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Modern 3D Printing Technologies in Space Industry

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Abstract: The purpose of this paper is to present an overview of how additive manufacturing technologies are currently applied in the space industry and what possible uses they might have in the future.

Keywords: space, 3D printing, additive manufacturing, ISS, 'Space Fabric'

1. INTRODUCTION

Currently, the 3D printing industry is developing quite dynamically. Year by year, additive manufacturing finds applications in new fields. Nowadays, it is possible to print with a wide variety of materials, including polymers, metals, ceramics, concrete, and even organic tissues. The main advantage of 3D printing is the fact that it is an additive method. This allows for the creation of various complex geometries without significant difficulty, which would be impossible to achieve with traditional subtractive methods. As a result, houses [1], a rocket [2], a satellite [3], parts of human organs [4], small implants [5], and even food [6] have already been printed. Scientists are convinced that in the near future, 3D printing will play a significant role in many fields, especially in the space industry.

2. METHODS OF 3D PRINTING

While printing a structure designed in CAD software, it is important to consider which 3D printing method to choose. The choice usually depends on the material that the element is going to be composed of, the size of the printed part, the desired precision, and the budget that is going to be devoted to printing. Below there is a brief description of two most common methods, the relatively cheap FDM and precise SLM.

2.1. Fused Deposition Modelling (FDM)

Fused Deposition Modelling (FDM), also known as Fused Filament Fabrication (FFF) [8], involves creating a model from a material in the form of a wire, called filament, by extruding it.

The extruder is responsible for controlling the amount and speed of material delivered to the nozzle, where it is heated and melted. The nozzle moves in three-dimensional space, applying the material layer by layer to gradually build the model.

This method is most commonly used while printing from polymers. However, it also allows for the manufacturing of metal and ceramic elements. To achieve this, a special filament is used, which is a mixture of metallic (or ceramic) powder with a polymer binder. In this case after the printing finishes, the model is heat-processed to remove contaminants from its structure. During this process, the polymer binder changes its state to gas and escapes due to the porosity of the structure.

2.2. Selective Laser Melting (SLM)

Selective Laser Melting (SLM), also known as Direct Metal Laser Sintering (DMLS) is an additive technology using a laser to melt and combine metallic powders, which were previously spread and smoothed as a thin layer. It allows for creation of precise and tough structures from alloys of steel, titanium, aluminium and even noble elements. It has already been used in medicine to fabricate dental implants made of alloys specially adapted for biological applications [5], in the space industry for printing rocket engine components [10] and most commonly for prototyping [10].

2.3. Others methods

There are many various and unique methods of 3D printing, usually designed for a given, specific purpose. Among others, there is bioprinting 3D [11] making it possible to print with cells and fabricate tissues, but also using concrete to create buildings with nontrivial geometries has been already achieved [12].

3. APPLICATIONS OF 3D PRINTING IN SPACE INDUSTRY

3.1. Creation of elements directly in space

The International Space Station (ISS) for the last 25 years has been a home for more than 270 astronauts [13]. To this day, problems connected with the supply of necessary materials or equipment are solved by sending about 3 tons of parts there each year. Nowadays, about 13 tones are stored on the station, with an additional 17 tones ready on Earth to be sent if necessary.

Solution this might work well for an object orbiting about 400 km above the surface of our planet, but resupplying a mission located on the Moon, Mars or heading into outer space would be very difficult [14]. That is why, the possibility of manufacturing needed elements in place and immediately is crucial in further development of space technologies. Moreover, this new solution would also allow for designing necessary parts at a base on Earth and sending ready-to-print files to the station or a ship without the time delay or financial expenses on organising the resupply mission.

In 2014 a FFF 3D printer was installed on the ISS, allowing for fabrication of polymer elements. Already it has been used to create a wrench, aerial parts, a part for the oxygen generating system and many more. Furthermore, after testing the samples printed on the station and comparing them with the ones fabricated on the ground, no significant difference has been detected between objects printed in microgravity and in ordinary conditions.

For the last few years the number of 3D printers on the ISS has been constantly increasing. In 2018 the “Refabricator” was launched to the space station [20], which is able to create its own filament from unnecessary, previously printed, polymer tools or elements. In addition, the device allows plastic bags and food packaging to be transformed into filament, meaning that this solution not only reduces the amount of waste that would have to be kept on a station, but also allows recycling unneeded objects made from polymers.

