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Research Survey

Product Development by Additive Manufacturing and 3D Printer Technology in Aerospace Industry

Murathan KALENDER[1], Yahya BOZKURT[2], Sezgin ERSOY[3], Serdar SALMAN[4]

[1] *Marmara University Metallurgy and Materials Engineering Department,34734 Kadikoy, Istanbul, Turkey*, murathankalender@hotmail.com, orcid.org/0000-0002-2526-4630

[2] *Marmara University, Metallurgy and Materials Engineering Department,34734 Kadikoy , Istanbul, Turkey*, ybozkurt@marmara.edu.tr, (Corresponding Author) orcid.org/0000-0003-1816-5922

[3] *Marmara University, Mechatronics Engineering Department,34734 Kadikoy , Istanbul, Turkey*, sersoy@marmara.edu.tr, orcid.org/0000-0002-4029-5603

[4] *National Defense University, Rectorate of National Defense University, Yeşilyurt , Istanbul, Turkey*, ssalman@marmara.edu.tr, orcid.org/0000-0002-9184-3876

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Abstract

The additive manufacturing and 3-dimensional manufacturing technology offer unparalleled flexibility in terms of part geometry, material composition and manufacturing time. There are many difficulties in manufacturing parts in the aerospace field. Thin-walled aircraft engine components and structures with complex geometry, the difficulties encountered in the processing of materials, are the other main factors that compel the aviation industry to adopt the use of layered manufacturing technology. It is progressing in the direction of radically changing the aerospace sector in the production of extremely complex and lightweight parts with material wastes that are almost none. The aerospace engine industry requires stronger, lighter and more durable components. Today's additive manufacturing technology provides new possibilities to meet these situations. In this study, research and development activities carried out in the field of layered manufacturing in the aviation industry have been examined and a literature review has conducted. In the experimental study, a scaled 3D prototype of an exemplary rocket equipment was produced using 3D printer technology. The manufacturing parameters of the study have been examined.

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Havacılık ve Uzay Endüstrisinde Katmanlı İmalat ve 3B Yazıcı Teknolojisi ile Ürün Geliştirme

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Öz

Katmanlı üretim ve 3 boyutlu üretim teknolojisi, parça geometrisi, malzeme bileşimi ve üretim süresi bakımından benzersiz bir esneklik sunar. Havacılık alanındaki parçaların imalatında birçok zorluklar vardır. Havacılık endüstrisinde, ince cidarlı uçak motoru bileşenleri, karmaşık geometriye sahip yapılar ve malzemelerin işlenmesinde karşılaşılan zorluklar katmanlı imalata yönelimi arttırmıştır. Son derece karmaşık ve hafif parçaların üretiminde kullanılan bu yöntem neredeyse hiç olmayan malzeme atıkları ile havacılık sektörünü kökten değiştirmek yönünde ilerliyor. Havacılık ve uzay endüstrisi, daha güçlü, daha hafif ve daha dayanıklı bileşenler gerektirir. Günümüzün katmanlı imalat teknolojisi bu durumları karşılamak için yeni olanaklar sunmaktadır. Bu çalışmada, havacılık endüstrisinde eklemeli imalat ile parça üretimi alanında yürütülen araştırma ve geliştirme çalışmaları incelenmiş ve literatür taraması yapılmıştır. Deneysel çalışmada, örnek bir roket ekipmanının ölçekli bir 3B prototipi 3B yazıcı teknolojisi kullanılarak üretilmiştir. Çalışmanın baskı parametreleri incelenmiştir.

1. INTRODUCTION

Rapid prototyping (RP) is the name given to the process of manufacturing methods and technologies since complex objects are produced. The rapid prototyping process can be realized in 3D CAD program or by using RE Technologies [1]. RE tools enable a 3D scanning of any object to be searched digitally. After this step, the file extension is designated as stereolithography (STL) and is separated into object layers with the corresponding slicing software. The RP process is now widely used in the industry because of its many advantages. One of the most important features of the RP process is that it enables the production and reproduction of any product or part of it by 3D scanning methods without any technical documentation. The basic steps of each RP process are shown in Fig. 1. These basic steps include CAD design, .STL file output, preprocessing, file transfer, build process and post processing [2].

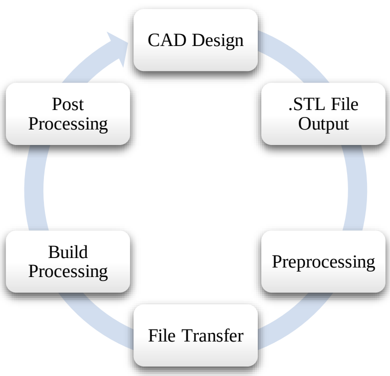

Figure 1. RP process cycle.

