm × 350 mm	—	[86]
		E.O.S; EOS M400 400 mm × 400 mm × 400 mm	—	[87]
		AddUp; FormUp 350 350 mm × 350 mm × 350 mm	—	[88]
		MetalFAB1 420 × 420 × 400 mm	—	[89]
		XACT metal; XM300C (1118 × 711 × 1397 mm	—	[90]
2	EBPBF	Part complexity	9	[60]
		Accuracy	9	[61]
		Surface finish	8	[62]
		Overall cost savings	2	[64, 65]
		Material utilization	3	[64, 65]
		Efficiency	5	[66]
		Post processing requirements	3	[67, 68]
		Mechanical properties	6	[69, 70]
		Platform flexibility	2	[71, 72]
		Maximum volume available	4	[73, 74]
		Building rates	5	[60]
		Defects	9	[75]

Table 2: Continued.

S. no	Technique	Parameters	Scale factor*	Reference
		Contamination risk	8	[76]
		Safety—prone to fire	9	[77]
		Energy consumption	8	[91]
		Dimensional accuracy	9	[92]
		Build speed for Ti6Al4V	9	[93]
		Maximum build volume	3	[78]
		Minimum layer thickness	9	[94]
		Good surface roughness	8	[62]
		Overall cost	10	[80]
		Machinery cost	9	[81]
		Raw material cost	7	[82]
		Operational cost	6	[95]
		Maintenance cost	8	[96]
		Arcam EBM spectra H 1,328 x 2,344 x 2,858 mm	—	[97]
		Arcam EBM spectra L 1,328 × 2,344 × 2,858 mm	—	[98]
		Freemelt ONE 100 mm H × 100 mm Dia	—	[99]
		Tada electric EZ300 250 × 250 × 300 mm	—	[100]
		Y150 China 150 × 150 × 180 mm	—	[101]
3	LMD	Part complexity	8	[60]
		Accuracy	6	[61]
		Surface finish	7	[63, 93]
		Overall cost savings	4	[64, 65]
		Material utilization	6	[64, 65]
		Efficiency	5	[66]
		Post processing requirements	3	[67, 68]
		Mechanical properties	7	[69, 70]
		Platform flexibility	5	[73, 74]
		Maximum volume available	8	[73, 74]
		Building rates	5	[60]
		Defects	9	[75]
		Contamination risk	8	[76]
		Safety—prone to fire	9	[77]
		Energy consumption	7	[102]
		Dimensional accuracy	7	[66]
		Build speed for Ti6Al4V	10	[93]
		Maximum build volume	8	[103]
		Minimum layer thickness	6	[93]
		Good surface roughness	7	[63, 93]
		Overall cost	6	[80]
		Machinery cost	5	[104]
		Raw material cost	6	[104]
		Operational cost	2	[104]
		Maintenance cost	4	[105]
			—	[106]

Table 2: Continued.

S. no	Technique	Parameters	Scale factor*	Reference
		OPTOMEC; LENS CS 800 AM CA 2997 × 2840 × 2662 mm	—	[107]
		InssTek MX-standard 800 × 1000 × 650 mm		
4	WAAM	Part complexity	5	[60]
		Accuracy	2	[108, 109]
		Surface finish	3	[110]
		Overall cost savings	8	[64, 65]
		Material utilization	9	[64, 65]
		Efficiency	9	[111]
		Post processing requirements	6	[67, 68]
		Mechanical properties	9	[69, 70]
		Platform flexibility	8	[73, 74]
		Maximum volume available	9	[73, 74]
		Building rates	10	[112]
		Defects	0	[75]
		Contamination risk	0	[66]
		Safety on fire	9	[109]
		Energy consumption	9	[113]
		Dimensional accuracy	5	[66]
		Build speed for Ti6Al4V	5	[114]
		Maximum build volume	10	[114]
		Minimum layer thickness	3	[115]
		Good surface roughness	3	[116]
		Overall cost	2	[80]
		Machinery cost	2	[117]
		Raw material cost	0	[118]
		Operational cost	0	[83]
		Maintenance cost	2	[117]
		AML3D ARCEMY	—	[119]
		METAL XL	—	[120]
		GEFERTEC–3DMP	—	[121]

6.7. Rocket Brackets. Two different types of brackets for aviation implementations have always been created using LPBF/DMLS additive manufacturing process, pressure preheating, and meticulous categorization. Figure 8 represents the rocket brackets.

By having to add supplemental stock to relatively thin zones and attempting to remove in postprocessing, the deformation observed on relatively thin zones might have been prevented. Mechanical characteristics throughout the stress-relieved state encounter ASTM F 3184-16 requirements, as well as the obtained characteristics, are comparable to those of molded products. Sometimes in remedy strengthened conditions, the LPBF technique seems to provide superior mechanical characteristics to benchmark molded products. Structural experimentation established that sufficient margins seem to be obtainable inside the constructed brackets through the use of the LPBF AM pathway, and supplemental weight savings have always been frequently accomplished across topology enhancement via DfAM (Design for Additive Manufacturing) [58].

7. Certification along with Qualification

Mostly in the aviation industry, additive manufacturing is progressively has been used to create novel metal goods. Nevertheless, as is the case with other commercial materials and processes, variability in component quality and mechanical characteristics owing to potential defects, insufficient control of dimensions, residual stress surface roughness, and microstructure could perhaps consequence in designs which thus preclude the utilization of a component in high-value or mission-critical applications. To guarantee quality and consistency and also to facilitate wider adoption, additively manufactured (AM) hardware requires vigorous quality control and also qualification and certification (Q&C) methods. Unfortunately, there are few high-quality documents obtainable publicly, forcing aerospace companies and organizations to develop their standards. Additionally, where components and frameworks are required to be certified by regulators, requirement interpretations have all been even now progressing. This subsection discusses current quality and compliance standards for metal additive manufacturing hardware used for aviation applications from both an industry and government perspective. The existing state of Q&C standardization is summarized, and guidelines are managed to make to accelerate the adoption of metal additive manufacturing hardware in the aviation industry [59]. State-of-the-discipline quality assurance and control (Q&C) methodologies, utilized by the business sector and also government to regulate AM materials, procedures, and components, have indeed been summarized [122–125]. Figure 9 shows the certification cycle by GE.

Table 2 enlists the quality parameters considered for major variants of AM techniques which were used predominantly for manufacturing of aerospace components. Scale factor in Table 2 denotes the impact of the process parameter over the AM technique to render quality products.

8. Concluding Remarks

MAM in aerospace is a wider coverage from manufacturing a minor component to complete engine and further leads to building the aircraft. The trend is always positive despite pandemics, and the research in this domain is never been stopped at any phase. Future prediction is up to the complete manufacturing of aircraft, and the era of MAM continues therein the manufacturing augments to aerospace. It means that printing in space accelerates than manufacturing on the earth. This technique is another way to emphasize interplanetary movements. The scope of this article is initiated with the manufacturing cycle; thereby, the discussion about the aerospace manufacturing cycle, therein, flows through over the design phase and followed by the process parameter selection. The immediate effect after printing is evaluation parameters, therein surface texture analysis is discussed. Thereby, it kindles to discuss the specific alloys which are widely used in the aerospace industry, and titanium alloy and Inconel alloys are discussed. This analysis paves a path for the utilization of these characters into specific components that are being discussed in this segment. Therein, the impact of this MAM over the aerospace sector and the guidelines to decision making on a suitable variant of MAM are discussed. Finally, the qualification and certification procedures are discussed, thereby concluding with the future scope of MAM in the aerospace sector.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author upon request.

Disclosure

This study was performed as a part of the employment of Hawassa University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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