POLITECNICO DI TORINO

Master's degree in Engineering and Management

Master of Science Thesis

3D Printing Market Analysis, Additive Manufacturing Applications in Aerospace and Case Study about Desktop Metal

Supervisor:

Prof. Luigi Benfratello

Candidate:

Yufei Guo

Abstract

The history of human beings is a period that people’s production is becoming more diverse and more efficient. In the early stone age, people worked hard to create simple tools one after another. With the development of technology, people started to use different kinds of machines to do production after the industrial revolution. The machines, which are designed to convert energy to work, have greatly changed the way people produce products. With the help of machines, the workers are liberated from heavy manual labor and people's material life has been greatly improved.

In 1981, the first 3D printer was invented and then opened the prelude to the rapid development of 3D printing. The 3D printer in which material is joined and solidified under computer control to create a 3D object, is also called additive manufacturing. This is a totally new attempt. The traditional manufacturing machine is to produce by subtracting materials. In contrast, a 3D printer is to produce by adding materials.

Nowadays, 3D printing is everywhere, in cars, in airplanes, in hospitals, in factories. It changes the way we manufacture, it brings new concepts to our minds, it makes our lives different. Maybe the 21st century is the century of 3D printing.

This thesis mainly talks about additive manufacturing, there are 4 chapters. The first chapter is an introduction to AM, including history, technologies, process steps, materials, etc. The second chapter discussed 3D printing from a market perspective. The advantages and limitations of 3D printing were listed. We made a rough assessment of the market and introduced the popular metal 3D printing market. Based on the information we have, we have made inferences about market trends. We talked about the 3D printers market next. Producers, consumers, and prices were included. How producers were distributed? What was the segment of consumers? How has the price changed? Then we gave examples of the applications in different sectors. In the third chapter, we mainly focused on the aerospace sector. We analyzed the current status of AM in aerospace. We tried to analyze the future development of 3D printing in combination with the current hottest technology, such as AI, IoT, big data and blockchain. In the final chapter, I did a case study about a 3D printing company, Desktop Metal. I analyzed what kind of external environment Desktop Metal is in from a strategic point of view. I learned about the internal situation of Desktop Metal through SWOT and VRIO. Then I listed some business strategies that Desktop Metal has adopted. From this case study, we can analyze how Desktop Metal has grown rapidly from 2015. What did Desktop Metal do? What can we learn from Desktop Metal?

Table of Content

1.Chapter1: Introduction to additive manufacturing

Additive manufacturing, which is also called 3D printing, is a process that produces products layer-by-layer. In this chapter, we will give a general introduction to AM, including history, , technologies, process steps and materials so that we could have an overall understanding of AM.

1.1 AM history

This is a timeline of important nodes in the development of AM below:

In 1986, American scientist Chuck Hull developed the first commercial 3D printing machine (Figure 1.1).

Figure 1.1 The first commercial 3D printing machine

E.M.Sachs (Massachusetts Institute of Technology) applied for the 3DP (Three-Dimensional Printing) patent in 1989. Four years later in 1993, Massachusetts Institute of Technology was awarded the patent for this.

In 1995, the American ZCorp company obtained the sole authorization from the Massachusetts Institute of Technology and began to develop 3D printers.

In 2005, the first high-definition color 3D printer Spectrum Z510 on the market was successfully developed by ZCorp (Figure 1.2)

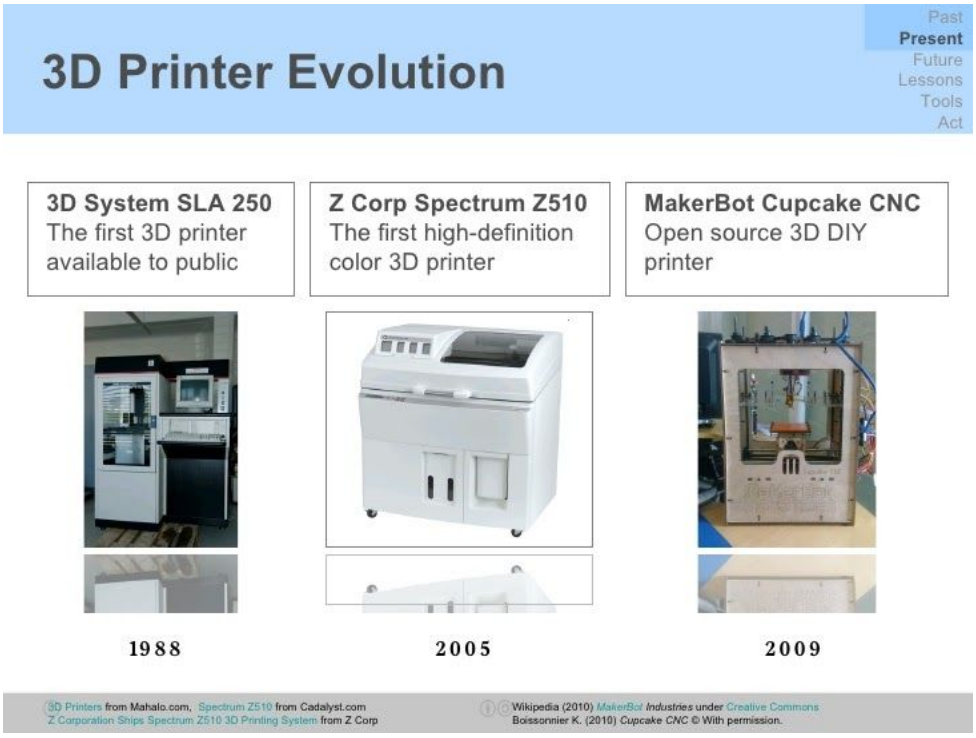


Figure 1.2 3D printer evolution, the first high-definition color 3D printer in 2005

In November 2010, the American Jim Kor team created the world's first car printed by a 3D printer, called Urbee (Figure 1.3)

Figure 1.3 Jim Kor and his car printed by 3D printer

On June 6, 2011, the world's first 3D printed bikini was released.

In July 2011, British researchers developed the world's first 3D chocolate printer.

In August 2011, engineers at the University of Southampton developed the world's first 3D printed aircraft. The entire structure of Southampton University Laser Sintered Aircraft (SULSA) was printed, from the wings to the integral control surfaces (Figure 1.4).

Figure 1.4 world’s first 3D printed aircraft

In November 2012, Scottish scientists used human cells to print artificial liver tissue with a 3D printer for the first time.

The world's first successful auction of a 3D printed artwork named "ONO God" happened in October 2013.

In November 2013, SolidConcepts, a 3D printing company located in Austin, Texas, designed and manufactured a 3D printed metal pistol(Figure 1.5).

Figure 1.5 world’s first printed metal pistol

On October 11, 2014, a team of British enthusiasts used 3D printing technology to create a rocket. They were also preparing to launch the world’s first printed rocket into the sky.

It was reported on June 22, 2015 that the state-owned Russian Technology Group Corporation used 3D printing technology to create a drone prototype, weighing 3.8 kg, with a wingspan of 2.4 meters, a flying speed of 90 to 100 kilometers per hour, and a range of 1 to 1.5 hour endurance.

On the morning of July 17, 2015, the first 3D printed building appeared in Xi'an, China. A two-floor villa was built in 3 hours(Figure 1.6).

Figure 1.6 world’s first 3D printed villa with 3 hours completion

As an emerging technology that entered the commercial field at the end of the last century, AM has developed rapidly in the past few decades. It took less than half a century from the inefficient 3D printer that appeared in the laboratory to AM spreading its antennae to various industries. On the one hand, we can say that the history of AM is not long, and there are still many problems that need to be resolved in the future. On the other hand, AM is developing rapidly, and stories that are not what it used to be are happening every day. An inconspicuous little achievement of AM may have stormy waves in the future.

1.2 AM technologies

The historical basis of additive manufacturing can be traced back almost 150 years ago. At that time, people used two-dimensional layer overlays to form three-dimensional topographic maps, which might be the prototype of additive manufacturing. But related technologies that could be used in AM were born in the 1960s and 1970s. In the late 1960s, photopolymerization technology gradually entered three-dimensional mold processing.

Photopolymerization-based 3D printing techniques, such as stereolithography, digital light processing, continuous liquid interface production, two-photon polymerization, and lithography-based 4D printing, utilize photosensitive polymer resins, which are selectively cured layer by layer using either a laser or digital light projection source (Adilet Zhakeyev et al., 2020).

In 1972, the powder melting processes were developed. Selective Laser Sintering(SLS) is one of the powder melting processes. SLS uses the principle of sintering powder materials under laser irradiation, controlled by a computer. This process is layer by layer. First spread a layer of powder material and then scrape it smoothly. The material is preheated to close to the melting point, later a high-intensity CO2 laser is used to selectively scan the cross-section of the layer to raise the temperature of the powder to the melting point and then sinter to form a bond, and then repeat the process of powder spreading and sintering until Complete the entire model forming.

In 1979, laminated sheet was verified to be applicable to additive manufacturing, this could be used to produce parts with complex internal structures.

By the 1980s and early 1990s, the number of AM-related patents and academic publications increased significantly, many innovative AM technologies appeared.

E.M.Sachs applied for the 3DP (Three-Dimensional Printing) patent in 1989, which is one of the core patents in the field of droplet spray forming non-forming materials.

The laser beam melting process also developed in the 1990s. Now a related technology mainly used in additive manufacturing is selective laser melting. This process uses a high-energy beam laser with a spot diameter of only 100nm to directly melt metal or alloy powder, layer by layer selective melting and accumulation, and finally form metallurgical bonding and densely organized metal parts.

Some additive manufacturing technologies were successfully commercialized, including stereo lithography (SL) technology, fused deposition modelling technology (FDM), and selective laser sintering technology (SLS). But at that time, high cost, limited material selection, size limitation and limited accuracy restricted the application of additive manufacturing technology in industry, and it could only be used for the production of small quantities of rapid prototypes or models.

The 1990s and 2000s were a period of growth for additive manufacturing. New technologies such as electron beam melting (EBM) have been commercialized, while existing technologies have been improved. At the same time, researchers' attention began to turn to the development of additive manufacturing related software. A special file format for additive manufacturing has appeared, and special software for additive manufacturing, such as

Magics of Materialise, has been developed. The improvement of equipment and the development of processes have greatly improved the quality of 3D additive manufacturing products, and they have begun to be used in tools and even final parts.
In the late 2000s, metal additive manufacturing technology stood out among many additive manufacturing technologies and became the focus of market attention. The equipment, materials and processes of metal additive manufacturing technology promote the development of each other. Many different metal additive technologies compete with each other and promote each other. The application direction is gradually becoming clear.

1.3 AM process steps

AM has a series of steps that move from the virtual CAD description to the physical resultant parts. Different products will involve AM in different ways and to different degrees. Small size, relatively simple products might only make use of AM for visualization models, while larger size, more complex products with greater engineering content may involve AM during numerous stages and iterations throughout the development process. Furthermore, early stages of the product development process may only require rough parts, with AM being used because of the speed at which they can be fabricated. At later stages of the process, parts may require careful cleaning and post-processing (including sanding, surface preparation, and painting) before they are used, with AM being useful here because of the complexity of form that can be created without having to consider tooling. Generally speaking, most AM processes involve, to some degree at least, the following seven steps (Figure 1.7).

