Additive Manufacturing and 3D Printer Technology in Aerospace Industry

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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 additive 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 addition, the aviation industry has combined the additive manufacturing process from concept design to end-use parts and repairs. Areas of application include rapid prototyping of components in the design phase using plastic and metal, followed by repair of damaged parts instead of direct production, scrapping or replacement of mold, tool and complex shape metal parts for mass production. Laser Metal Spool (LMD) Technology is the best method to repair aviation components. In this study, research and development activities carried out in the field of additive manufacturing in the aerospace 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 pressure parameters of the study have been examined.**

Keywords—3D Printer, 3D Modeling, 3D Prototype, Layered Fabrication, Printing Technologies

I. INTRODUCTION

3D printing is a layered manufacturing technique used to fabricate various structures and complex geometries from model data. The process consists of printing successive layers of material on top of each other. This technology was called stereolithography (SLA) by Charles Hull in 1986 and subsequently emerged after developments such as melt agglomeration modeling (FDM), inkjet printing. 3D printing which incorporates various methods, materials and equipment, has evolved over the years and has been capable of transforming production and logistics processes. Additive production is widely applied in different industries including defense industry, aviation industry, construction, prototyping and biomechanics. The reception of 3D printing, especially in the construction sector, has been very slow and limited, for example, despite the advantages. This method gives less freedom of design and automation [1].

New applications and new materials with emerging technology are emerging. In addition, additive production methods are constantly being developed. One of the main reasons for this technology to become more accessible is the expiration of previous patents, which enable manufacturers to develop new 3D printing devices. Recent developments have reduced the cost of 3D printers, and are thus widely spread across the field of application, becoming widespread in schools, homes, libraries and laboratories. First of all, 3D printing is widely used by architects and designers to produce aesthetic and functional prototypes due to its rapid and low cost prototyping capabilities. used. The use of 3D printing minimizes the additional costs incurred in a product development process. However, as a result of special product demands, some costs increase accordingly. Product customization has become difficult for manufacturers due to their high costs. Layered manufacturing can print in 3 dimensions of relatively low cost customized products in small quantities. Customized functional products currently comprise around 50% of the 3D printing industry. Wohlers Associates predicted that in 2020 the economy would revolve around the production of commercial products [2]. This technology has contributed to the production of a wide range of medical materials and implants, as well as the aerospace industry [3]. It has been used in construction sector as another application area. For example, an area of relatively inexpensive houses ($ 4800 per house) was built by WinSun in China. This print was successfully printed in less than a day. [4].

While 3D printers sold for home use have sold around $ 8,000 in recent years, this figure has declined to $ 250 in 2015 (3Ders, 2015). For example; Solidoodle, which was sold to $ 599 and benefited from plastic raw materials in production, made a quick start in 2012 (McKendrick, 2012). Solidoodle, which is sent as a ready set, allows the end customer to easily connect a Solidoodle to a computer and easily produce a 3D model with a maximum size of 20 cm x 20 cm x 20 cm (solidoodle, 2015). The cost of production in this technology consists of two items: 3D printer and output material (production material). One kilogram of plastic output material used in printers can be supplied to approximately $ 43. [5]

There are a hundred and eighty companies that commercially produce 3D printer production worldwide (3Ders, 2015). 3D-Systems, Objet and Stratasys are strong players in the majority of the US market. At the end of 2012, the company became the market leader with 156 million dollars of revenue and the company became the second largest market by combining Objet and Stratasys. It is estimated that this combination will have a positive impact on the end user by increasing competition (additive3d, 2012; Gooch, 2012; 3Ders, 2015). According to the report of 3D Hubs, a social platform for 3D printer owners operating in Amsterdam and according to the report of the distribution of printer brands used by 10,000 members in 120 different countries the market for new players entering different models especially for the end user. it appears to have changed its structure (3dhubs, 2015). [5]

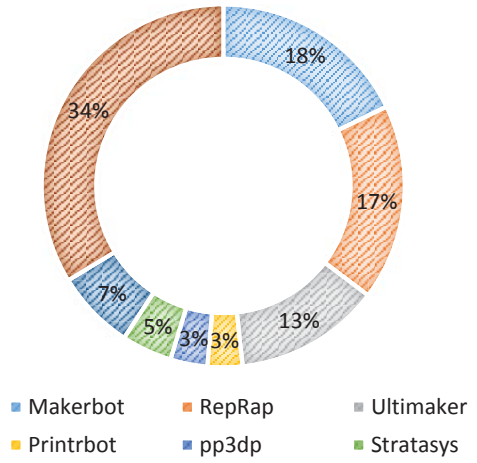

Fig..1. 3D printer companies [5].

