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Metal Part Production with Additive Manufacturing for Aerospace and Defense Industry

Koray ÖZSOY*[1], Burhan DUMAN, Diyar İÇKALE GÜLTEKİN
[1] Isparta University of Applied Sciences, Senirkent Vocational School, Electric and Energy Department, TURKEY

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*İlgili yazar/Corresponding Author: korayozsoy@isparta.edu.tr

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Abstract: In the aerospace and defense industry, the production of parts using existing technologies is difficult. The production problem of these difficult parts is solved by the Additive Manufacturing (AM) method. It is possible to produce parts with complex geometry which cannot be manufactured by traditional manufacturing method. In addition, more functional, lighter and more economical parts are produced by AM method.In our country, the most innovative and value-added applications of additive manufacturing technologies are used in the aviation, aerospace and defense industries. The main uses of additive manufacturing technology in the field of aviation and defense to accelerate the time of product launch to market by shortening the design and manufacturing process, to increase productivity, to reduce costs and to provide cost advantage in low number production. In the light of this information, instead of the existing technology in the aeronautics and defense industry sector, metal parts manufacturing comes to the fore with AM method. In the study, the current state of additive manufacturing technology in the aerospace sector is examined. In addition, advantages and disadvantages of AM method for aerospace and defense sector are presented.

Havacılık ve Savunma Sanayisi İçin Eklemeli İmalatla Metal Parça Üretimi

Anahtar Kelimeler
Eklemeli imalat
Havacılık-uzay
Savunma sanayi
Metal parça

Özet: Havacılık, uzay ve savunma sanayi sektöründe, mevcut teknolojiler kullanılarak parçaların üretimi zor olmaktadır. Bu zor parçaların üretim sorunu Eklemeli İmalat (Eİ) yöntemi ile çözülmüştür. Geleneksel yöntem ile imal edilemeyen karmaşık geometriye sahip parçaların imal edilmesi Eİ yöntemi ile mümkün olmaktadır. Ayrıca Eİ yöntemi ile daha fonksiyonel, daha hafif ve daha ekonomik parçalar imal edilmektedir. Ülkemizde Eklemeli imalat teknolojilerinin en yenilikçi ve katma değerli uygulamaların kullanıldığı sektör, hiç kuşkusuz havacılık, uzay ve savunma sanayidir. Eklemeli imalat teknolojisinin havacılık ve savunma alanında temel kullanım amaçları; tasarım ve imalat sürecin kısalmasıyla ürünlerin pazara çıkış süresini hızlandırmak, verimliliği arttırmak, maliyetleri düşürmek ve düşük adetli üretimde maliyet avantajı sağlamaktır. Bu bilgiler ışığında havacılık ve savunma sanayi sektöründe mevcut teknoloji yerine Eİ yöntemi ile metal parça imalatı ön plana çıkmaktadır. Çalışmada, havacılık ve uzay sektöründe eklemeli imalat teknolojisinin mevcut durumu incelenmiştir. Ayrıca Eİ yöntemin havacılık, uzay ve savunma sektörü için avantaj ve dezavantajları sunulmuştur.

1. Introduction

ASTM F42 Technical Committee describes "Additive Manufacturing (AM)" as a process of joining materials to make objects from 3D CAD (Computer-Aided Design) model data, layer upon layer, as opposed to subtractive manufacturing methodologies (ASTM, 2010). In addition, AM is named with some other terms such as direct digital manufacturing, rapid prototyping, rapid manufacturing, layer manufacturing, and freeform fabrication (Jacobs, 1992). Studies in metal part manufacturing sector up to now comprised of those related to enhancement, development and renovation within the limits of manufacturability constraint. The most significant progress in this field is the effort to eliminate manufacturability constraint. The most favorable solution in studies to annihilate manufacturability constraint is gained by manufacturing endeavors by AM method.