3D printers are based on the principle of computer numerically controlled plastic injection systems, but are actually the most advanced state of the art additive manufacturing technology. The temperature at which the extrusion takes place varies depending on the type of filament used for 3D printing. The filament material is in the form of a thin thread and is maintained in a wound state. The completed 3D object is formed by melting the filament out of the nozzle and overlapping each layer. Fig. 2 shows the 3D printing process. The feed rollers transport the winding filament into the extruder chamber. The extruder allows the material to reach its operating temperature and transports the material by pressing the heater with the pressing mechanism to form each layer of the 3D object on the platform. The extruder can move along the XY surface. After the first layer is completed, the platform is lowered in the Z direction by the thickness of the completed layer. This event continues in the loop until the 3D object is completed. The extruder and the platform are driven in the XYZ directions by a stepper motor that controls the temperature and position of the heater, the extruder speed, and a set of parameters defining layer thickness [3].

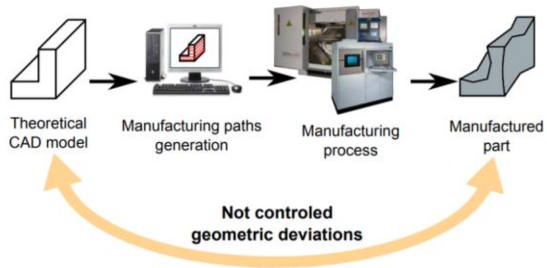

Figure 2. The usual numerical chain for Additive Manufacturing [4].

Today's 3D printer technology covers many different technologies. These technologies include laser sintering, fused deposition (FDM), polymer curing. Although it is widely used and has different design, the most commonly used technology is the devices that use the fused deposition modeling technique. In this technique, the object having a 3D model in the computer is stacked in 2-dimensional layers and a 3-dimensional product is obtained. In order to realize this process, it is necessary to have 3 axis CNC technology used in manufacturing sector. It is a software and material stacking tool to communicate with control card and CNC. FDM starts with a software process, the software mathematically separates the.STL format models into layers and sends them to a 3-axis CNC controlled device to build them one on top of the other. Usually thermoplastic materials are used. Thermoplastic materials are very suitable materials for this technology since they can be melted many times and liquefied in a certain temperature range compared to thermoset materials. The thermoplastic material must be extruded from a nozzle heated to the melting temperature in order to be stacked properly. This nozzle is controlled by the computer and moved to simulate the geometry of the part, and with the accumulation of thermoplastic material, the part is stacked and produced in 2-dimensional layers on the tray. Today, this process is mostly used in the field of rapid prototyping and 3D printing [5].

Equipment used in the aerospace industry should be stronger, lighter and more durable than other materials. Today, layered manufacturing technology provides new opportunities to meet these situations. In addition, the aviation industry has combined the additive manufacturing process from concept design to end-use parts and repairs. This technology involves rapid prototyping of components at the design stage using plastic and metal, followed by direct production of molds, tools and complex shape metal parts for mass production. It also includes repairing damaged parts rather than scrapping or replacing them. Laser Metal Deposition

(LMD) technology is the best method for repairing aerospace components. In the case of LMD for repair, the metal powder is fed directly to the damaged part of the part and cured by laser. Until recently, aviation parts were produced by forging and other traditional processes, but there is loss of material in conventional manufacturing processes. In the case of additive manufacturing, the maximum use of the material comes to the fore. This significantly reduces cost [6]. The distribution of printing types according to the material type is shown in Fig. 3.

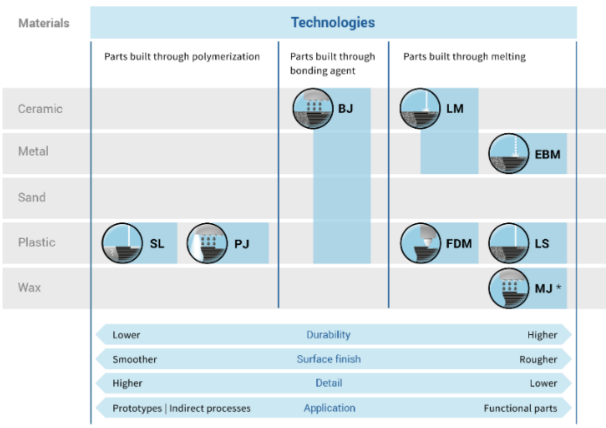

Figure 3. Layered manufacturing methods and basic properties [7].