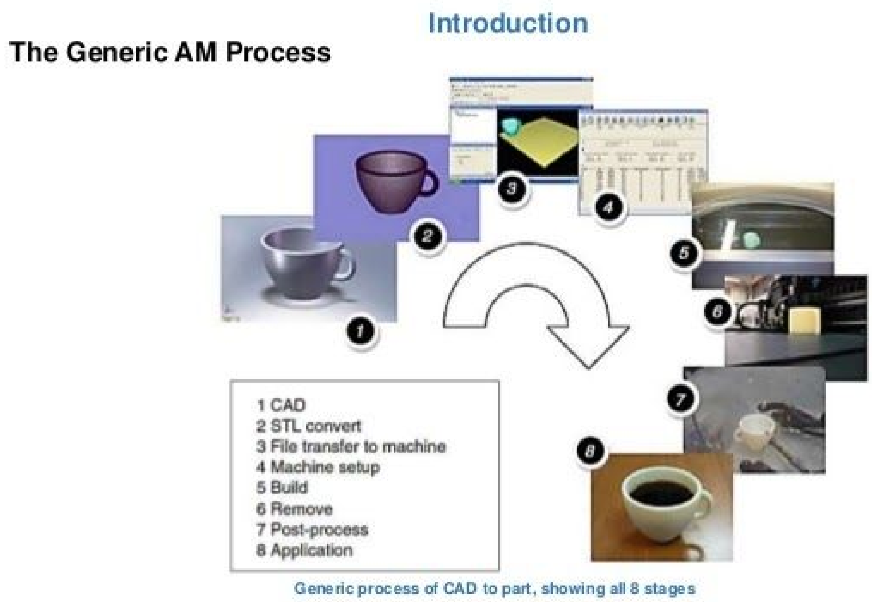


Figure 1.7 generic process of CAD to part, showing all eight steps

1.3.1 Step1: CAD

All AM parts must start from a software model that can fully describe the external geometry. This can involve the use of almost any professional CAD solid modeling software. The output must be a 3D solid or surface representation. Reverse engineering equipment (e.g., laser and optical scanning) can also be used to create this representation. In this step, designers have almost no restrictions, they can draw any product they think creative on the software.

1.3.2 Step 2: Conversion to STL

STL is a file format native to the stereolithography CAD software created by 3D Systems. Figure 1.8 gives an example. When the CAD model is designed, it's an ideal shape. AM process needs to convert the CAD model to STL model, so that the 3D printer can start working. A 3D printer cannot print a perfect curve, it can only divide the curve into many short straight lines, and make these small line segments look like a perfect curve through approximation. Nearly all AM machines accept the STL file format, which has become a standard, and nowadays nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

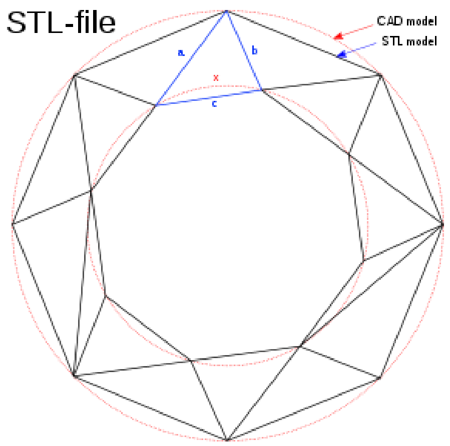


Figure 1.8 Conversion from CAD to STL

1.3.3 Step 3: Transfer to AM Machine and STL File Manipulation

The STL file describing the part must be transferred to the AM machine. Here, there may be some general manipulation of the file so that it is the correct size, position, and orientation for building.

1.3.4 Step 4: Machine Setup

The AM machine must be properly set up prior to the build process. Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc.

1.3.5 Step 5: Build

Building the part is mainly an automated process and the machine can largely carry on without supervision. Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place like running out of material, power or software glitches, etc. In this case, the benefit and efficiency are maximized.

1.3.6 Step 6: Removal

Once the AM machine has completed the build, the parts must be removed. This may require interaction with the machine, which may have safety interlocks to ensure for example that the operating temperatures are sufficiently low or that there are not actively moving parts.

1.3.7 Step 7: Post-processing

Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed. This therefore often requires time and careful, experienced manual manipulation.

1.4 AM materials

Since AM has completely changed the methods and principles of the traditional manufacturing industry and it is a subversion of the traditional manufacturing mode, 3D printing materials have become the main bottleneck restricting the development of 3D printing. It is also the key point of 3D printing breakthrough innovation. At present, 3D printing materials mainly include polymer, metal, ceramic and composite.

1.4.1 Polymer materials

Polymer materials include engineering plastics, bioplastics, thermosetting plastics and UV Curable Resin.

Engineering plastics refer to industrial plastics used as industrial parts or housing materials. They have the advantages of high strength, impact resistance, heat resistance, high hardness and aging resistance. The normal deformation temperature can exceed 90°C. The materials can be machined, painted and electroplated. Engineering plastics are currently the most widely used type of 3D printing materials. Common materials include acrylonitrile-butadiene-styrene copolymer (ABS), polyamide (PA), polycarbonate (PC), and polyphenylsulfone (PPSF), Polyetheretherketone (PEEK), etc.

ABS material (Figure 1.9) has the advantage of impact strength. At present, ABS is mainly pre-made into silk and then powdered for use. The application range covers almost all daily necessities, engineering supplies and some machinery supplies. There are many colors of

ABS materials, such as ivory white, white, black, dark gray, red, blue, rose red, etc., which are widely used in the fields of automobiles, home appliances and consumer electronics.

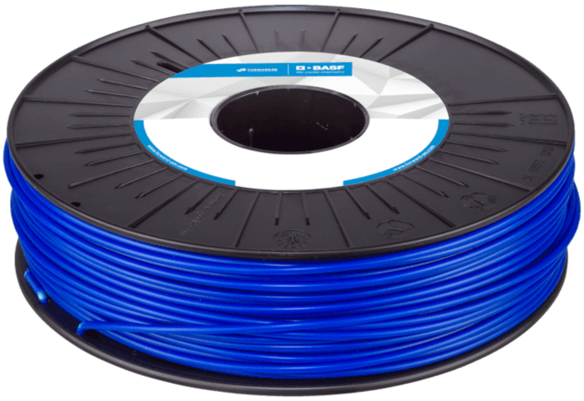


Figure 1.9 ABS material

PA material (Figure 1.10) has the advantage of high strength, it also has a degree of flexibility. Therefore, PA materials can be directly used to manufacture equipment parts by 3D printing. The PA carbon fiber composite plastic resin parts, manufactured by 3D printing, have the advantage of high toughness. These parts can be used for mechanical tools instead of metal tools.

Figure 1.10 Products obtained by 3D printing with PA

PPSF material (Figure 1.11) has the highest strength, heat resistance and corrosion resistance among all thermoplastic materials. It is widely applied in aerospace, transportation and medical industries, usually used as final parts.

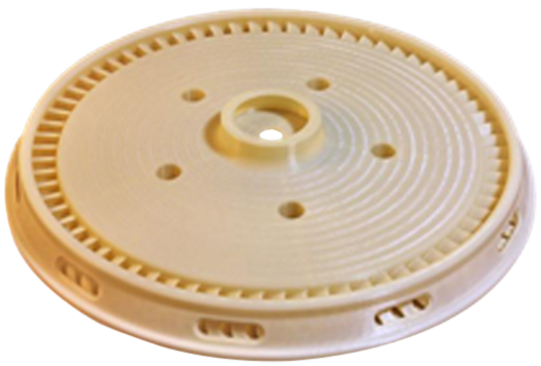


Figure 1.11 PPSF materials

PEEK (Figure 1.12) is a special engineering plastic with excellent properties such as high temperature resistance, self-lubricating and high mechanical strength. It can be manufactured and processed into various mechanical parts, such as automobile gears, aircraft engine parts, automatic washing machine runners, medical equipment parts, etc. PEEK has excellent abrasion resistance, biocompatibility, chemical stability and the closest Young's modulus to human bone. It is an ideal artificial bone replacement material and is suitable for a long-term implantation in the human body. The 3D printing technology based on the principle of fused deposition molding is safe and convenient. It doesn’t require the use of lasers and it is simple in post-processing. The 3D printing technology is combined with PEEK materials to produce bionic artificial bone.

Figure 1.12 PEEK materials

3D printing bioplastics mainly include polylactic acid (PLA), Poly(ethylene terephthalateco-1, 4-cylclohexylenedimethylene terephthalate) (PETG), polycaprolactone (PCL), etc., with good biodegradability.
PLA (Figure 1.13) is a new type of bio-based and biodegradable material. It has good biodegradability. It can be completely degraded by microorganisms in nature under specific conditions after using. Then this process finally produces carbon dioxide and water without polluting the environment, which is very beneficial to the protection of the environment. Hence PLA is recognized as an environmentally friendly material.

Figure 1.13 PLA materials

PETG is a bio-based plastic synthesized from bio-based ethylene glycol produced from sugarcane ethylene. This material has good thermoforming, toughness, weather fastness, short thermoforming cycle and high yield. As a new type of 3D printing material, PETG has the advantages of PLA and ABS. In 3D printing, the shrinkage rate of the material is very low, and the material has good hydrophobicity. So there is no need to store it in a hermetic space. Due to the low shrinkage rate and low temperature, PETG has a broad development and application prospects in the field of 3D printing products.
PCL material is a kind of degradable polyester with a low melting point, only about 60℃. Like most biological materials, people often use it for special purposes such as medical delivery equipment, suture, etc. Meanwhile, PCL also has shape memory. In 3D printing, due to low melting point, it doesn't require a high printing temperature, which could save energy. In the medical field, it can be used to print heart stents, etc.
Thermosetting plastics have the characteristics of high strength and fire resistance, which are very suitable for 3D printing powder laser sintering molding processes.
UV Curable Resin is composed of polymer monomer and prepolymer. Due to its good liquid fluidity and instant light curability, liquid UV Curable Resin has become the first choice for 3D printing consumables for high-precision product printing. UV Curable Resin has the

advantage of low odor and low irritating ingredients, which makes it suitable for personal desktop 3D printing systems.

1.4.2 Metal materials

Nowadays, stainless steel, superalloy and titanium are the most common metal materials used in 3D printing.

Stainless steel is the cheapest metal printing material. Stainless steel has a variety of different glossy and frosted surfaces. It is often used for 3D printing of jewelry, functional components and small sculptures, etc.

Superalloy have become the main 3D printing materials used in the aviation industry due to their high strength, stable chemical properties, difficulty in forming, and high cost of traditional processing techniques. With the long-term research and further development of 3D printing technology, aircraft parts manufactured by 3D printing have been widely used due to their cost advantages.

Titanium alloy parts manufactured by 3D printing technology have the advantages of high strength and precise dimensions. The smallest size that can be produced can reach 1mm, also the mechanical properties of the parts are better than the forging process. The British company Metalysis has successfully produced impellers and turbochargers and other auto parts using titanium powder by 3D printing. Titanium metal powder consumables have broad application prospects in 3D printing automobiles, aerospace, etc.