II. 3D Printers

First, the use of 3D printer technology developed in the 1980s has become increasingly widespread [7]. 3D production using 3D printers is not defined by a single term, but can also be called additive manufacturing [8]. 3D manufacturing technology is used in the fields of engineering, architecture and industrial design [9]. Additive manufacturing can be used not only to produce prototypes, but also to obtain products such as machine parts and mold tools [10].

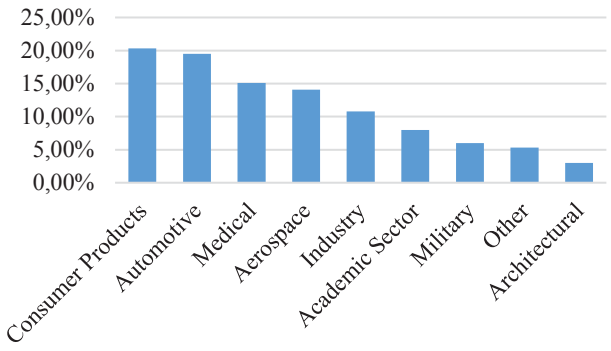

Fig..2. Additive manufacturing in different sectors.

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 3-D process is the process of converting a computer-aided three-dimensional design into a solid object [11]. It is created by adding a layer from the base of an object to the top [12]. 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 [13]. 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. [5] 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 (ABS, 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 [14].

III. 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 last 25 years, complex parts in the form of form and form come to the fore. 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 [15].

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, 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 [15].

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. [15]

IV. 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. [17]

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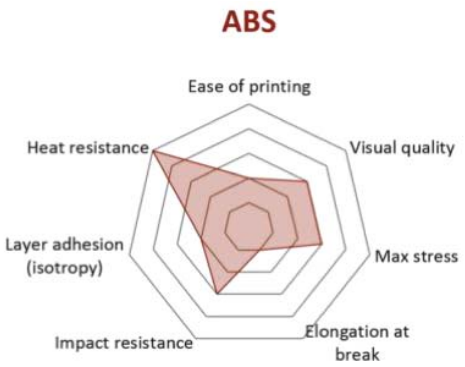

Fig.3. Mechanical and chemical properties of ABS material [18]

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 [19].

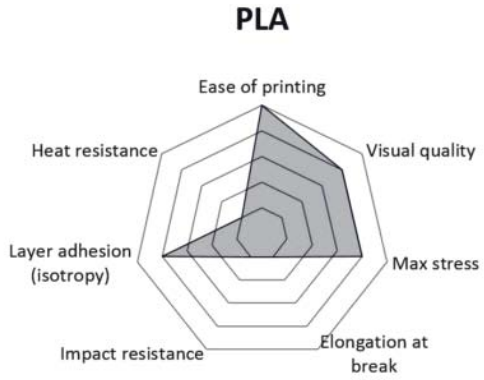

Fig.4. Mechanical and chemical properties of PLA material [18]

Thermoplastic polyurethane 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.

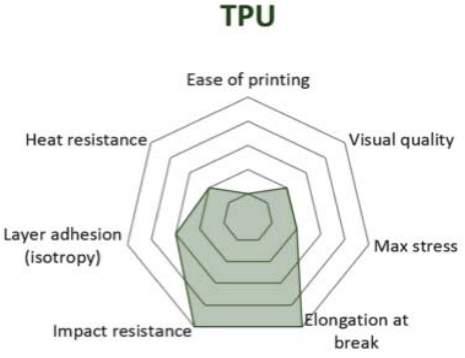

Fig.5. Mechanical and chemical properties of TPU material [18]

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. Durable materials are more frequently used in the medical field. It needs a heated platform.