Additive manufacturing and melt agglomeration [8] are also widely used in the aerospace industry. Last year, NASA announced that it has achieved an important milestone in the creation of a fully 3D rocket engine. At the Marshall Space Flight Center in Huntsville, Alabama, 12 test fires were successfully fired on NASA's largely 3D-printed rocket engine prototype. Furthermore, we can see that advanced technology such as Blue orgin, SpaceX and Virgin Orbit are in the process of being produced and tested. For a rocket to be launched into space, more than 2M parts must be produced with little or no tolerance [9]. In addition to the high precision of these parts, rapid production is also provided by the additive manufacturing method. A technology used in the field of aerospace was used for product development in our study.

2. 3D PRINTERS

The use of 3D printer technology developed has become increasingly widespread in 1980's [10]. 3D production using 3D printers is not defined by a single term, but can also be called additive manufacturing [11]. 3D manufacturing technology is used in the fields of engineering, architecture and industrial design [12]. Additive manufacturing can be used not only to produce prototypes, but also to obtain products such as machine parts and mold tools. Figure 4 shows the application of additive manufactering in different sectors [13].

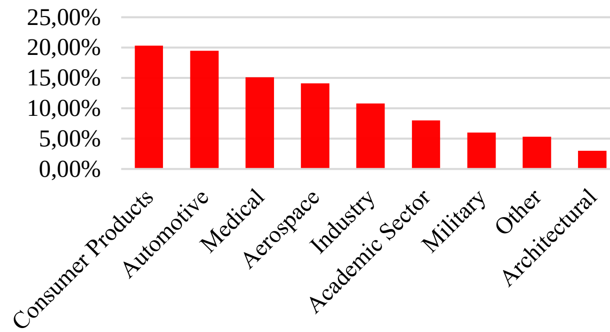

Figure 4. Additive manufacturing in different sectors.

One of the features a professional industrial designer should have is to master the process of testing and creating ideas. This used to involve time consuming tasks such as sandblasting, cutting and prototyping in model workshops. While this situation has been continuing recently, many jobs can be tested by converting them into CAD data.

The 3D process is the process of converting a computer-aided three-dimensional design into a solid object [14]. It is created by adding a layer from the base of an object to the top [15]. With the use of additive manufacturing technology, the material usage and production time are reduced and the cost of the parts is reduced. This technology also provides freedom of design, facilitating the production of complex geometry parts [16]. 3D printers are the means of production of the new era, which works with the logic of a laser or inkjet printer and transforms products from digital media into a 3D solid object in a layer-based structure defined as) additive manufacturing 3D. It can be produced by three-dimensional printers with different technologies. The most common of these technologies is FDM (Fused Deposition Modeling) or aggregation technology. Thermoplastic as Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA) materials that can be shaped by heat are used in this technique. SLS (selective laser sintering) is another widely used method. The Sintering technology of the SLS method generally involves the conversion of powder metals used in powder metallurgy into solid objects under pressure and heat. Rapidly reflect the laser beams onto the powder material and form layers. Many different materials such as plastic, ceramic and metal can be used depending on the power of laser technology. The reason why SLS technology produces much slower than FDM technology is that a smooth powder surface should be laid on each layer while printing in three dimensions. The spreader head must move very slowly so that the dust can be properly laid on the surface. One of the preferred methods in today's industry is that although it moves slowly, it can easily manufacture complex geometry objects. Some techniques are being developed to promote metal printing. It is one of these developed methods to stack metal as a welding robot welds onto a metal surface. Thanks to this newly developed method, there is no need to use expensive technology to print metal structures on 3D printers, and large investment costs are eliminated [17].

3. ADVANTAGES of ADDITIVE MANUFACTURING

The use of 3D printer has many advantages for companies that produce in the aerospace industry. Particularly, the production of parts with complex geometry forces the manufacturer. Looking at the pieces produced in the last 25 years, the complex and complex pieces stand out. In addition, many problems arise when the production of these parts is made by conventional production methods. One important issue is reducing the cost by simplifying the production and manufacturing process. Product designers can improve the properties of the part to be produced with small corrections in this manufacturing method. The solution of functional and aesthetic problems can be solved with 3D printer technologies. In addition, parts of a design consisting of multiple component parts can be printed as a whole. This is an important issue in terms of cost and time. Fewer parts allow less assembly analysis and less complexity.