Moreover, in 2024 the first 3D printer was sent to ISS, which is able to print from metal, making it possible to create tougher and better small tools or parts on the station. This device works due to the use of a wire made from a type of stainless-steel, which is being melted by a laser [22].

3.2. 3D printing food

It has already been demonstrated that 3D printing might also solve the problem of access to diverse food in space. The ability to create animal tissues would broaden the possible meals containing fresh meat, enriching the astronauts’ diet. In 2019, the Israeli company Aleph Farms showed that with the use of cow stem cells, it is possible to print a steak that, after baking, fully resembled ordinary meat in terms of structure, taste and consistency. Furthermore, a printer Bioprinting Solutions’ 3D used to fabricate this steak was designed to be also able to print in microgravity conditions.

Lastly, an Italian startup, Novameat, developed a method of printing fully vegan meat [23], which does not require animal stem cells, but is based on a mixture of plant-based ingredients. The printed items were also fully resembling ordinary products' features meaning that, in the future, fabrication of meat meals might not even depend on the creation of real tissues.

3.3. 3D printing parts of rocket engines

Another field where 3D printing is commonly used is the industry connected with creating complicated and atypical parts of rocket engines. In 2013 Elon Musk published on Twitter an image of printer EOS 3D, during fabrication of the SuperDraco rocket chamber [15]. A possibility of creating strong and complex structures has been spotted also by a Spanish company Pangea, which after embracing 3D printing technologies increased the efficiency of its engines by 15% in comparison to ones produced by conventional means [6]. Moreover, in recent years this technology has been used to create a Terran R rocket with its engine Aeon R, a satellite [16] and even 11 parts or tools, which were sent to Mars on the Perseverance rover in 2020.

3.4. Future possible applications

3D printing will play an important role during the colonisation of the Moon or other celestial bodies. Not only would it facilitate building structures in human-unfriendly environments, but it is also much easier to launch a spaceship with a 3D printer and compact packed filament than to transport large, fabricated on Earth elements [17, 18]. Furthermore, scientists are now trying to develop a method of filament production, which will use materials found on a given celestial object, mostly focusing on a lunar regolith.

The possibility of 3D printing a space base or a part of it in the future is increasing year by year. In 2015, NASA started a competition for a 3D-printed space habitat and in 2019 awarded the winners [21].

4. POSSIBILITY OF PRINTING COMPLICATED STRUCTURES

4.1. Designed by NASA 'Space Fabric'

Additive technologies, such as 3D printing, allow for creation of structures, which might not be fabricated by any other means. It has been shown by NASA with a design of 'Space Fabric'. This structure resembles a mediaeval chainmail, allowing the elements building it for a free movement.

Primarily, the 'Space Fabric' was designed as a protective layer for astronaut's suits or spaceships to save them from the impact of rapidly moving cosmic powder. Furthermore, it could also be used to cover the legs of landers from below and to thermally isolate them if the mission would happen on icy celestial bodies, which in the Solar System might be a moon of Jupiter – Europa [19].

4.2. Understanding the model and creation of the new design

Thanks to a cooperation with the Silesian University of Technology during the first edition of research projects implemented with secondary school students under the Excellence Initiative - Research University, our team, inspired by 'Space Fabric', decided to print similar structures [24] to better understand how they precisely work. Models [24] shown on *Figures 1-2* have been printed from a PLA using a FDM printer, however the model on a *Figure 3* was created from a stainless steel using the SLM method.

After the investigation of designs downloaded from the Internet a completely new model was created in the Inventor Pro software (fig. 4) and printed on a Prusa 3D printer (fig. 5-6).