Additive manufacturing is one of modern (unconventional) manufacturing methods. The method is based on "adding material layer upon layer". The main objective in this method is to manufacture the parts that are impossible to be manufactured by conventional manufacturing methodologies due to their geometric complexities and to remove manufacturability constraint. Apparently, studies on this subject are considered important in recent literature references (Giannatsis vd., 2009; Custompartnet, 2010).

Additive manufacturing methods represent same basic manufacturing techniques with some differences related to basic materials used and principles to interconnect layers. On this point, there are various additive manufacturing methodologies using different manufacturing technologies. Some examples may be presented as 3D printing, Molten Accumulation Modelling, Laser Beam Melting, Layer Upon Layer Material Manufacturing, and Selective Laser Sintering / Selective Laser Melting.

In 1989 Nyrhilä discovered a new term for sintering powder mixture with minimum compression and without pressure and had it patented (Espace.net, 2014). EOS Gmbh, which was founded in 1989 and purchased in 1990 its first commercial machine STEREOS 400 produced by Stereolithography technology, introduced laser sintering device in 1994. Once being the biggest rival of 3D Systems company in Europe, thereafter in 1997 it stopped manufacturing the device that works according to laser beam (stereolithography) technology since it lost the case opened by 3D Systems due to a patent controversy. Henceforth, EOS manufactures only EOSINT devices working on metal powder accumulation principle by heating (EOS GmbH, 1989; Turkcadcam, 2018).

In 1990 Selective Laser Melting (SLM) technique was originally developed by the Fraunhofer Institute in Germany and was commercialized by Fockele&Schwarze (F&S) GmbH. Due to an agreement in June 2002, all purchases, marketing and technical assistance services for Selective Laser Melting (SLM) devices were commenced to be undertaken by MCP-HEK GmbH (Turkcadcam, 2018). In April 2011, 5N Plus announced that it made an acquisition of MCP Group SA (5nplus, 2014).

SLM, a process parallel with SLS (Selective Laser Sintering) that is based on metal melting, was patented in 1996 by Meiners as a method exposing heat by means of a laser beam on metal powder in a protective gaseous atmosphere so long as it becomes completely molten (Meiners, 2001; Levy vd., 2003).

The primary studies on electron-beam melting started in 1993 when Ralf Larson got the patent relating to the interconnection of electrical conductor powders via being melted by electron beam. These efforts were followed by corporate studies at Chalmers University of Technology in Gothenburg in 1995. Thereafter, in 1997 Larson founded the firm Arcam AB in order to commercialize this technology. History of commercial institutions working on additive manufacturing so far is summarized in Figure 1.