1.4.3 Ceramic materials

Ceramic materials have the advantages of high strength and high hardness, high temperature resistance, low density, good chemical stability and corrosion resistance. They have a wide range of applications in aerospace, automotive, biological and other industries.

1.4.4 Composite materials

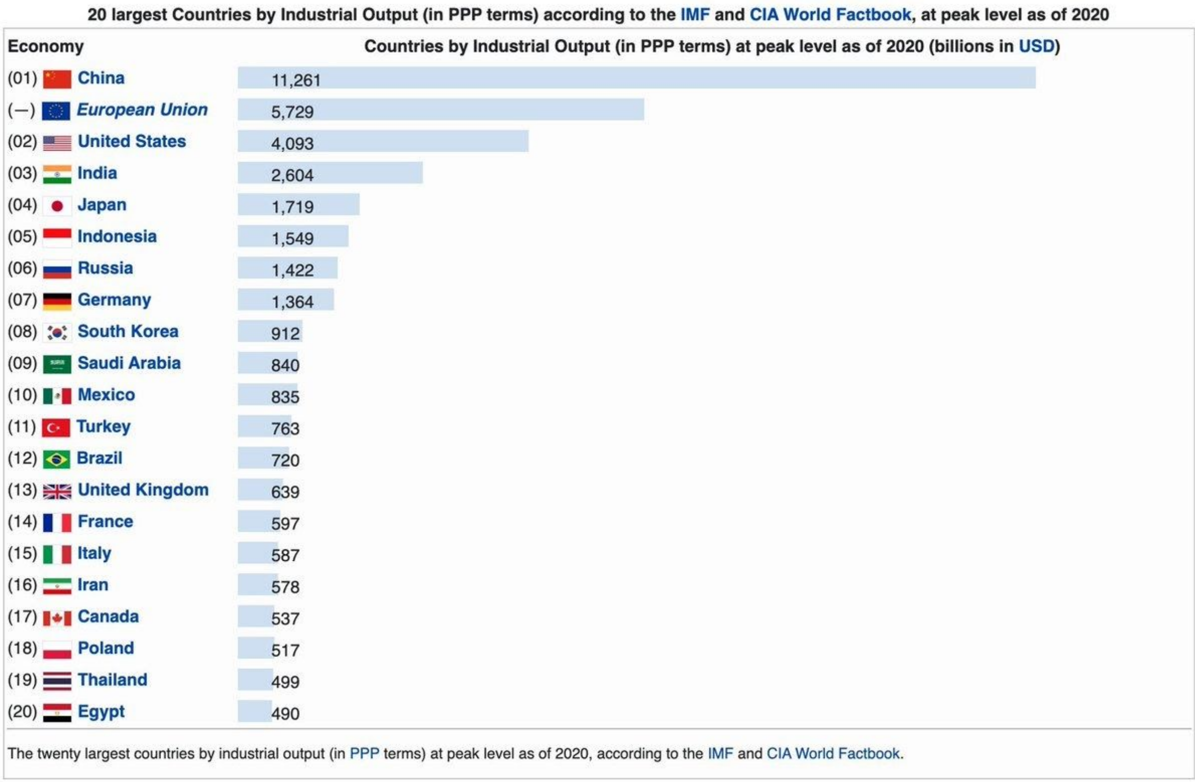
The use of 3D printing for rapid tooling and manufacturing has promised to produce components with complex geometries according to computer designs. Due to the intrinsically limited mechanical properties and functionalities of printed pure polymer parts, there is a critical need to develop printable polymer composites with high performance. 3D printing offers many advantages in the fabrication of composites, including high precision, cost effective and customized geometry (Xin Wang et al., 2016).

1.5 Conclusions

AM has been widely used in many industries so far, from simple components to high-tech products. Although AM only has a short history, it still made many breakthroughs on the technical level. Just like other processing methods, materials are an unavoidable topic. At present, the development of material types and performance has received extensive attention. The wide promotion of AM is inseparable from technological breakthroughs in materials. Today's AM materials have great limitations, which restrict their applications in many aspects. In the future, on the one hand, AM will pursue the goal of faster and cheaper to achieve industrial needs. On the other hand, AM will seek to discover more new materials to expand related industries.

2.Chapter2: 3D printing from a market perspective

As the secondary sector of the economy, industry is the lifeblood of a country. Both developed and developing countries attach great importance to their own industrial development. Figure 2.1 shows 20 largest Countries by Industrial Output (in PPP terms) according to the IMF and CIA World Factbook, at peak level as of 2020. China, EU and US have contributed to the most industrial output. These three are now playing the most important roles in 3D printing. In this chapter, we will discuss 3D printing from a market perspective. What are the pros and cons of 3D printing? How about the 3D printing market? What is the market trend of 3D printing? How 3D printing impacts different industries?



20 largest Countries by Industrial Output (in PPP terms) according to the IMF and CIA World Factbook, at peak level as of 2020

Economy	Countries by Industrial Output (in PPP terms) at peak level as of 2020 (billions in USD)
(01) China	11,261
(—) *European Union*	5,729
(02) United States	4,093
(03) India	2,604
(04) Japan	1,719
(05) Indonesia	1,549
(06) Russia	1,422
(07) Germany	1,364
(08) South Korea	912
(09) Saudi Arabia	840
(10) Mexico	835
(11) Turkey	763
(12) Brazil	720
(13) United Kingdom	639
(14) France	597
(15) Italy	587
(16) Iran	578
(17) Canada	537
(18) Poland	517
(19) Thailand	499
(20) Egypt	490

The twenty largest countries by industrial output (in PPP terms) at peak level as of 2020, according to the IMF and CIA World Factbook.

Figure 2.1 20 largest Countries by Industrial Output (in PPP terms) according to the IMF and CIA World Factbook, at peak level as of 2020

2.1 3D printing advantages

AM can be widely used to industry due to its ability to change the market structure. AM has advantages over traditional processing. In this part, the advantages of AM will be listed, including time saving, process optimization, cost reduction, potential risks reduction, complexity and design freedom, customization, sustainable manufacturing. These advantages are based on additive manufacturing itself, which brings opportunities to 3D printing.

2.1.1 Time saving

One of the main advantages of 3D printing is that the production speed of parts is more efficient compared to traditional manufacturing methods. According to Figure 2.2, 3D design will start when there is a concept or an idea. Then the right material will be selected. After file conversion, 3D printing will start to build objects.

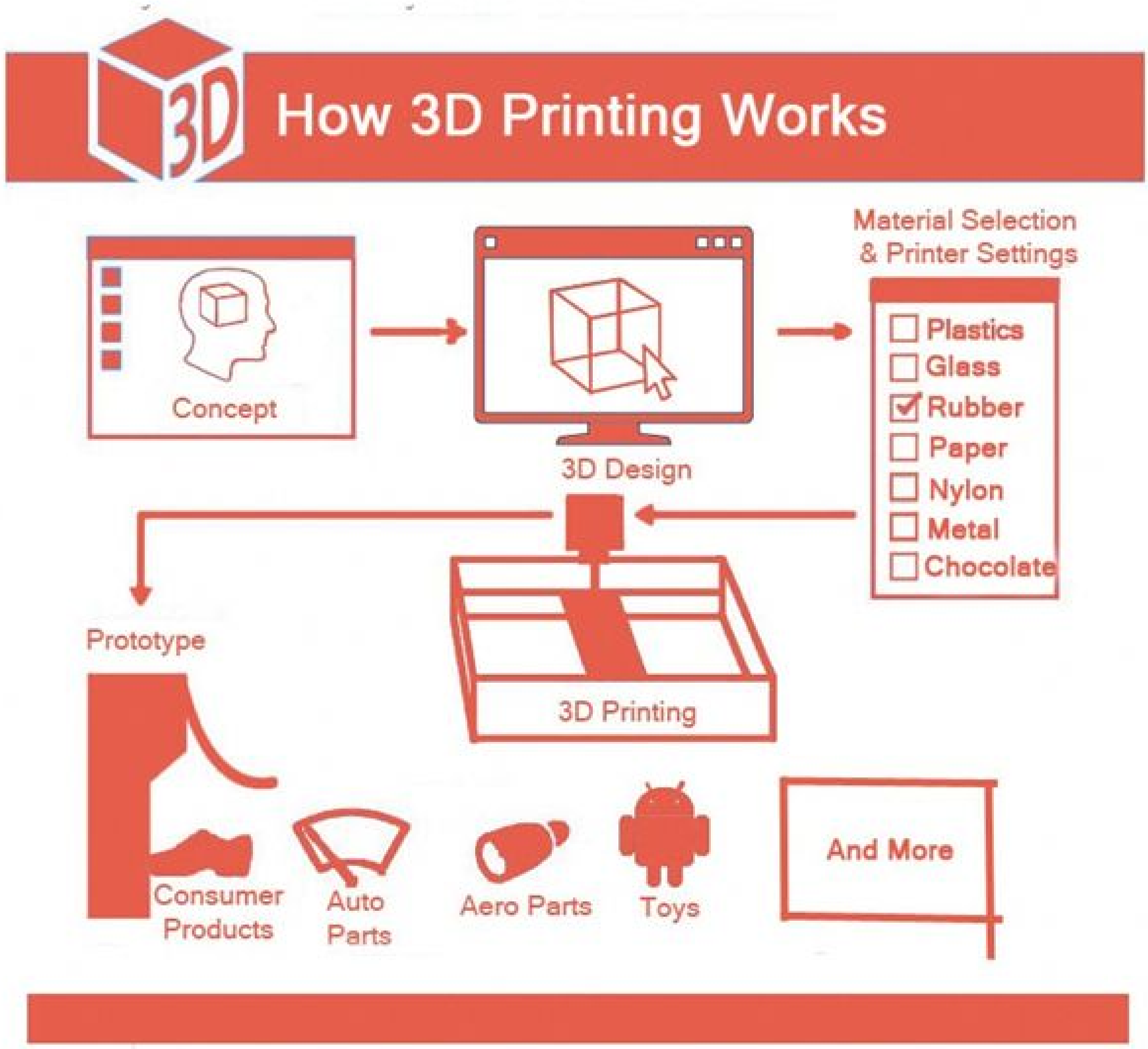


Figure 2.2 3D printing process

In this process, only design and 3D printing processes take time. Design is done in a 3D modelling software, while 3D printing is operated in a 3D printer. To produce objects of the same size, 3D printing is actually slower than traditional manufacturing. However, if you consider the entire process from beginning to post-process, 3D printing truly saves time. The 3D printing process is more simplified than traditional manufacturing, it doesn't need mold to form parts, it just prints parts. That is to say, 3D printing can save time because it's not necessary to produce molds. Also 3D printing doesn't need complicated processes such as welding and grind. What's more, the final assembling is much easier than that of traditional manufacturing. Although the traditional manufacturing technology is mature, the assembly process needs to follow very strict tolerance standards. Hence we say that 3D printing can save time by simplifying processes, factories use less time from design to final assembly.