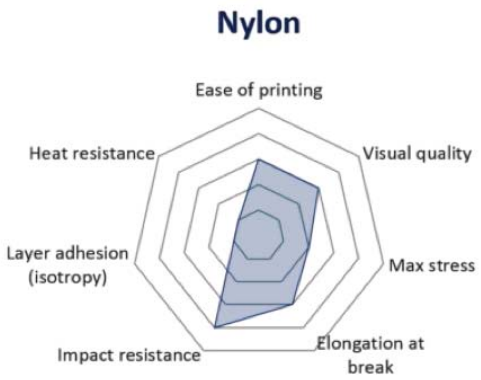

Fig.6. Mechanical and chemical properties of nylon material [18].



Fig.7. Product made of PA 11 material with 3D printer technology [20].

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. 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. [21].



Fig.8. Product made of carbon material with 3D printer technology [20].

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. For the most part, such printing is used by large technology firms rather than individuals or hobbies.



Fig.9. Product made of steel powder material with 3D printer technology [20].

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 prototypes and vacuum casting molds. This has changed with the introduction of new technologies, and now it is now possible to imprint the end-use parts that reflect common engineering requirements.

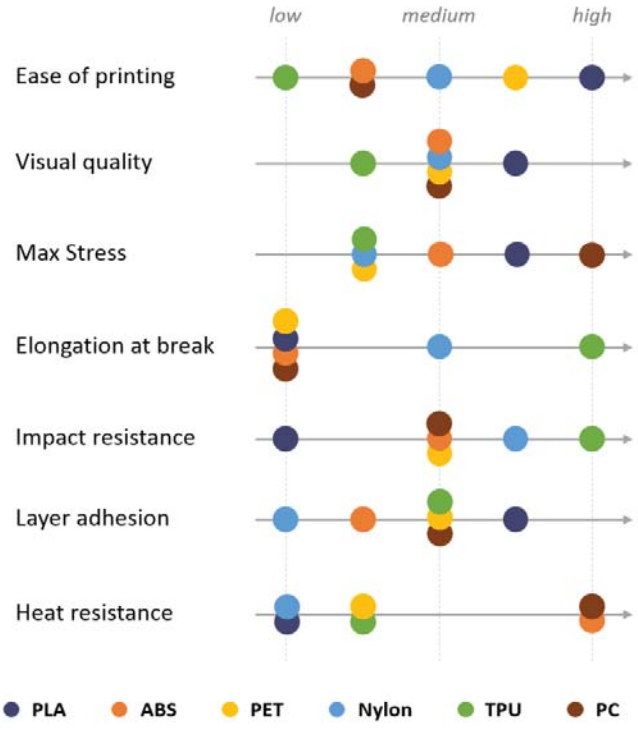

Fig.10. Mechanical and chemical properties of different materials. [22]

V. 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 prototypes, 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. [22]

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 produced various prototype thermoplastic parts using commercially available laser sintering techniques for commercial aircraft 737, 747, 777 and 787 [23]. Using this technology, the Boeing company profited $ 3 million from each 787-Dreamliner aircraft produced [24]. Although some of these produced 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 [25].

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 [26].

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 [27].

VI. EXPERIMENTAL

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 22.3 x 22.3 x 30.5 cm. The SolidWorks program is preferred for the internal component of the rocket [Fig.11.]. Then the files converted to baskı .stl program format are prepared for printing along with the Cura program [Fig.12.].



Fig.11. Rocket design in SolidWorks

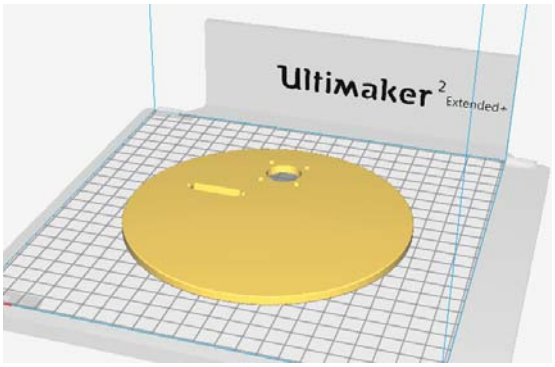

Fig.12. Part of the rocket that holds the electrical connection in the middle body in Cura.