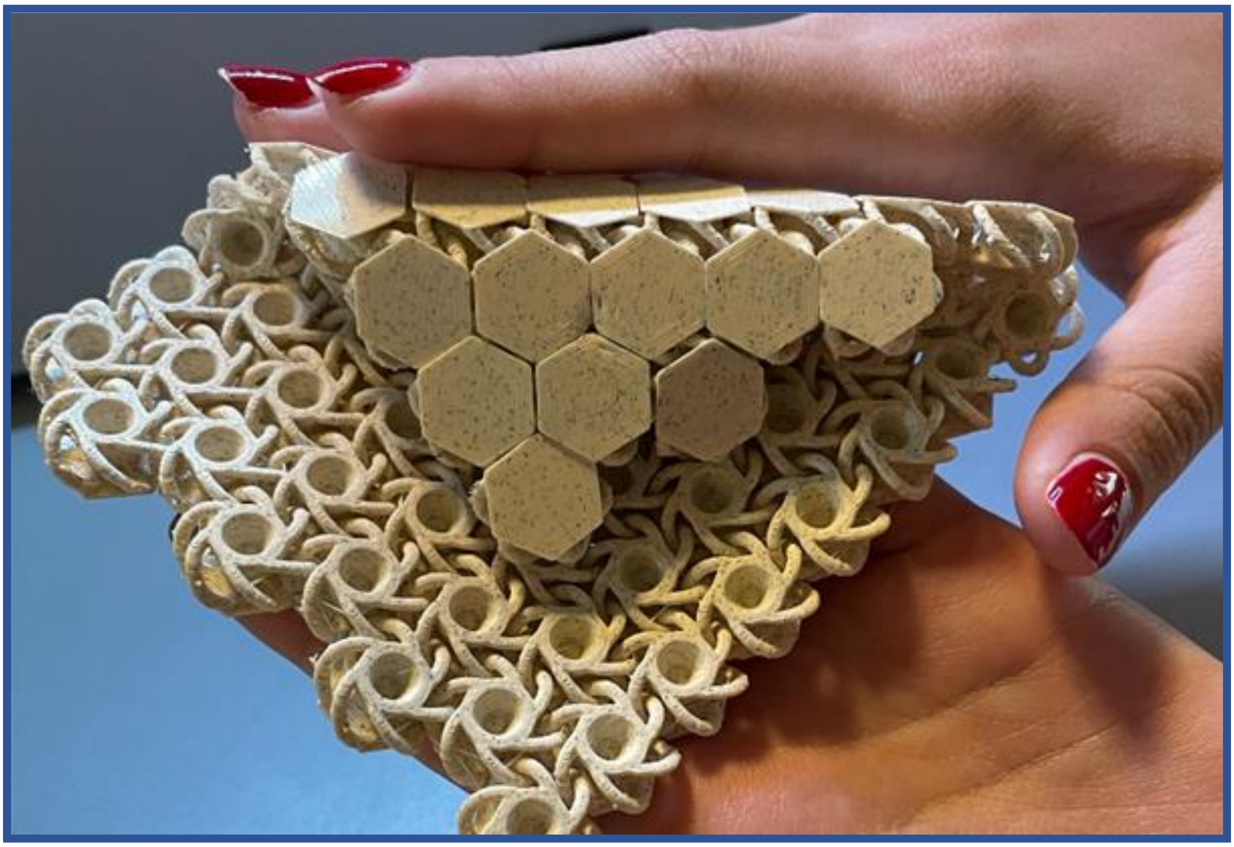

Figure 1. Model printed from PLA

Figure 2. Model printed from PLA

Figure 3. Model printed from stainless-steel

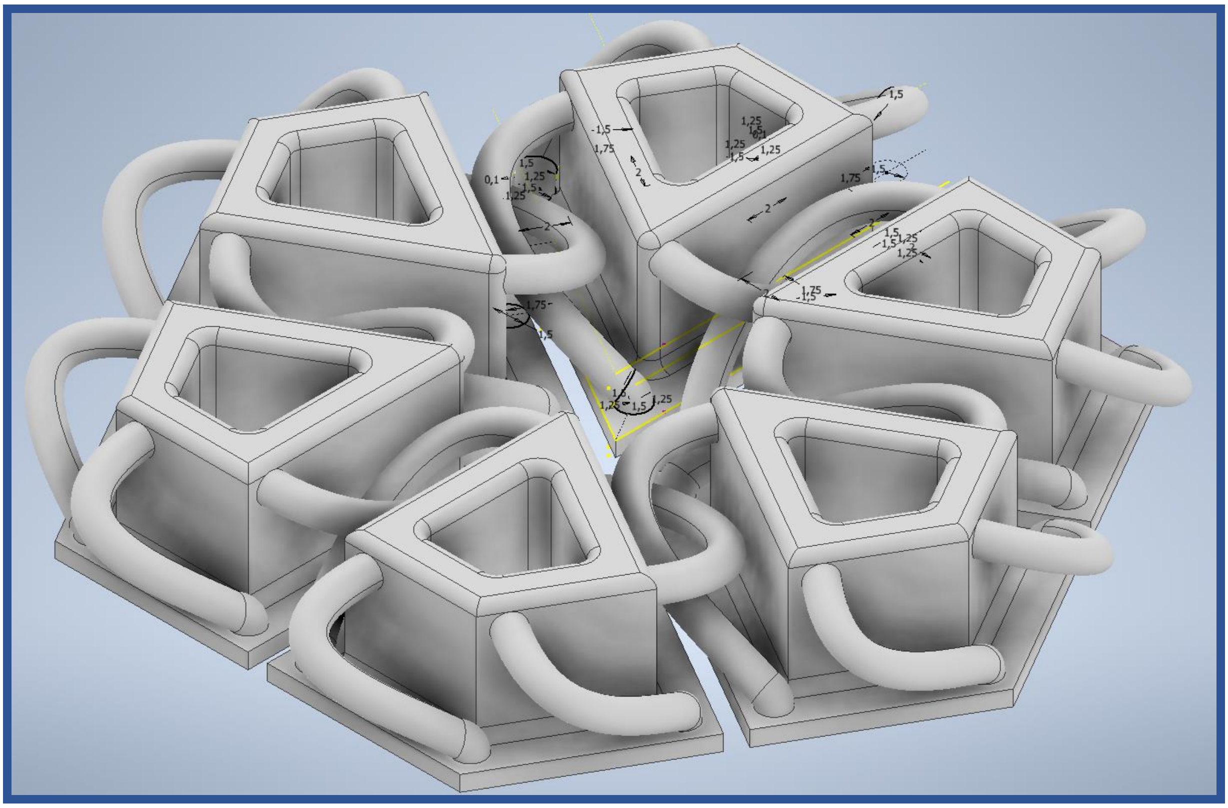

Figure 4. Designed CAD model of a structure