2.1.2 Process optimization

Figure 2.3 gives the processes of both 3D printing and traditional manufacturing. There are differences between 3D printing and traditional manufacturing processes. 3D printing, which is from CAD design to 3D print and then install, is a really simple process. Once CAD design is done, 3D printers will start to work in a few hours. Traditional manufacturing methods, however, from CAD design to the final install, the process consists of many steps, including cutting steel, build, weld, grind, drill, sanding, cooling, etc. These steps not only take plenty of time, but also complicates the production line. When designing the layout of an industry factory, these steps must be taken into consideration. If we use 3D printing into production instead of traditional manufacturing, the production line can be totally simplified. Many steps can be cut, also factories can reduce the cost of layout.

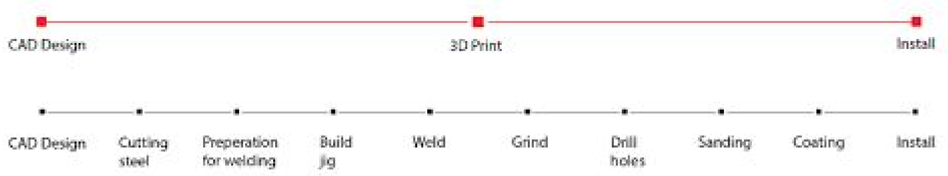


Figure 2.3 3D printing(red) process and traditional manufacturing(black) process

Most products require a large number of parts to be manufactured through traditional technology and then they are assembled. Excessive operations will affect the quality and reliability of the design. 3D printing satisfies integrated production of parts. The ability to produce parts in one unit greatly reduces the dependence on different manufacturing processes (machining, welding, painting), thus designers can better control the quality of the final product.

Process optimization also brings an opportunity when there is a mistake in the design stage. In traditional manufacturing, before production, we need to set up a complete production line. The production line will be set according to the design of products. If there is a tiny mistake, and it’s not noticed, once the production line is founded, it will be a really big trouble. As for 3D printing, it’s not a problem at all. When you want to modify your design, all you need to do is to modify the CAD file in software and convert into STL file again, then the 3D printer will start to print a new one without any efforts.

2.1.3 Cost reduction

Manufacturing costs can be divided into three categories: machine operating costs, material costs and labor costs. Here we will discuss how 3D printing impacts cost sectors.

2.1.3.1 Operating cost

Most desktop-level 3D printers consume the same power as computers. Industrial 3D printing technology consumes a lot and may consume more electricity to produce a single part. However, the ability to generate complex geometries in just one step can lead to higher efficiency and turnover. Machine operating costs are usually the lowest contribution to the total cost of manufacturing. Traditional manufacturing is a mixture of many steps, including cutting, milling, forging, casting, welding, drill, etc. These steps consume energy, also they take more maintenance and management cost. 3D printing, due to its simple process, only consumes power when building objects and post-processing. In general, to produce the same object, 3D printing could reduce operating cost, because 3D printing has less steps compared to that of traditional manufacturing.

2.1.3.2 Materials cost

The material cost of 3D printing varies by technology. Desktop FDM printers use wire coils and cost approximately $25 per kilogram, while SLA printing requires resin, the retail price is approximately $150 per liter. The range of materials available for 3D printing makes it difficult to quantify the comparison with traditional manufacturing. The price of nylon powder used in SLS is about $70 per kilogram, while the price of nylon particles used in injection molding is only $2 to $5 per kilogram. Material costs are the largest source of 3D printed parts costs. This is also an important reason that restricts many companies from purchasing 3D printers. Currently 3D printing doesn't have any advantages in price compared with traditional manufacturing. On the one hand, the materials that can be used in 3D printing are more expensive than that can be used in traditional manufacturing. On the other hand, materials limitations restrict 3D printing from choosing cheaper materials.

2.1.3.3 Labor cost

One of the main advantages of 3D printing is lower labor costs. Except for post-processing, most 3D printers only need one or two operators. The machine then follows a fully automated process to produce parts. In traditional manufacturing, due to a series of steps, it's necessary to employ enough operators, which raises the labor cost. Also traditional manufacturing usually requires skilled machinists and operators, which requires companies to pay training costs and time. Therefore, the labor cost of 3D printing is much lower than traditional manufacturing.

2.1.3.4 Comparison with traditional manufacturing

Compared with traditional manufacturing processes, the cost of small batch 3D printing is extremely competitive. For the production of prototypes for verification of shape and assembly, it is much cheaper than other alternative manufacturing methods (such as injection molding) and is generally competitive in manufacturing disposable functional parts. With the increase in production, traditional manufacturing technology will become more cost-effective, so 3D printing is an important supplement to traditional manufacturing.

2.1.4 Potential risks reduction

In the traditional process, if a defective prototype is accidentally manufactured, the designer's time and money will be wasted. Using traditional mold processing and manufacturing methods, even small changes may bring huge financial expenses (high mold opening costs).

People can verify the design by 3D printing prototypes that can be used for production before purchasing expensive manufacturing equipment (such as molds or tooling and fixtures), thereby eliminating the risk in the prototyping process. This helps to verify the feasibility of the project through trial and error at low cost of 3D printing before the large investment required for large-scale production.

2.1.5 Complexity and design freedom

Traditional manufacturing methods have higher limits on the products that can be manufactured, for example draft angle (Figure 2.4). During the forging casting process, when designing the mold for the target object, it's important to consider realistic problems like draft angle. In Figure 2.4, we can see if we want to make an object with vertical structure, we can't design a vertical mold. That is, when casting is finished, it will be difficult to take the object out of mold. So there are limitations for design in the traditional casting process. The mold design should consider a draft angle that ensures smooth drafting. 3D printing solves the problem of design freedom. In 3D printing, it's not necessary to take care of this kind of issue. When a vertical structure is required in design, we just draw a 3D model in software. Then a 3D printer will start to build this structure without any restriction.

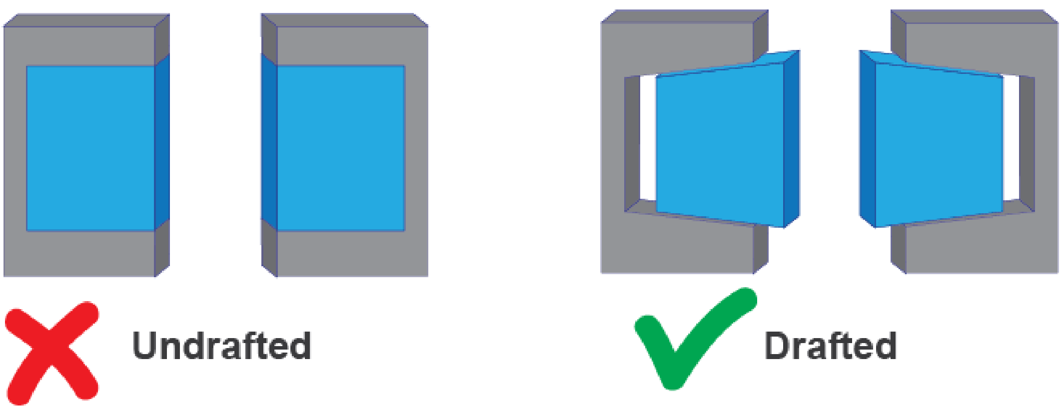


Figure 2.4 Traditional manufacturing takes draft angle into consideration

For 3D printing, there may be some restrictions on the minimum size features of accurate printing, but in most cases the main limitation is how to optimize the printing direction to reduce the support dependence and the possibility of printing failure. This provides designers with a lot of design freedom and allows for the easy creation of very complex geometric shapes. In traditional manufacturing, it's really difficult to manufacture complex structures. For example in the cutting process, there are many kinds of tools (Figure 2.5). To produce a complex shape, we need to use different kinds of tools. However, if it's required to produce internal structure, it's hard for tools to go inside the workpiece. In this case, normally we need to produce a mold before and then get what we need through the casting process. So if we want a complex shape, We can directly get what we need through 3D printing. Figure 2.6 is a case with complex shape that is produced by 3D printing. Through traditional manufacturing, it's not a straightforward process, which results in more processes.
Here it's clear that 3D printing has obvious advantages which may lead AM to catch up with traditional manufacturing in complexity and design freedom.