There will also be fewer obstacles in part design. Factors such as selection of draft angles, partition lines, and much more will be reduced. It is now possible to design parts that are not easily reproduced by machining in the machine, which have a sharp shape or a waste of material during the machining process, in which the machining time of the machine is not reduced. Designers will be able to optimize their strength/weight ratios by minimizing material use in response to machining costs. In the end, they will make calculations about the production possibilities by minimizing the discussions that may cause time loss. This method contributes to the reduction of material wastage, the cost of disposing of waste material, the costs of material transportation, the reduction of stock costs for raw materials and the direct production of the final product, which reduces overall costs. Thus, the damage that may occur due to design changes or disappointing sales will be reduced because less stock is kept [18].

In addition, manufacturers can facilitate their purchase. Because the evaluation of the ordered part will have more flexible parameters than the mass production parts. Normally, a machine operating with a single add-on manufacturing system that fulfills the function of all the different machine types required to process a product during its production will be sufficient. In this case, while the basic investment costs will be reduced, the number of operators and qualified employees to work will decrease. Small production volumes can make production planning with less effort. Moreover, the time and costs for quality control will be reduced, as the important parts of each other are not to be manufactured separately. As the machining process is eliminated, misunderstandings in terms of design can be solved by rapid changes in design dimensions along with high precision, thus achieving high part repeatability. Finally, the stock required for the spare part can be reduced. Only spare parts can be produced on demand, even for absolute parts. For consumers, they can buy products for more individual needs and wishes. First there will be a wide variety to choose from. Secondly, products that are produced on order and can be supplied on an economic scale, even contributing to their design, can be purchased. Moreover, the manufacturer's ability to produce lower costs during production will enable the consumer to purchase the product at a lower cost [19].

4. BASIC MATERIALS USED in 3D PRINTERS

ABS and PLA filaments are used in 3D printers. Besides, PET, PVA, HIPS, Nylon, Carbon and glass reinforced filaments are used. Another type of filament is the durable filament types such as wood, bark, bronze, copper, carbon fiber mixed with PLA plastic. The mixing ratio of these materials with PLA is usually 30-40%. ABS plastic (Acrylonitrile Butadine Styrene) is a rigid thermoplastic polymer. This type of plastic is a petroleum product and can be dissolved with ABS acetone. Products printed using ABS material are suitable for use between 20 and 80 ° C. Since the initial melting temperature of the ABS material is 105 ° C, softening and deformation can occur if a temperature above 80 ° C is reached. It is also a material that deteriorates when exposed to intense UV radiation. ABS is a type of material that is frequently preferred in 3D printers due to its high resistance and impact resistance. Due to the fact that it requires much higher temperature than PLA material during use on a three-dimensional printer, it requires a more difficult calibration process. Producing a good piece with ABS material is more difficult than PLA material. Due to the high temperature of the ABS material, there is a risk of distortion when printing large parts. The mechanical and chemical properties of the ABS material are shown in the diagram in Fig. 5 [20].

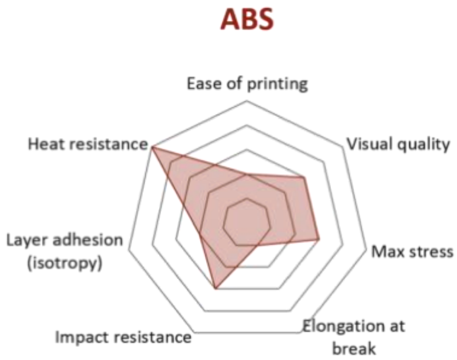

Figure 5. Mechanical and chemical properties of ABS material [21].

Polylactic acid (PLA) material is the most widely used three-dimensional printer material according to the current statistics. The main reason this material is preferred is that it is easy to work because it can melt at low temperatures. The PLA material is much less likely to be distorted when printing. Therefore, it does not make it necessary to use heater plates. Polylactic acid is obtained from products containing starch, not petroleum, as opposed to ABS material. Therefore, it is a less harmful material in terms of health. The negative properties of the PLA material are much lower strength than the ABS material. PLA material resistance to high temperatures is very low compared to ABS material. The mechanical and chemical properties of the PLA material are shown in the diagram in Fig. 6 [22].