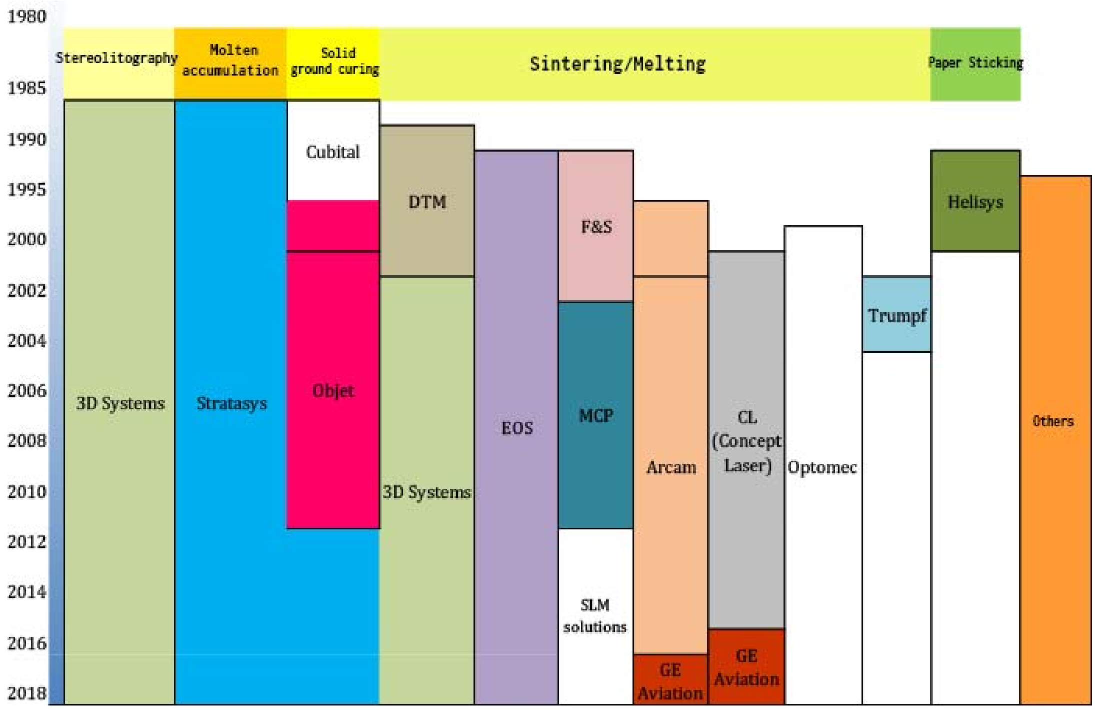

Figure 1. Commercial institutions in additive manufacturing field from past to present

Market sharing of installation-based metal additive production companies is shown in Figure 2, based on the report by IDTechEx named "Additive Manufacturing of Metals 2015-2025 (IDTechEx, 2018).

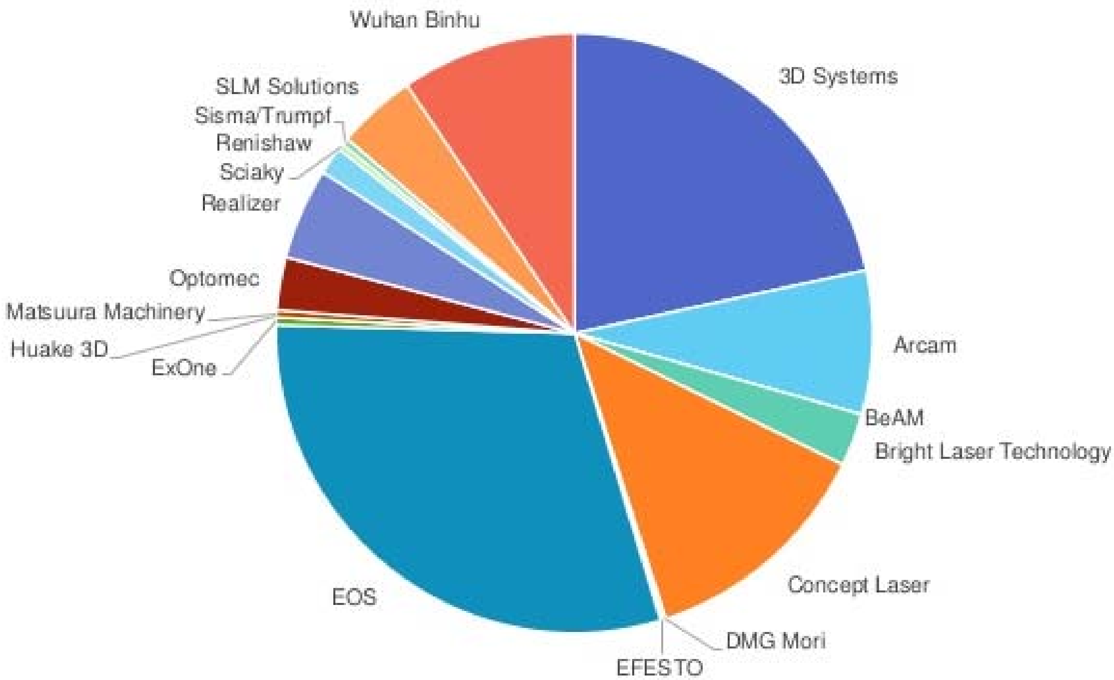

Figure 2. Market sharing of installation-based metal additive production companies (IDTechEx, 2018).