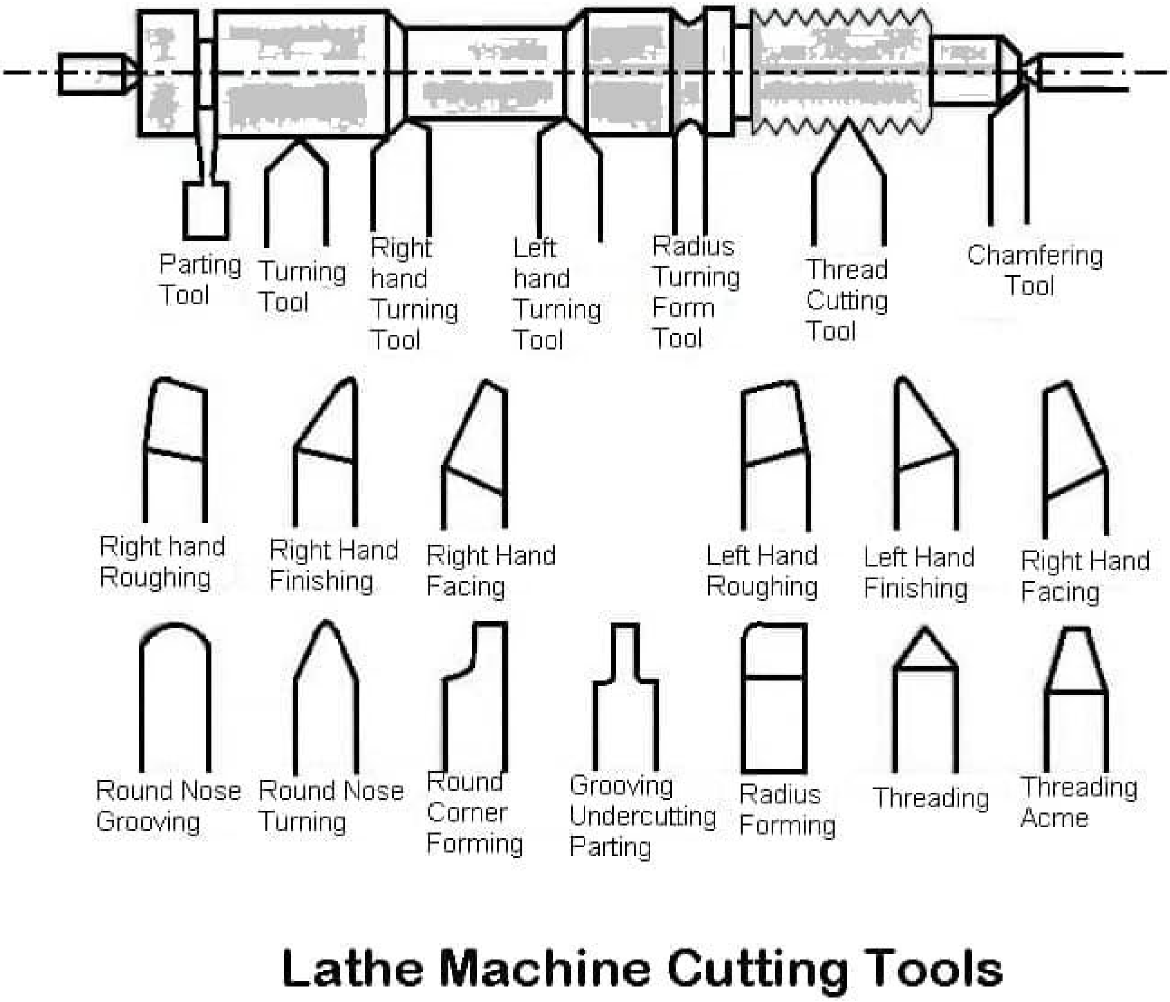


Figure 2.5 Lathe machine cutting tools

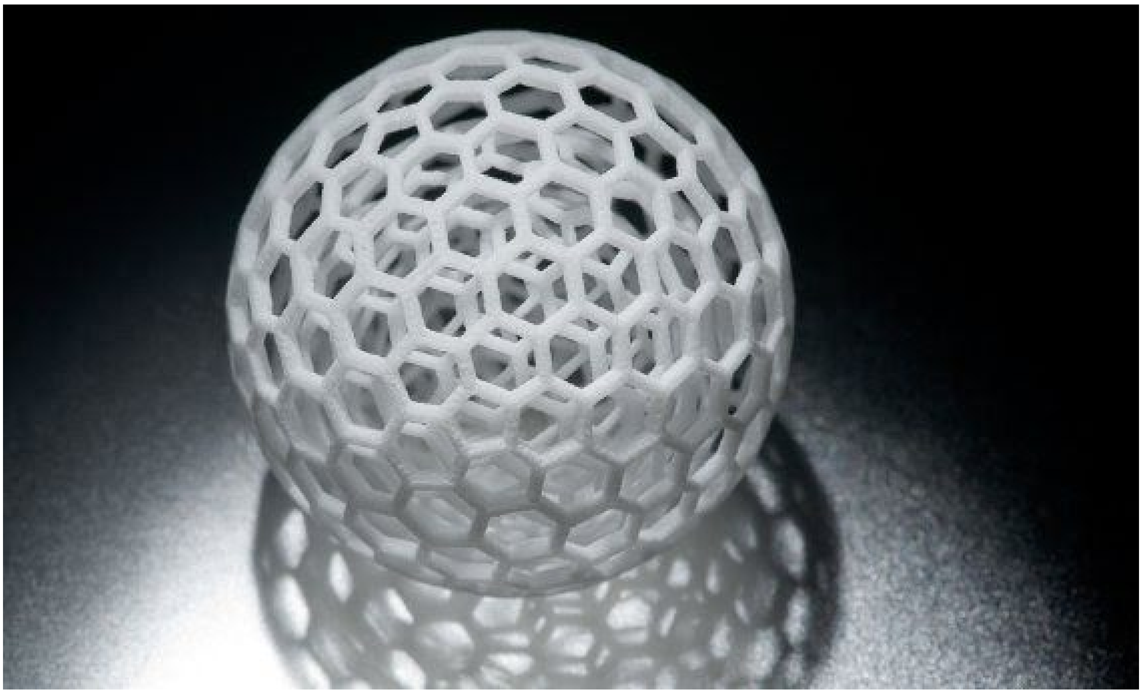


Figure 2.6 Complex shape by 3D printing

2.1.6 Customization

3D printing can not only provide greater design freedom, but also completely custom designs. Since the current 3D printing technology can only manufacture a small number of parts at a time, it is very suitable for small batch customized production. This customized concept has been accepted by the medical and dental industries for the production of customized prostheses, implants and dental aids. From tailor-made high-end sports equipment that is perfect for athletes to custom sunglasses and fashion accessories, 3D printing can cost-effectively produce custom parts at once.

Figure 2.7 and Figure 2.8 are AM in medical applications. Everyone's structure is roughly the same, but when you look closely, everyone is different. In traditional manufacturing, the cost of mass production is lower than 3d printing for sure. But when it comes to the medical sector, it’s not suitable for traditional manufacturing at all. Whether it is a prosthesis or a denture, customization is customer demand. Small batch production or individualization is the weakness of traditional processing. Traditional processing often requires more fixed costs before production, including equipment, etc. If customized medical devices use traditional processing, the cost will be so high that customers abandon their needs. The place that belongs to 3D printing is highlighted here. Just like what we mentioned before, 3D printing has a price advantage in small batch production. Compared with traditional manufacturing, 3D printing has much less fixed cost before production, all needed are 3D design software and 3D printers. When there is a specific demand, we design in software and then convert into STL file. Next 3D printers can start to build the object according to the

STL file. The cost for each object only depends on design and materials, which is lower than that of traditional processing. So people prefer 3D printing in customization.

Figure 2.7 Artificial denture with 3D printing

Figure 2.8 Artificial bones with 3D printing

2.1.7 Sustainable manufacturing

Traditional manufacturing, such as milling and cutting, remove a large amount of excess material from the original material, resulting in a large amount of waste. AM, on the contrary, is a process that only consumes as much material as the product needs. Among the

potential sustainability benefits of AM, three opportunities stand out (Simon Ford & Mélanie Despeisse, 2016):
1.AM improves resource efficiency: improvements can be realised in both production and use phases as manufacturing processes and products can be redesigned for AM.
2.AM extends product life: this is achieved through technical approaches such as repair, remanufacture and refurbishment, and more sustainable socio-economic patterns such as stronger person-product affinities and closer relationships between producers and consumers (Kohtala, 2015).
3.AM reconfigures value chains: AM has shorter and simpler supply chains, also has more localised production, innovative distribution models and new collaborations.
Based on these 3 aspects, AM creates opportunities for improving sustainability.

2.2 3D printing limitations

In section 2.1, we listed advantages brought by 3D printing. However, 3D printing has not been able to completely replace traditional manufacturing at present, because some restrictions restrict 3D printing.

2.2.1 Materials limitations

In section 1.4, AM materials were listed, including polymer, metal, ceramic and composite. Still there are many kinds of materials that can’t be used in 3D printing. The reasons are various, material price is too high, material performance cannot meet product requirements, material related technology is immature, etc.
On the one hand, material limitations hinder the wide application of 3D printing in other industries. For example, the bearings are composed of various alloys, such as Babbitt, copper-based and aluminum-based alloys. These materials can’t be used in 3D printing, bearings processed by 3D printing will seriously substandard in performance. On the other hand, due to material limitations, 3D printed products are not as good as CNC in some aspects. CNC, of which the materials will not deform during processing, provide better surface finish than 3D printing. The rigid material and cutting action keep the product together, and there is less chance of error or deformation. Also CNC doesn’t heat the materials and just directly transforms them, while 3D printers must heat materials to build the intended product. Therefore, compared with 3D printers, CNC materials remain stronger and have better structural integrity.

2.2.2 Machine limitations

Although the related technologies of 3D printers are becoming more and more mature, they still have very big limitations in production.

3D printing can be roughly divided into 3 printing speeds, the first printing speed is 40-50mm/s, the second printing speed is 80-100mm/s, and the third is 150mm/s. And some of the 3D printers on the market have reached 150mm/s or more. However, the high-speed operation of 3D printers brings lower quality, and the print quality is significantly reduced when the speed exceeds 150mm/s.

As for CNC (Figure 2.9), the formula below shows which factors impact cutting speed:

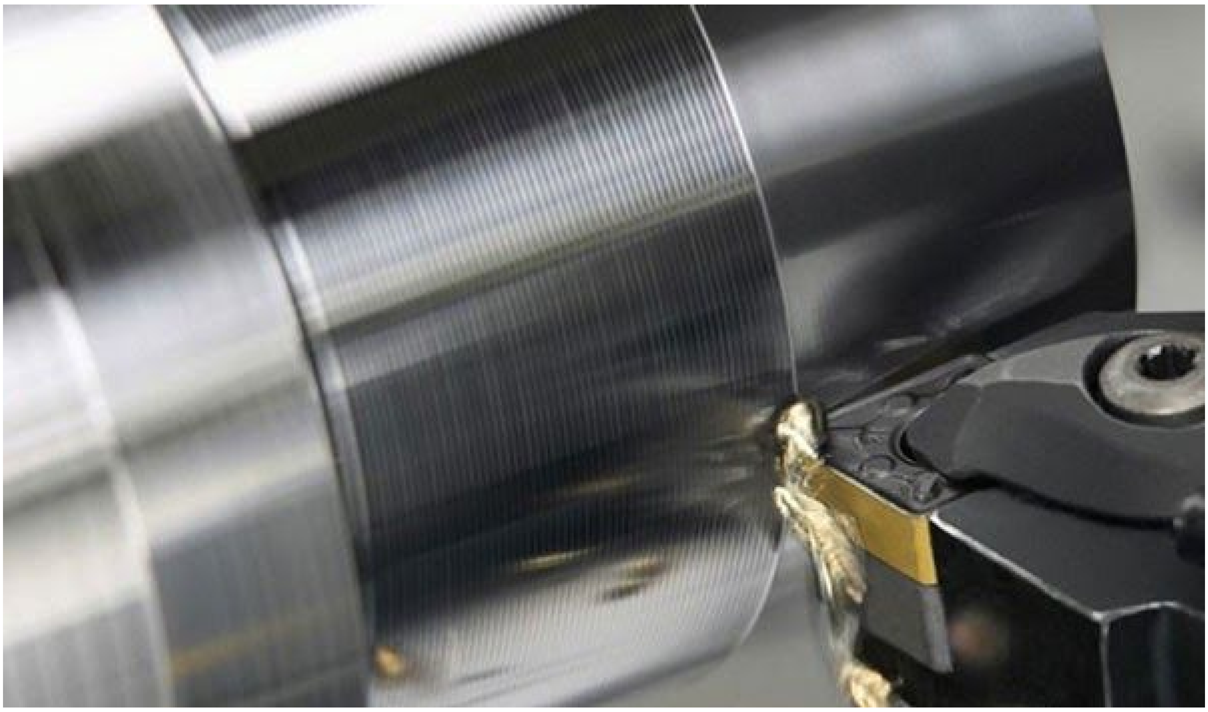


Figure 2.9 Tool and workpiece in CNC process

$$V_c = (\pi * D * S) / 1000$$

Vc: Line speed of tools

D: Diameter of tools

S: Rotating speed

According to this formula, the diameter of the tool and the rotating speed are proportional to cutting speed. The cutting speed of CNC can increase with the increase of D or S. So CNC cutting speed can reach a very high level and working conditions remain stable.

Here we can find 3D printing has limitations when the processing speed is too high. In this situation, working conditions will decrease and product quality will decrease as the processing speed increases.

In terms of productivity, 3D printers also have limitations. In section 2.1.1, it’s concluded that 3D printing can save time from design to production, that’s because 3D printing can start production directly after design is finished. However when there is a mass production, normally CNC is chosen. CNC takes less cost and production time compared to 3D printing.

In 3D printing, the processing speed depends on the number of layers of the workpiece being analyzed, the extrusion speed of the nozzle, the movement speed of the nozzle in the three directions of XYZ. In the current development situation, to produce a workpiece of the same size and structure, CNC is usually faster than 3D printing. Since 3D printing is inferior to CNC in terms of productivity, CNC is often selected during mass production.