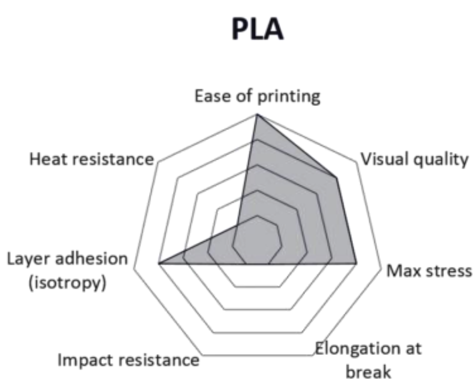

Figure 6. Mechanical and chemical properties of PLA material [21].

Thermoplastic polyurethane (TPU) material is a material with high wear resistance and flexibility. Due to its easy processing, it is preferred in different sectors besides being used in printers. The heat conduction of the TPU material is very low. It has superiority compared to other polymers in terms of strength. It is used for making materials such as shoe sole, TPU material, yellow bands on roads, white goods, furniture, pipe components. The mechanical and chemical properties of the TPU material are shown in the diagram in Fig. 7.

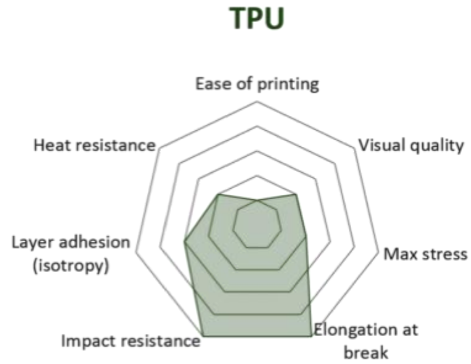

Figure 7. Mechanical and chemical properties of TPU material [21].

Nylon is a strong, hard and flexible 3D printing material. It is very sensitive to moisture, which makes printing and storage difficult. The nylon filament has a very high level of interlayer adhesion, which is an excellent choice for functional parts such as connectors and hinges (Fig. 9) [23]. Durable materials are more frequently used in the medical field. It needs a heated platform. The mechanical and chemical properties of the nylon material are shown in the diagram in Fig. 8.

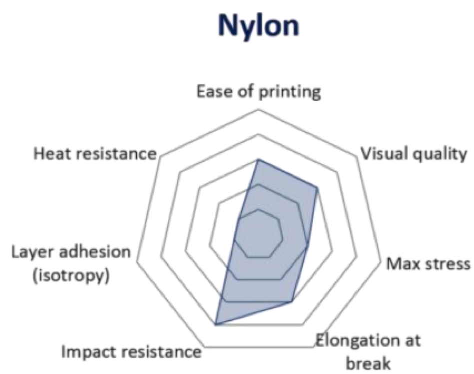

Figure 8. Mechanical and chemical properties of nylon material [21].

Figure 9. Product made of PA 11 material with 3D printer technology [23].

Carbon-reinforced filaments have a very hard and rigid structure. It can be used in mechanical parts, protective containers and in applications requiring high durability

(Fig. 10). Its flexibility is very low and it can break when stretched. However, its strength is higher than other materials. The ideal printing temperature is between 195 ° C ° 220 ° C. One of the advantages is that there are few problems with cooling and cracking problems during cooling. Therefore, the dimensions of the designed part are seen to be healthier after printing [24].

Figure 10. Product made of carbon material with 3D printer technology [25].

Most advanced 3D printers use powder materials. These powders then selectively fuse with heat - usually from a laser. The power of this method is that it can work with almost any material. If something can be converted to dust, there is usually a way to print. The results can range from copper, iron, steel or gold to ceramic or glass. Best of all, the finished product is structurally strong as a piece made of the same material through conventional production - often stronger because it does not require additional welding or processing (Fig. 11). For the most part, such printing is used by large technology firms rather than individuals or hobbies.

Figure 11. Product made of steel powder material with 3D printer technology [26-29].

One of the more restrictive and therefore less used materials in 3D printing is resin. Compared to other 3D-applied materials, the resin offers limited flexibility and power. The resin made of liquid polymer reaches its final state when exposed to UV light. Resin is generally found in black, white and transparent varieties, but some printed items are produced in orange, red, blue and green. In the past, the photosensitive polymer resin was mainly used for visual archetypes and vacuum casting molds. This has changed with the introduction of new technologies, and it is possible nowadays to imprint the end-use parts that reflect common engineering requirements.

5. STUDIES IN AVIATION and AEROSPACE INDUSTRY

Additive manufacturing machines are increasingly used in aerospace and missile applications for both military and civil purposes. Layered manufacturing, construction for both civilian and military facilities, as well as the construction of guided missile construction and civil aircraft for the production. Rapid production of archetypes, easy to test and design processes, manufacturing, promises to shorten delivery times. Produced with this feature, the manufacturer, military and civilian militants will create a great impact. If Boeing and Airbus did not want mechanical and / or thermodynamic resistance, they started to produce plastic parts with these devices [26].