Latest technological developments and invention of new materials in additive manufacturing have brought about aeronautics and defense industry as a crucial field of application. Due to the fact that powders of metals like steel, aluminum and titanium just like various plastic and composite materials are generally the ones that are supposed to endure high temperature, they are commonly used in aeronautics and defense applications. Challenging requirements such as light components and fragile design of aerostructure are primary factors enabling the growth of the market of additive manufacturing for aeronautics industry. In aeronautics industry, additive manufacturing is widely used for the production of critical pars of planes or for small-scale production related to high performance and quality. Unique competencies of additive manufacturing about the production of complex parts like wings of jet planes, engine parts, astronomical telescopes, metal guns and rocket parts have enhanced its appreciation in aeronautics and defense industries (Marketsandmarkets, 2013).

2. Current Situation on Additive Manufacturing Technology in Aeronautics and Space Industry

Additive manufacturing has a great potential in aerospace industry. Additive manufacturing devices are increasingly used in aerospace and rocket applications in both military and civil applications (Kalender vd., 2019). International companies like General Electric (GE) Aviation, Lockheed Martin, Airbus and BAE System, MTU Aero-Engine, Rolls-Royce plc. Pratt & Whitney, GE Avio Aero are among those that commonly use this technology (Iecetech,2014; Müller and Karevska, 2016). Boeing, the biggest commercial and military aircraft and helicopter manufacturer of the world, has announced that most aircraft parts are planned to be replaced by those produced by additive manufacturing. In the space and aerospace industry, companies invest in innovations and new products in order to keep in touch with the competition, leading the sector to a leading position in additive manufacturing applications. Additive manufacturing applications in this sector are the production of aircraft components, aircraft fuselage, interior section and cabin systems. The market volume of these products is expected to be 390 Million US Dollars for aircraft parts, 148.3 Million US Dollars for aircraft body and 122.6 Million US Dollars for other applications in 2020 (Technavin, 2016)

Boeing firm has been planning to make most parts of aircrafts producible by using additive manufacturing so that they can, with the purpose of avoiding possible delays, deliver the parts to specific destinations where those parts must be stocked in different stations. Nathan Hulings, the spokesman of Boeing, stated that 150 different parts of the F/A-18 Super Hornet aircraft were produced by using additive manufacturing (Geekwire, 2018). GE Company spent 1.5 billion USD for research and development efforts with regard to endeavors concerning additive manufacturing since 2010. The firm acquired shares of ARCAM and CONCEPT LASER in 2016 and transformed its current additive technology into a consummate state. In 2015 GE started check flights of new generation aircraft engine LEAP that embodies 19 fuel injectors produced by means of additive manufacturing devices for the first time.

In 2015, FAA (Federal Aviation Administration) produced engine sensor protection unit T25 that is used on GE90-94B engines by additive manufacturing and had it certified. T25, enabling measurements of pressure and temperature for engine control systems, was installed onto 400+ GE90-94B engines. It was stated that T25 sensor protection unit was just a starter in GE aviation in terms of additive manufacturing (Figure 3a). What is more, fuel injector produced by GE was featured to be 5 times more durable and 25% lighter (Figure 3b) (GE Aviation, 2019).

Figure 3. a) FAA approved T25 pressure heat sensor b) LEAP plane engine fuel head for CFM (Kellner, 2015 and 2017) which are produced with additive manufacturing method.

Lockheed Martin produced titanium dispatch tanks in 2009 by using Electron Beam Direct Melting (EBDM), a space systems additive manufacturing method launched by Sciaky company. EBDM method is preferred by many aviation companies such as Airbus, General Electric and Lockheed Martin because Inconel is ideal to manufacture large-scale parts that are made of tantalum, titanium and other high value metals (LENS, 2018).