2.2.3 Intellectual property (IP) limitations

In this part, We will discuss the two aspects of IP in copyright and patent.

3D printing is closely related to copyright law from the modeling stage to the printing stage. Generally speaking, there are two ways to make 3D printed models. One is to directly scan three-dimensional objects to obtain 3D printed models, which cannot be protected by copyright law. Another one is to use 3D printing design software to create 3D printing models, which can be protected by copyright law.

With the application of 3D printing technology in different fields, product manufacturing is gradually moving towards digital, intelligent and customized development. Patent law faces many new problems. The key of the patent law is to determine whether the 3D printing model can constitute the "key component" of the patented product.

Although there are copyright law and patent law for reference, due to the rapid development of 3D printing, the update of relevant laws has been slower than the technical level. Therefore IP disputes about 3D printing have not stopped yet. Facing the challenges posed by 3D printing technology, the IP legal system should respond positively. Otherwise IP limitations will constantly cause problems.

2.3 3D printing market overview

Figure 2.10 is a 3D printing segments pie chart, featuring the hardware, software, materials, post-processing systems, QA & process inspection categories.

Among all the segments, hardware is the biggest category that makes up 57.1% of the overall AM landscape. Software makes up 19.9%. Then materials occupy 18.0% and post-processing contributes 3.1%. From this pie chart, it’s obvious that hardware, software and materials occupy almost the entire industry market. Therefore, it is not difficult to analyze that industry resources have flowed to these major sectors. From another perspective, this pie chart, to some extent, tells us that these segments are interrelated. The software provides a platform to design objects. The hardware starts to use materials to build objects. 3D printed objects need to go through post-processing. These segments constitute the complete market at this stage.

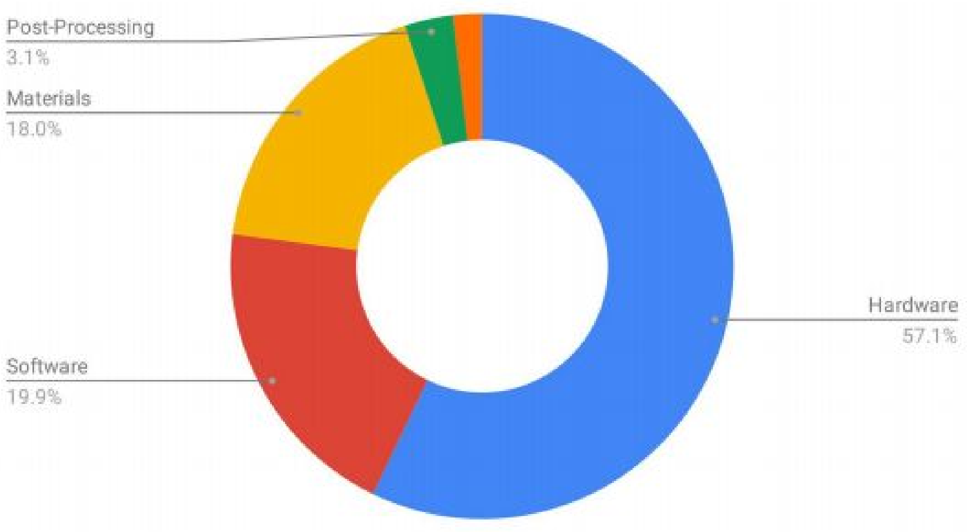


Figure 2.10 Category segment (Source:AMFG)

Figure 2.11 gives a breakdown of the AM landscape. Hardware category includes metal machines, desktop machines, polymer machines, ceramics machines, electronics machines. Software category includes workflow software, simulation software and design & CAD software. Materials category includes metals, polymers, composite, etc.

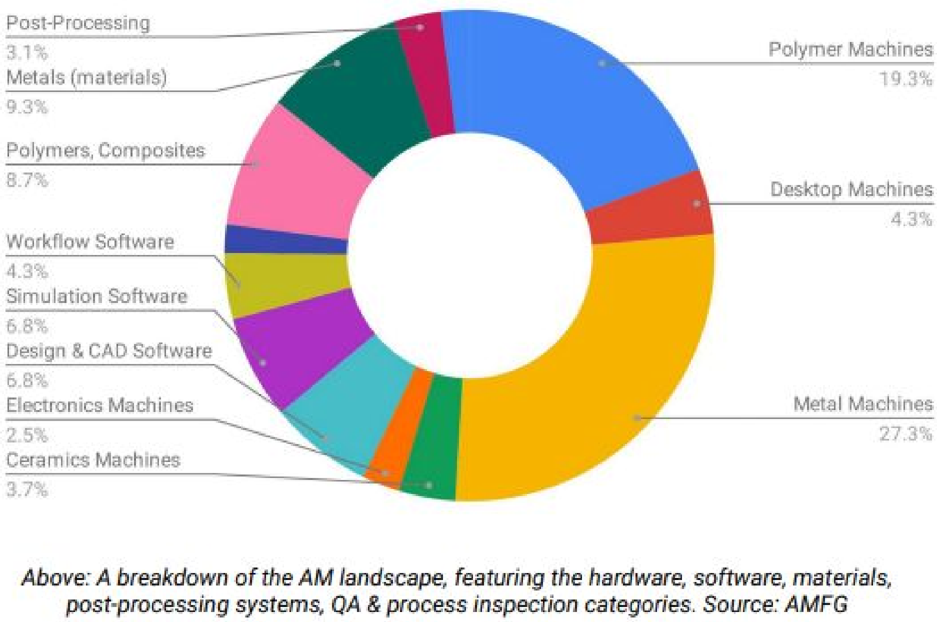


Figure 2.11 A breakdown of the AM landscape (Source:AMFG)

The 3D printing market has generally shown an exponential increase in these years (Figure 2.12). The Figure shows the size of the global 3D printing market from 2013 to 2021. The market size has grown from $4.4 billion in 2013 to $21 billion in 2021. According to the source, the global 3D printing market is expected to grow to 21 billion U.S. dollars globally in 2021 (Arne Holst, 2020). Based on this positive trend, governments and investors will keep confidence in 3D printing, which gives the industry a cardiotonic. The growth of the entire market also means more and more investment and human resources will come into the industry, which can update technologies and enlarge the market size.

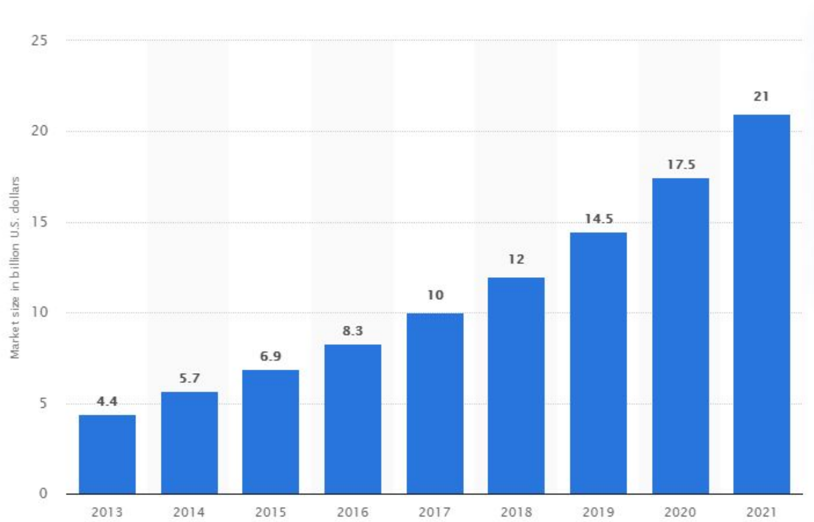


Figure 2.12 Global 3D printing market size forecast 2013-2021

2.4 3D printing metal market

From Figure 2.11, it's apparent that metal machines make up 27.3% of the overall 3D printing market, which is the biggest segment among the breakdown. In this part, we will mainly focus on this segment.

The global 3D printing metal market size was valued at USD 772.1 million in 2019 and is expected to grow at a compound annual growth rate (CAGR) of 27.8% from 2020 to 2027. Increasing penetration of 3D printing metal owing to greater design flexibility, low waste, and cost effectiveness in the overall manufacturing landscape is estimated to be a key factor driving the market. In the US 3D printing metals market, the market still has an exponential growth trend (Figure 2.13), which provides a comfortable environment for entrepreneurs in the US. As a result, many emerging companies of metal 3D printing were born, such as Desktop Metal. From this bar chart (Figure 2.13), it's obvious that powder occupies an absolute market compared with filament. Powder form dominated the market in 2019 with a volume share of 92.6%. Powders used for additive manufacturing are characterized by high packing density and spherical morphology, which grant good flow properties. Filaments are expected to register a CAGR of 25.8%, in terms of volume, from 2020 to 2027.

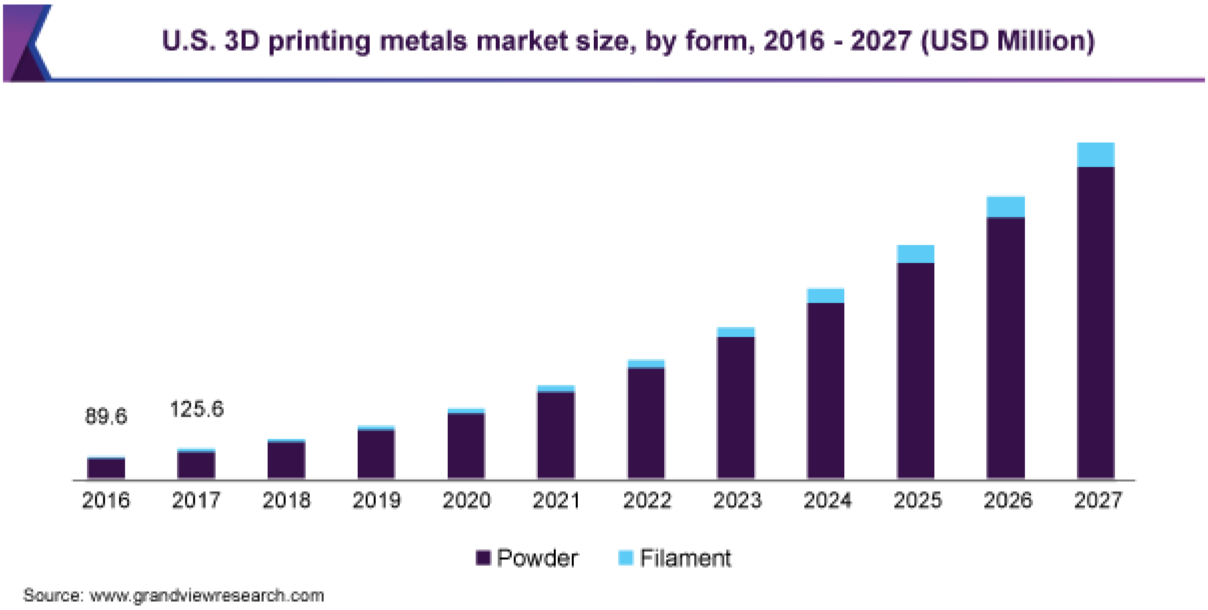


Figure 2.13 US 3D printing metals market size 2016-2027

Figure 2.14 is a pie chart that illustrates global 3D printing metal market share by application in 2019. The main applications are aerospace & defence, medical & dental, automotive, etc. The aerospace and defense application segment accounted for the largest revenue share of 45.6% in 2019. Metal AM technology is considered to be the new industrial revolution within the global aerospace or aviation sector. The medical and dental application segment is projected to expand at a CAGR of 28.5%, in terms of volume, from 2020 to 2027.