Many companies in the aviation industry have begun the production trials of different aircraft parts by taking advantage of the 3-D printers. For example, Boeing has manufactured various archetypethermoplastic parts using commercially available laser sintering techniques for commercial aircraft 737, 747, 777 and 787 [26]. Using this technology, the Boeing company profited $ 3 million from each 787-Dreamliner aircraft manufactured [27]. Although some of these manufactured parts have a complex structure, production processes are performed by eliminating the production limits in a shorter time, with less cost and with the desired features with 3D printer techniques [28].

The first 3D printer that NASA has worked on for a long time and was able to work in the space environment under the Made In Space program was sent to the International Space Station. Specially designed for astronauts and developed to meet their simple needs, the 3D printer is much different from the printers we use in everyday life. In order to be able to withstand the firing force during deployment, the 3D printer, which had been used for a long time, was sent along with other injured food and items that the astronauts could use there [29].

In further stages, layered manufacturing can also be used in the manufacture of energizers, such as explosives, solid rocket propellants, which are directly associated with the energy of the missiles. Thus, this type of material can be used in the most efficient and most reliable way. In July 2017, NASA tested the world's first three-dimensional rocket engine igniter. The igniter was manufactured using copper alloy and inconel (chrome and steel alloy). Thus, both the cost and the time savings were achieved from the manufacture of the igniter [30].

GE Aviation has been evaluating layered manufacturing for more than ten years and now successfully manufactured the cobalt chrome leap engine fuel nozzle part with the laser additive manufacturing melting method as shown in the Fig. 12. The Leap engine fuel nozzle has already cleared ground-based engine tests and is approved for use in civil aircraft. The AM component has replaced a 20-component component with low cost, weight, joints and improved performance [6].

Figure 12. Laser sintered leap engine fuel nozzle in cobalt chrome [6].

Each LEAP engine has 19 fuel nozzles as shown in the Fig. 13. By 2018, the production volume is expected to be increased from 25,000 to 40,000 and by 2020 more than 100,000 parts will be manufactured.

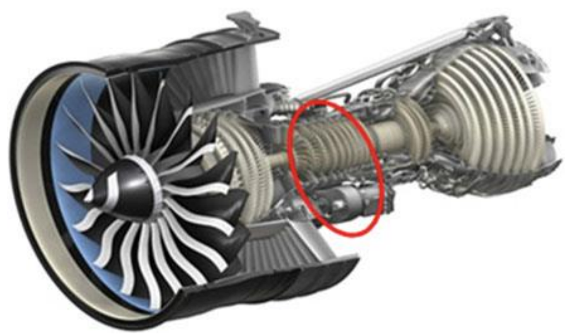

Figure 13. Leap motor manufactured by GE [6].

SAFRAN Group has identified the layered manufacturing method as a breakthrough technology for a number of engine components for both Turbomeca and Snecma to develop prototypes and engines. Turbomeca, which manufactures helicopter engines and Snecma aircraft engines, has used this technology extensively during the design phase. The manifold is the hydrogen turbo pump for the silver-crest business jet engine and the Vinci rocket engines of the Snecma company shown in the Fig. 14. It has successfully used technology for the rapid implementation of design changes and also for the repair of components. Through this method, extensive research has been made to develop complex assemblies as an integrated single component. Examples are guide vane assemblies, integrated fuel manifold and combustion chamber, and the like [6].

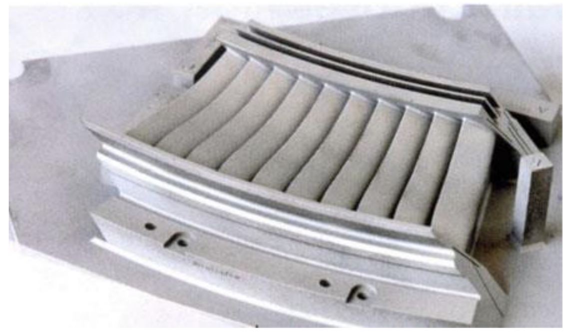

Figure 14. Engine wing made of high temperature resistant alloys [5].