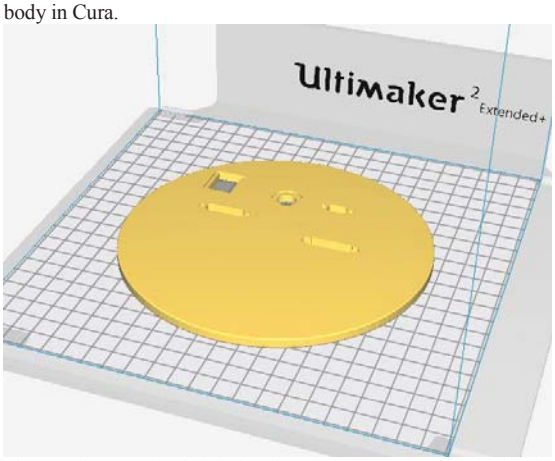

Fig.13. The part that holds the electrical connection on the head of the rocket in Cura.

TABLE I. PRINT INFORMATION FOR THE HEAD PART OF THE ROCKET.

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

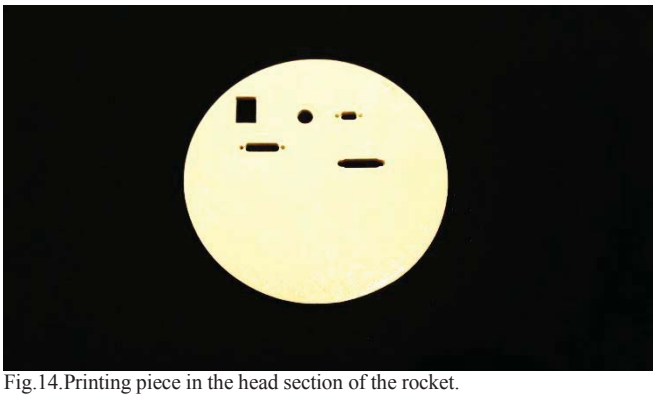

Fig.14.Printing piece in the head section of the rocket.

TABLE II. 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

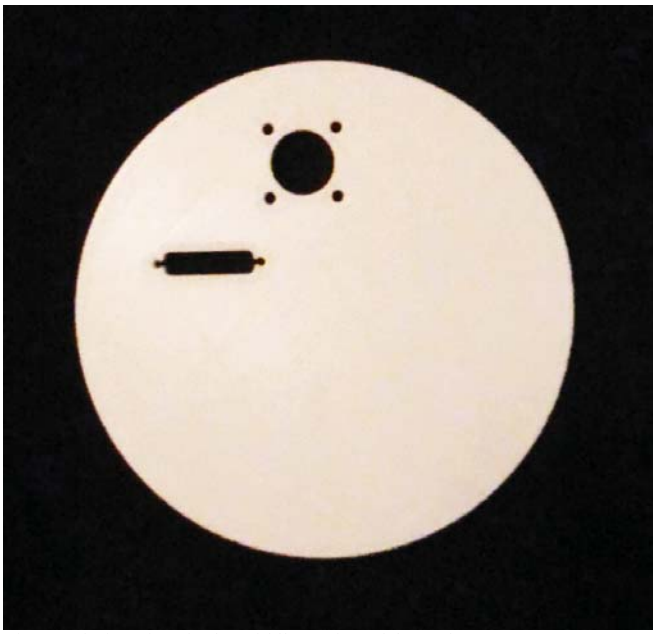

Fig.15.Printing piece in the middle section of the rocket.

In the study, the simulation material which is oriented to increase the practicality of the assembly of the rocket system. The design of the rocket part should be considered to be true. Material selection should be made with material close to the properties of the actual system. The occupancy rate of the material is the most important parameter here. The production success of the material is thought to be directly proportional to the success in the training of the connector connection of the rocket system.

VII. CONCLUSIONS

In this study, the electrical connections for the rocket model are produced by the additive manufacturing method using internal 3D printer. The surface quality of the material used was aimed and the printing was achieved with success. Such prototype models can be produced by spending more time in other manufacturing processes. In addition, goods and workload burden is increasing. Prototype products prepared using the 3D Printer eliminate these problems. Various products can be obtained according to the material parameters. It was aimed to investigate the mechanical properties of prototypes prepared with different materials in the future.

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