Lightened “Nacelle hinge bracket” parts were produced for Airbus A320 aircrafts by additive manufacturing, using selective laser melting method. Thanks to both topology and material selection, total mass saves of 64% was sustained in the study (Figure 4).

Figure 4. Airbus hinge holder part (EADS, 2015)

In MTU Aero Motor company, the biggest subsystem supplier for aircraft engines, studies on quality assurance and standards in process chain regarding engine part production by additive manufacturing are ongoing. Borescope eye production for PW1100G-JM engine -empowering Airbus A320- was achieved by means of EOS M280 additive manufacturing device (Figure 5).

Figure 5. Image of 16 pieces of borescope eye and pulling samples being produced (Bamberg vd., 2015)

Rolls-Royce Trent XWB-97 is the biggest aviation/engine part produced by ARCAM electron beam melting, an additive manufacturing method. As shown in Figure 6, front bearing bed made of titanium in approximate diameter of 1.5 meters and of 0.5-meter thickness, possessing 48 aero foils on the engine is produced via additive manufacturing. Production phase has been shortened here as a result of additive manufacturing by 30% while costs and production speed have been optimized (Rolls-Rovce, 2019).

Figure 6. Image of Rolls Royce Trent XWB engine front bearing bed (Rolls-Rovce, 2019).

Around twelve parts of Pratt&Whitney Bombardier aircrafts' engines were manufactured by using Electron Beam Melting (EBM) and Direct Metal Laser Sintering (DMLS) techniques, both of which are among additive manufacturing methods (Figure 7). Those parts are fasteners, fuel collectors and injection nozzles made of nickel and titanium. Pratt&Whitney actualized a decrease in part weights by 50% thanks to the design optimization.

Figure 7. Image of Pratt Whitney jet engine that is produced with additive manufacturing with stator to be used in bombardier (Pratt-Whitney, 2015).

Additive manufacturing today displays better performance in production of large-scale parts when compared to conventional methods. Firms producing additive manufacturing tools pursue research and development practices regarding betterment about limitations of device dimensions. In this respect, Lockheed Martin has been working on additive manufacturing technology having a large production volume at Oak Ridge National Laboratory (ORNL). One of the problems encountered in the domain of aeronautics and space is the limitation of construction volume and dimensions of product. By means of metal wire and arch additive manufacturing, a fortified trunk metal panel was produced by Stelia Fuselega Aerospace company that improved itself step by step regarding limitations of product dimensions (Figure 8) (Stelia, 2018).

Figure 8. Trunk panel that is produced with additive manufacturing (Stelia, 2018).

In our country, the most innovative and value-added applications of additive manufacturing technologies are used in the aviation, aerospace and defense industries. Additive manufacturing applications are important for Turkey. The companies in the aviation and aerospace sectors have high technology awareness. First time in our country, in 1993 the Arçelik company originated rapid prototyping section of R&D Department when it bought one SLA-250 (Ektam, 2019). The main uses of additive manufacturing technology in the field of aviation and defense to accelerate the time of product launch to market by shortening the design and manufacturing process, to increase productivity, to reduce costs and to provide cost advantage in low number production(SBB, 2019; Kayacan and Yilmaz, 2019). When it comes to leading defense and aerospace companies in Turkey, cold section stationary parts and blast chambers of jet engines, landing gear holders/absorbing structures, special mission equipment integration support-adaptation parts perform via additive manufacturing technology.