NASA engineers used Layered Manufacturing technology to produce the complex metal rocket injector part for the next generation space launch system (SLS) J-2X engine. The rocket injector was manufactured from a selective laser melt (SLM) layered manufacturing method using nickel chromium alloy powder (Fig. 15). The conventionally manufactured injector had 115 parts and the 3D printed injector had only two parts. The part is constructed as a single joint, which is structurally stronger and more reliable, ensuring the overall safety of the vehicle. For NASA, time and cost savings have been a significant improvement. This section will undergo structural and hot fire tests and will eventually be used on the J-2X engine by 2019 [6].

Figure 15. First test piece manufactured on M2 Cusing machine [6].

Hindustan Aeronautics, Ltd. (HAL) is taking major steps to make India's only military aircraft manufacturer “Made in India bir a world-class label. HAL used 3D printing technology to create a prototype model for a 25 kN aircraft engine as shown in the Fig. 16. The first engine prototype, Aero India expo-2015, was exhibited as an operational model. Images shows the various engine prototype components made of Nylon plastic using the Selective Laser Sintering layered manufacturing method. The Bangalore-based company RAPITECH SOLUTIONS INC has manufactured these components in less than 20 days. In this project, layered manufacturing has significantly reduced prototype development time and cost compared to traditional production [6].

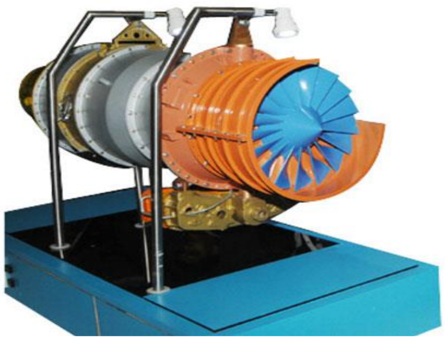

Figure 16. Prototype of 25 KN aircraft engine consisting of selective laser sintering additive manufacturing technology in Aero Hinustan [6].

6. EXPERIMENTAL

The subject of the study is to develop the working model in order to realize the electrical connections in the rocket model. In this study, description of the rocket connector in the sample model and Ultimaker 2+ model printer of FDM technology was used. The printer has a printing table of 223 x 223 x 305 mm. The SolidWorks program is preferred for the internal component of the rocket (Fig.17). Then the files converted to .stl program format are prepared for printing along with the Cura program (Fig.18,19) and printed part shown Fig. 20,21. The printing parameters are shown in Table 1,2.

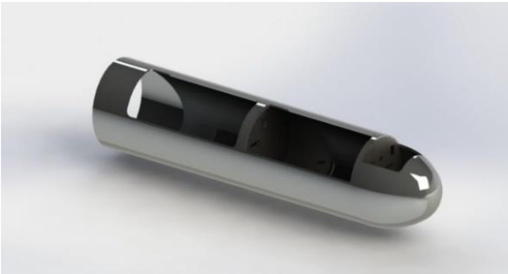

Figure 17. Rocket design in SolidWorks.

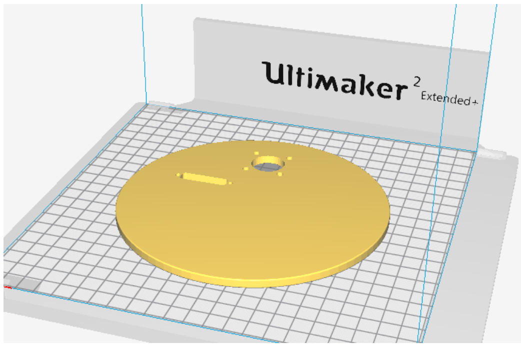

Figure 18. Part of the rocket that holds the electrical connection in the middle body in Cura.

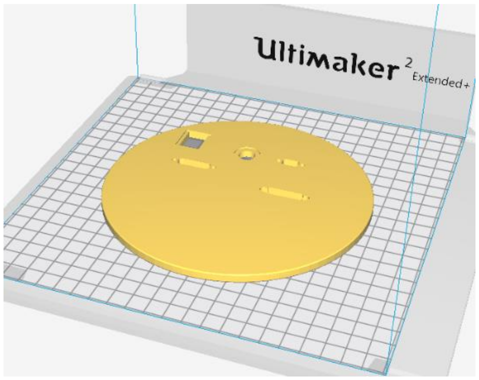

Figure 19. The part that holds the electrical connection on the head of the rocket in Cura.

Table 1. Print information for the head part of the rocket.