Figure 5. Designed model printed from PLA, view from top

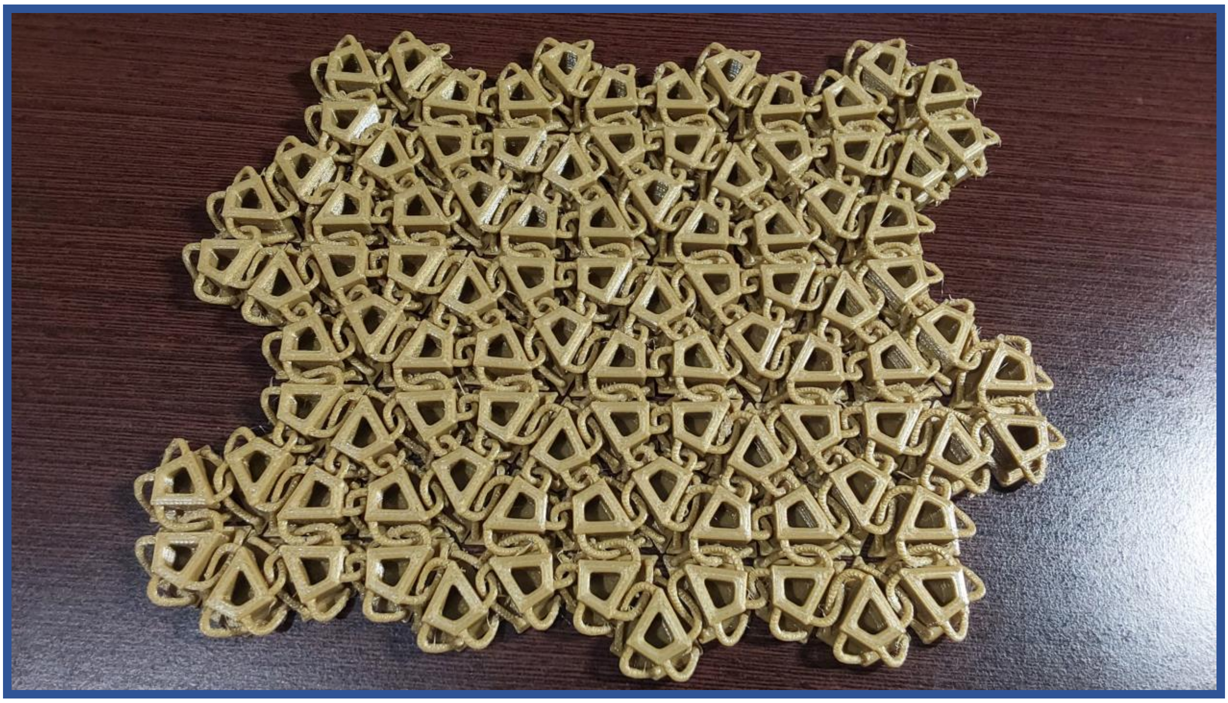

Figure 6. Designed model printed from PLA, view from bottom

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