3. Advantages of Additive Manufacturing Technologies for Aerospace Industry

Additive manufacturing method presents many advantages for aerospace industry. Those can be counted as follows (EADS, 2015 and DefenceIQ, 2016):
• As they don't require private jig/mold and similar tools at production stage, additive manufacturing technologies have various advantages in mold designing and production activities such as gains being made from labor and costs.
• With additive manufacturing method it is possible to produce space and aviation parts having complex geometries with metal powder material.
• Within frame of 2023 vision of our country, it may become inevitable to use layered manufacturing technologies in the production of national regional planes, motors and unique helicopters in civil aviation field.
• Most important criterion in manufacturing parts for space and aviation industry is the lightness of parts. It is difficult to produce light porous parts by using methods other than additive manufacturing method.
• With the usage of additive manufacturing technologies in repair, maintenance activities in space and aviation industry, it is possible to produce spare parts in a fast way
• Design easiness obtained with biomimetics (natural imitation) will open new horizons especially for aerospace industry.
• It has been calculated that with the additive manufacturing there will be an annual reduction in carbondioxide being released to the atmosphere as relating with commercial aviation enterprises
• It is expected that additive manufacturing technologies will contribute for reduction of remaining materials. Besides there will be reductions as relating with fuel consumption.

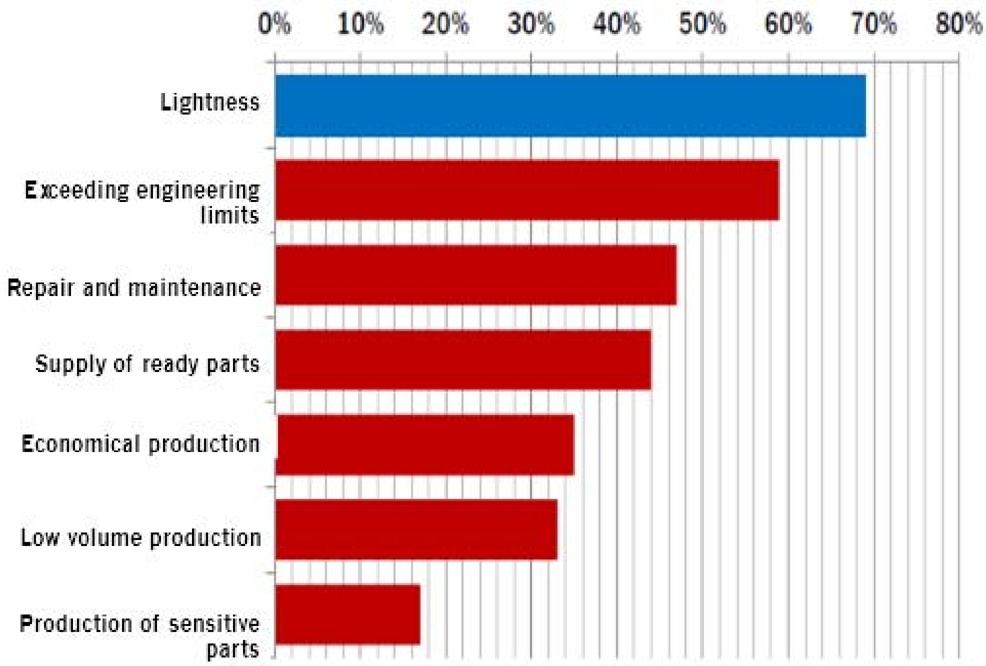

Figure 9. Percentage ratios of benefits of additive manufacturing method towards year 2026 (DefenceIQ, 2016).

4. Disadvantages of Additive Manufacturing Technologies for Aerospace Industry

Some disadvantages brought about by additive manufacturing for aerospace industry can be sorted as follows (Balc vd., 2012; Nichita, 2007; DefenceIQ, 2016):
• Cost of materials that are used in additive manufacturing is high. Furthermore, mechanical features of parts which are produced with additive manufacturing method can be different than the materials being used.
• They have disadvantage due to high consumption expenditures (gas, powder material, fuel etc.).
• Additive manufacturing counters are obtained with high investment costs.
• It is not very suitable for serial production as the processing is slow and construction volume is low.
• When compared with similar computerized control machines, its production costs are higher (raw material, tools and devices, gas etc.).
• During additive manufacturing process, in situations of welding micro pores and hair cracks can occur.
• There can be need to make final processing on the manufactured parts (heat treatment, polishing etc.)