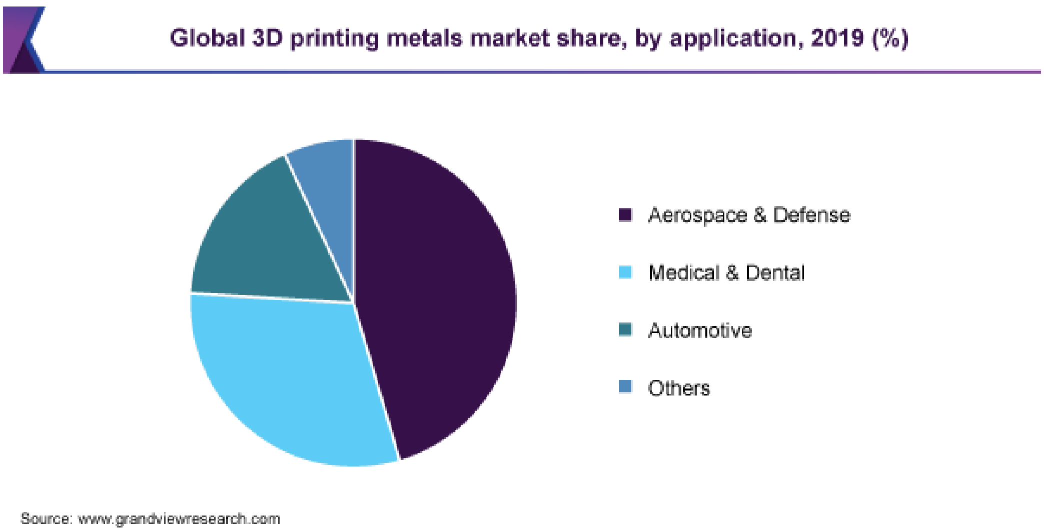


Figure 2.14 Global 3D printing metals market share, by application, 2019

Since we always like to compare 3D printing with CNC, in industrial applications, only when the advantages of 3D printing outweigh the disadvantages, we can be confident that 3D printing can be widely used. Currently, 3D metal technologies have features of freedom of part design, part complexity, light weighting, part consolidation and design for function (Thomas Duda & L. VenkatRaghavan, 2016). These features garner particular interests in metal additive manufacturing for aerospace, oil & gas, marine and automobile applications.

2.5 3D printing market trend

In order to predict the future 3D printing market and grasp the market advancement in advance, we need to understand 3D printing market trends. Here we will discuss the 3D printing market trend in 5 perspectives.

2.5.1 Metal 3D printers: competition is increasing

Metal 3D printing is constantly developing. With the creation of new processes and the development of existing technologies, many technologies will be used for commercialization in the next two years. On the one hand, this growth is tremendously exciting. The growing number of active companies within this segment illustrates the rapid pace of innovation that is happening in this sphere. On the other hand, with competition increasing in this category, the coming months and years will determine which metal AM technologies and manufacturers will ultimately dominate.

2.5.2 Polymer 3D printing continues to mature

While metal 3D printing has received a great deal of press attention over the last couple of years, the steady growth of the polymer market has almost gone under the radar. The increasing number of industrial applications being found is one of the key reasons behind the growth of the polymer segment.

Another important factor is that materials suppliers are developing high-performance polymers, which retain their mechanical strength even in highly demanding, industrial environments. These developments have the additional benefit of broadening the portfolio of materials that can be used for 3D printing.

There have also been developments on the polymer hardware side, which ensure that polymer 3D printing can meet industrial manufacturing needs.

2.5.3 Software is becoming critical for industrialisation

As additive manufacturing industrialises, software is playing an increasingly significant role across all areas of the AM workflow. While design, CAD and simulation have always been a requirement, the production of industrial-grade and lightweight parts requires software that can adequately cope with the specific requirements of the additive manufacturing process. As a result, software used for design and product development is becoming more advanced out of necessity, leveraging technologies like generative design and topology optimisation.

It’s not only design and simulation solutions that are dominating the software space. Workflow software is a subcategory that has emerged over the last five years - but only in the last two has it seen greater interest outside of a core client base of service providers. As manufacturing departments look to manage and scale their 3D printing efforts, workflow software that can manage the production process is becoming a vital component.
The market for workflow software will, therefore, continue to grow as the need for greater visibility, centralisation and automation is increasingly felt by service providers and Original Equipment Manufacturer (OEMs) alike.

2.5.4 Automation is a key focus across segments

While additive manufacturing offers game-changing benefits for production, the reality is that many areas of the production process itself remain manual.
This lack of automation is a key source of frustration among many manufacturers. As a result, companies within the AM landscape are increasingly offering automated solutions to reduce the time needed to perform key tasks.
For example, post-processing, known for its labour-intensive and manual processes, is one area that can greatly benefit from automation. A similar trend can be seen on the software side, where automating manual tasks along the AM workflow is a key imperative. Software vendors are therefore offering solutions to automate repetitive, manual tasks, like production scheduling and file repair.

2.5.5 Collaborations, partnerships and acquisitions abound

The additive manufacturing industry is still relatively small, particularly when compared to the wider $12 trillion manufacturing market. Hence, many companies have recognised that collaboration and, in some cases, acquisitions, will be key to accelerating the adoption of the technology.

2.6 3D printing applications

3D printing is used in the following sectors:

2.6.1 Automotive

Automotive industry faces new challenges every day, new design trends and technological deployments from research push companies to develop new models and facelifts in the short term, requiring new tools or tool reshaping. Concerning the current world economic scenario, decreasing time for tooling up becomes as important as decreasing time-to-market. Such a scenario opens up the horizons for new manufacturing approaches like additive manufacturing (R. Leal et al., 2017).

The volume of prototypes of auto parts is very large, and the traditional prototype development cycle cannot meet the rapid development needs of modern automobiles. 3D printing can not only shorten the development cycle by 40%, but also reduce costs by 20%. Especially with the development of technology, the shape and structure of parts become more and more complicated, which makes the development and production of molds more difficult. 3D printing technology can overcome this problem well.
Figure 2.15 is a 3D printed engine block, Figure 2.16 is a pair of 3D printed gears.

Figure 2.15 3D printed engine block

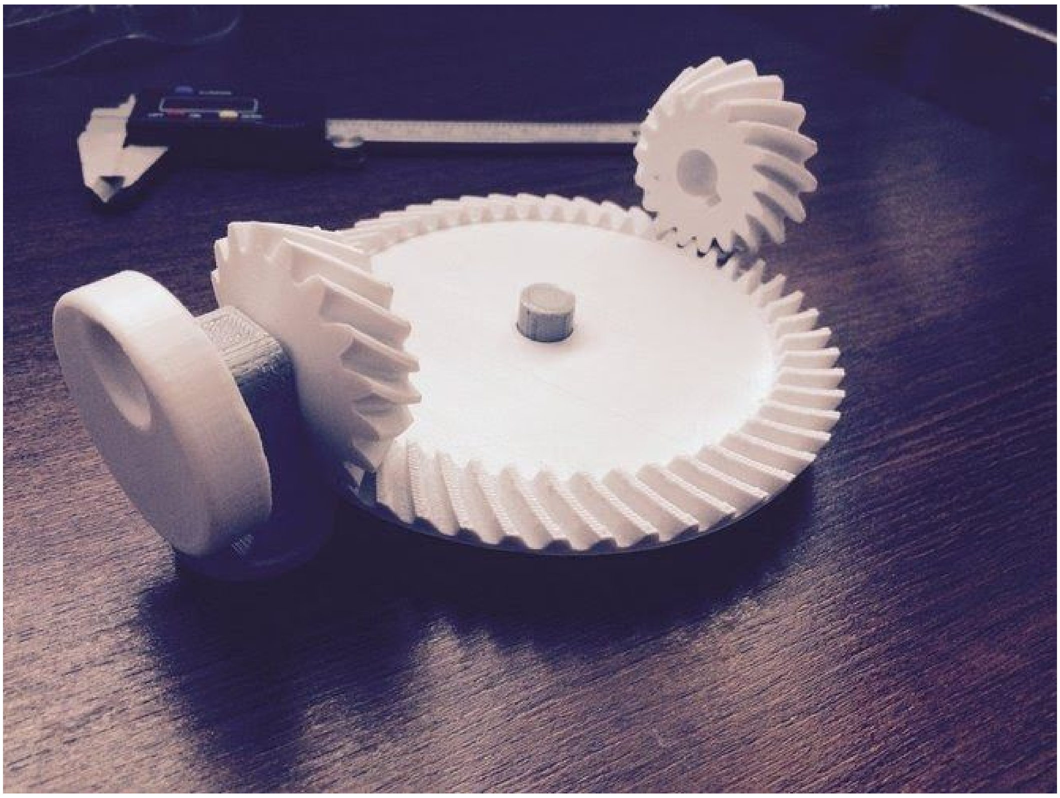


Figure 2.16 3D printed gears

2.6.2 Aerospace

Additive Manufacturing offers unmatched flexibility in terms of part geometry, material composition and lead-time. It is moving towards revolutionizing the aerospace manufacturing sector through production of highly complex, lightweight parts with reduced material waste. It can also be employed for repair of complex components such as engine blades/vanes, combustion chamber, etc. Complex geometry thin walled aircraft engine components and structures, difficulty in machining of materials are other main factors forcing aerospace sector to adopt the use of additive manufacturing technology (L. Jyothish Kumar & C. G. Krishnadas Nair, 2016).

Aerospace technology is a symbol of national defense strength and a manifestation of national politics. The competition among countries in the world is fierce. Therefore, all countries want to try to develop newer weapons and equipment at a faster rate. Metal 3D printing technology has greatly shortened the manufacturing process of high-performance metal parts, especially high-performance large structural parts. There is no need to develop molds used in the manufacturing process of parts, which will greatly shorten the product development and manufacturing cycle.

Most aerospace manufacturing fields use expensive strategic materials, such as titanium alloys, nickel-based superalloys and other difficult-to-process metal materials. The utilization rate of materials in traditional manufacturing methods is very low, generally not more than 10%, or even only 2%-5%. Metal 3D printing technology, as a near-net molding technology, can be put into use with only a small amount of subsequent processing, and the material usage rate has reached 60%, and sometimes even reached more than 90%. This not only reduces manufacturing costs and saves raw materials, it is also keeping up with sustainable development strategies.

2.6.3 Orthopaedics

The applications of AM have increased extensively in the area of orthopaedics. The AM applications are for making anatomic models, surgical instruments & tool design, splints, implants and prosthesis (Mohd. Javaid & Abid Haleem, 2018).