Used Material	PLA Material
Nozzle Diameter	0,6mm
Layer Height	0,15mm
Wall Thickness (Top,Bottom)	1,8mm
Infill Lines	%10
Printing Speed	40mm/s
Printing Time	3h. 47min.
Spent Material	3,39m/27gr

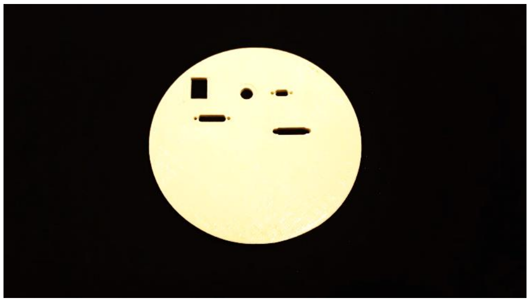

Figure 20. Printing piece in the head section of the rocket.

Table 2. Print information for the middle part of the rocket.

Used Material	PLA Material
Nozzle Diameter	0,6mm
Layer Height	0,15mm
Wall Thickness (Top,Bottom)	1,8mm
Infill Lines	%10
Printing Speed	40mm/s
Printing Time	3h. 45min.
Spent Material	3,37m/26gr

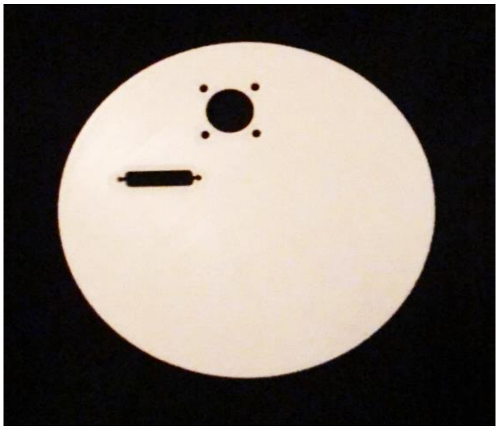

Figure 21. Printing piece in the middle section of the rocket.

7. CONCLUSION

In this study, the working model of electrical connection part used for rockets was investigated. Printing was achieved via using high surface quality materials. Such prototype models can be produced by spending more time than other manufacturing processes. It is obvious that 3D production technology can respond even in systems that are inexpensive, difficult to obtain and have a special and confidential design. In addition, the problems that occur in traditional production methods can be eliminated by additive manufacturing. As a result, additive manufacturing production in the aerospace industry reduce the cost and time.

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9. VITAE

Murathan KALENDER was born in 1996 in Istanbul. In 2014, he graduated from İsmet Aktar Anatolian Technical High School. He is currently a 4th year undergraduate student at Marmara University, Faculty of Technology, Metallurgical and Materials Engineering and Mechanical Engineering.

Yahya BOZKURT was born in 1975 in Antakya. He graduated from Marmara University, Faculty of Technical Education, Department of Metal Education in 2000. In December 2000, he became a research assistant at the Department of Metal Education, Faculty of Technical Education, Marmara University. Professor Dr. Serdar Salman and Assoc. Dr. Hüseyin Uzun completed his doctoral studies with his consultancy in September 2008. He became Assistant Professor in 2009, Associate Professor in 2012 and Professor in 2018. He still continues to work at the same university.

Sezgin ERSOY was born in 1977 in Istanbul. He completed his undergraduate education in Automotive, Master of Science in Mechatronics and Technology Trainings and his Ph.D. degree in Nano-Polymer Composites. Has national and international works. I am currently working as a faculty member in the Department of Mechatronics Engineering, Faculty of Technology, Marmara University.

Serdar SALMAN was born in 1962 in Istanbul. He studied at Ege University in 1979-1980. He graduated from Istanbul Technical University, Sakarya Engineering Faculty, Metallurgical Engineering Department in 1984. In 1985, he became a research assistant at the Department of Metal Education, Faculty of Technical Education, Marmara University. In 1991, for a period of 9 months, YOK - World Bank II. Within the scope of Industrial Education Project, he was in England (University of Huddersfield) for education and research. In 1992, he became an instructor at Marmara University, Faculty of Technical Education, Department of Metal Education. In 1995, he was appointed as an Assistant Professor to MÜTEF Materials Education Department. He became Associate Professor in 1997 and Professor in 2003 at the same department. Between 27/01/2003 and 27/01/2006, he worked as the Deputy Dean of the Faculty of Technical Education at Marmara University, and in 2007 (3 months) as the Deputy Dean. Between 2007-2008, he was a visiting professor at GATECH-Atlanta USA for one year. Between 2012-2015, he was the Founding Dean of Mehmet Akif Ersoy University, Faculty of Engineering and Architecture. He is currently the vice-rector of the National Defense University.