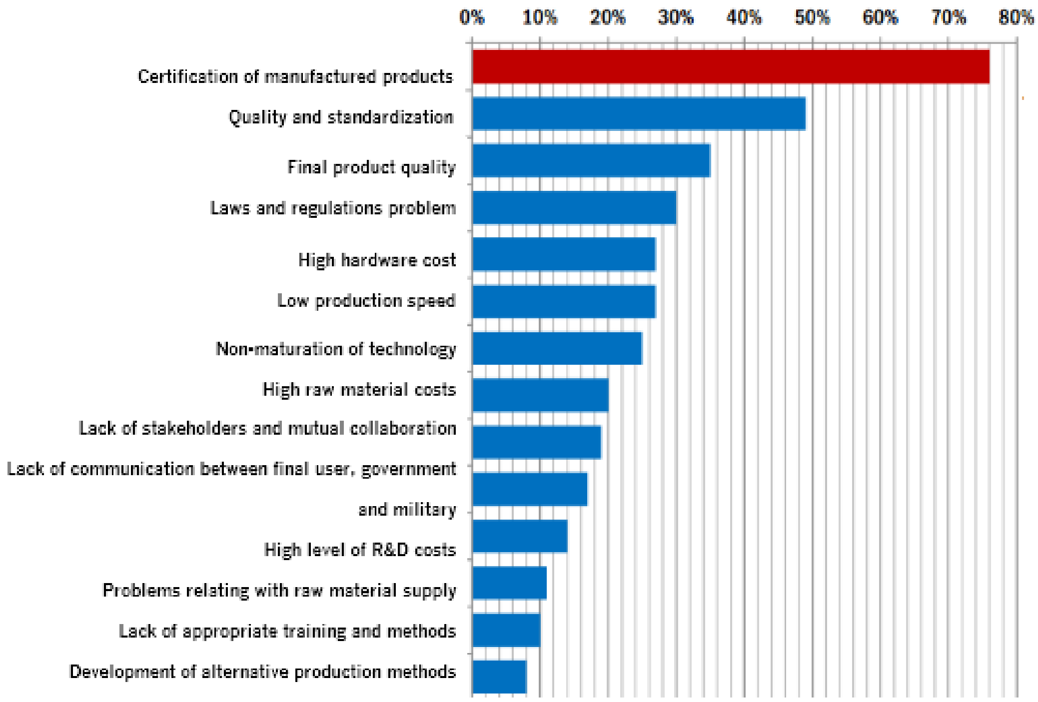

Figure 10. Illustration of percentage ratios of difficulties experienced in the development of additive manufacturing methods (DefenceIQ, 2016).

5. Conclusion and Recommendations

In the study, current situation of additive manufacturing technology in aerospace industry has been evaluated. Besides the advantages and disadvantages of AM method for the aerospace and defense industries have been presented. The results obtained with this study have been summarized as below:

• Recent technological developments and presence of new materials in additive manufacturing has made aeronautics and defense industry become an important application.
• Difficult requirements such as sensitive designs of plane parts and light components have been major factors enabling the production of additive manufacturing market for the aeronautics industry.
• In the aeronautics industry, additive manufacturing is mainly used for the production of critical parts of planes or for low scale production that is related with high performance and quality.
• In the studies being conducted to eliminate the constraint of producibility, most positive result was obtained in the production studies conducted with additive manufacturing method.
• Unique capabilities of additive manufacturing technology for the production of complex parts such as jet wings, motor parts, space telescope, metal weapons, and rocket parts has enabled to improve for the aviation and defense industry to be adopted.
• Material market used for additive manufacturing technology includes polymer and metal. As industries, there are space, automotive, consumption, health, security, industrial machines, and training and research industries.
• According to the market research report being published it is expected for the composite annual growth rate of additive manufacturing market to increase to %23 from 2013 to the year of 2020 and it is expected for it to reach to the amount of 8.41 bill dollars in 2020.

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