3D printing has the characteristics of free forming, and has unique advantages in the rapid and accurate manufacturing of porous and complex microstructure implants, which is beneficial to reduce the waiting time of patients and improve the quality of surgery.

The research on the materials of 3D printed orthopedic implants mainly focuses on two categories: PEEK and titanium (including titanium alloys). Titanium metal has high specific strength, low elastic modulus similar to cortical bone, low density, high corrosion resistance and good biocompatibility. So it is used as a trauma bone nail plate, knee/hip joint prosthesis and spinal implants, that are widely applied in the field of orthopedic implants.

2.7 Conclusions

In this chapter, we make a list of advantages and limitations of 3D printing. From the market overview, we know the current status of 3D printing in the global market. Metal 3D printing is one of the biggest segments among the breakdown. The market trend helps us predict the future market of 3D printing. The applications of 3D printing in automotive, aerospace and orthopaedics reflect that 3D printing can complement traditional manufacturing to improve efficiency and quality.

3.Chapter 3: 3D printers market

In Chapter 2, we have talked about 3D printing from a market perspective. In this part, we will mainly focus on the printers market. The printer market in this chapter includes different sectors, which help us understand from different aspects.

3.1 Producers

Producers are mainly from Europe, Asia and the US. They produce 2 kinds of printers in general, industrial-grade and desktop printers. Industrial-grade printers can satisfy the production requirement, while desktop printers have small size and normally cost less. Desktop producers are much more than industrial-grade producers in the market, because industrial-grade printers have higher requirements for capital, technologies, scale, etc. In this section, we will discuss the producers in the printer market.

3.1.1 Distribution

In 2014, 49 manufacturers from around the world produced and sold industrial-grade AM systems, with 22 companies in Europe, nine in China, eight in the US, seven in Japan, two in South Korea, and one in Israel. Most of the metal powder bed fusion systems were manufactured outside the US. Seven manufacturers of these systems were in Europe and three were in China. Up to now, the number of industrial-grade AM systems producers has grown continuously.

As for desktop printers, mostly companies are just small startups, with a few that generated revenues of $1 million or more within a year of launch.

3.1.2 Well-known producers

In this section, we will introduce 4 famous 3D printers producers in terms of scale and reputation.

3D Systems (Figure 3.1), headquartered in Rock Hill, South Carolina, is a company that engineers, manufactures and sells 3D printers, 3D printing materials, 3D scanners, and offers a 3D printing service. Chuck Hull, the CTO and former president, invented stereolithography in 1986. The company creates product concept models, precision and functional prototypes, master patterns for tooling, as well as production parts for direct digital manufacturing. It uses proprietary processes to fabricate physical objects using input from computer-aided design and manufacturing software, or 3D scanning and 3D sculpting devices. 3D Systems' technologies and services are used in the design, development and production stages of many industries, including aerospace, automotive, healthcare, dental, entertainment and durable goods. The company offers a range of professional- and production-grade 3D printers as well as software, materials, and the online rapid part printing service On Demand. It is notable within the 3D printing industry for developing stereolithography and the STL file format.

Figure 3.1 3D Systems

EOS GmbH (Figure 3.2), headquartered in Krailling near Munich, is one of the world's leading providers of systems, materials and solutions in the field of laser sintering technology, a generative manufacturing process ("3D printing"). This process enables the fast, flexible and inexpensive production of components on the basis of 3D CAD data. EOS GmbH has made a significant contribution to the development and dissemination of this technology.

Figure 3.2 EOS

Stratasys, Ltd. (Figure 3.3) is an American-Israeli manufacturer of 3D printers and 3D production systems for office-based rapid prototyping and direct digital manufacturing solutions. The company is incorporated in Israel. Engineers use Stratasys systems to model complex geometries in a wide range of thermoplastic materials, including: ABS, polyphenylsulfone (PPSF), polycarbonate (PC) and polyetherimide and Nylon 12. Stratasys manufactures in-office prototyping and direct digital manufacturing systems for automotive, aerospace, industrial, recreational, electronic, medical and consumer product OEMs.

Figure 3.3 Stratasys

SLM Solutions Group AG, headquartered in Lübeck, Germany, is a manufacturer of 3D metal printers listed on the stock market and co-owner of the word mark SLM®. The shares of SLM Solutions Group AG have been listed in Prime Standard of the Frankfurt Stock Exchange since May 9, 2014. A variety of Selective Laser Melting machines with laser outputs from 100 to 2800 Watt are sold.

Figure 3.4 SLM solutions

3.1.3 R&D

33 system manufacturers reported R&D spending in 2014. Average R&D spending was 37.5% of 2014 revenues, compared to 19.1% of revenues in 2013 and 16.4% in 2012. The steep increase can be attributed to several startups companies reporting R&D spending of 200% or more (Wohlers report, 2015). Producers tend to spend more and more on R&D. On the one hand, every year the companies need to develop new products to seize market share. On the other hand, fierce competition forces companies to increase R&D investment.

3.1.4 Profitability

In 2019, the highest-valued 3D printing company was the world's leading metal 3D printing manufacturer, EOS GmbH, with a valuation of up to 2.6 billion US dollars. In 2018, EOS's revenue exceeded 400 million U.S. dollars, and its net profit margin was greater than 10%. EOS's core technologies and products are two types of industrial 3D printers, based on SLS and SLM technologies. At the same time, EOS also established a 3D printing investment fund, looking for new technologies and products.

The U.S. Carbon3d, which invented high-speed light-curing 3D printing technology, has been valued at $2.2 billion. Desktop Metal, which invented low-cost desktop metal 3D

printing, is valued at $1.5 billion. The US Markforged, which realizes low-cost 3D printing of carbon fiber/metal and other materials on the desktop, is valued at over $1 billion. These three start-up companies with innovative technological breakthroughs have made rapid progress in recent years. The amount of financing has continued to rise, and their products have gradually been recognized by the market. They may even bring breakthroughs which may impact the traditional light-curing technology and metal technology.
Stratasys in the US lost $10.96 million in revenue of $663.2 million in 2018 and had a market value of $1.23 billion in 2019. 3D Systems lost $46 million in revenue of $687.7 million in 2018, and its market value was $990 million in 2019. Compared with the market value of tens of billions of dollars in 2014, the market value of the two old giants of 3D printing has dropped by 90%. They have been gradually surpassed by a group of new entrants.

3.2 Consumers

Industrial-grade and desktop printers include different consumers from different sectors. In this section we will introduce consumers in the printers market. Consumers, also called buyers, are persons or a group who intends to order, orders, or uses purchased goods, products, or services primarily for personal, social, family, household and similar needs, not directly related to entrepreneurial or business activities. A consumer is one that buys goods for consumption and not for resale or commercial purpose. The consumer is an individual who pays some amount of money for the thing required to consume goods and services. As such, consumers play a vital role in the economic system of a capitalist economy. Without consumer demand, producers would lack one of the key motivations to produce: to sell to consumers. The consumer also forms part of the chain of distribution.

3.2.1 Segments

Those who buy printers vary in all fields. From 2002 to 2014, accumulated revenues of each field were calculated. Figure 3.5 is a pie chart which shows the result of this calculation. Consumer products & electronics is the biggest contribution to total revenues, which accounts for 21.8%. Motor vehicles account for 18.6%, which is the second biggest segment of consumers. Medical & dental, industrial/business machines, aerospace also make up for more than 10% of total revenues, which are 16.4%, 13.4%, 10.2%. Academic institutions, government/military, architectural and the other sectors also impact the printer market. The trend of consumer segments depends on how AM technologies apply in different sectors. When parts can realize the same functions by 3D printers, with the cost decreasing, they can gradually substitute initial parts. Then the sector will contribute more and more to the total revenues.

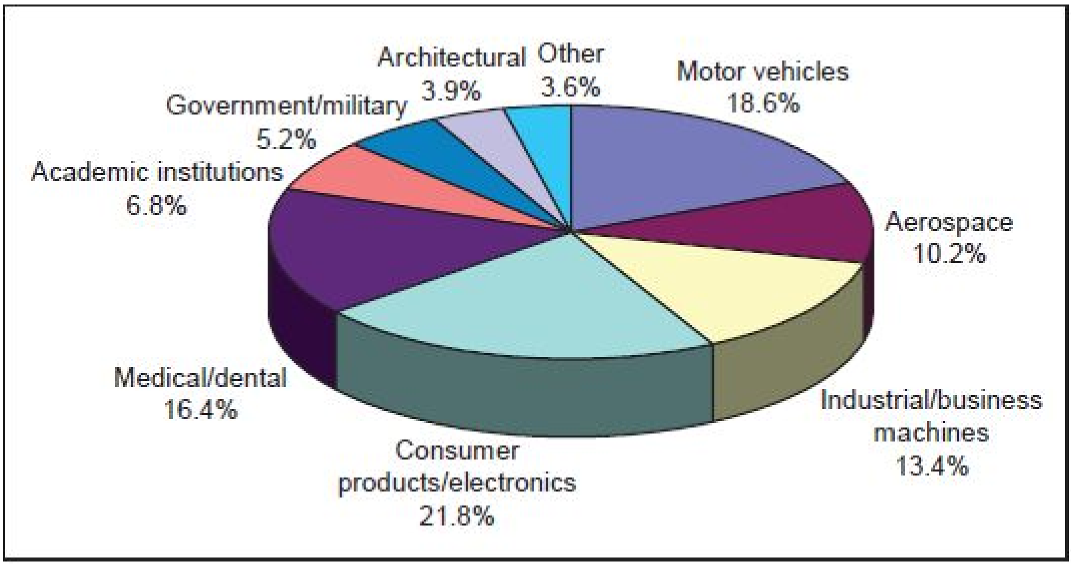


Figure 3.5 Different industries revenues (Source: Wohlers Associates, Inc.)

3.2.2 Regions & Countries

The main installations are from Asia/Pacific, Europe, North America. By the end of 2012, North America led the world in the adoption of AM technologies, which accounted for 39.9%. Europe at that time made up 29.3% of the total market. Asia/Pacific also accounted for 26.2% (Figure 3.6).

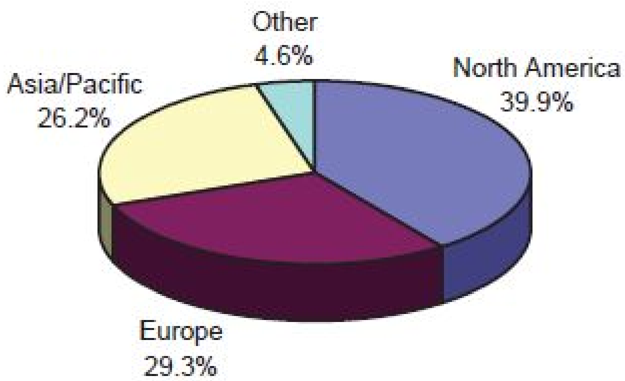


Figure 3.6 Installations by regions (Source: Wohlers Associates, Inc.)

If we focus on installations by countries, an interesting result is that the US and the other countries contributed to half of the market by the end of 2012. Turkey, Canada, Germany, France, Sweden, UK, Italy, Spain, Japan, Korea, China, Taiwan, Russia together made up the other half of the market (Figure 3.7).

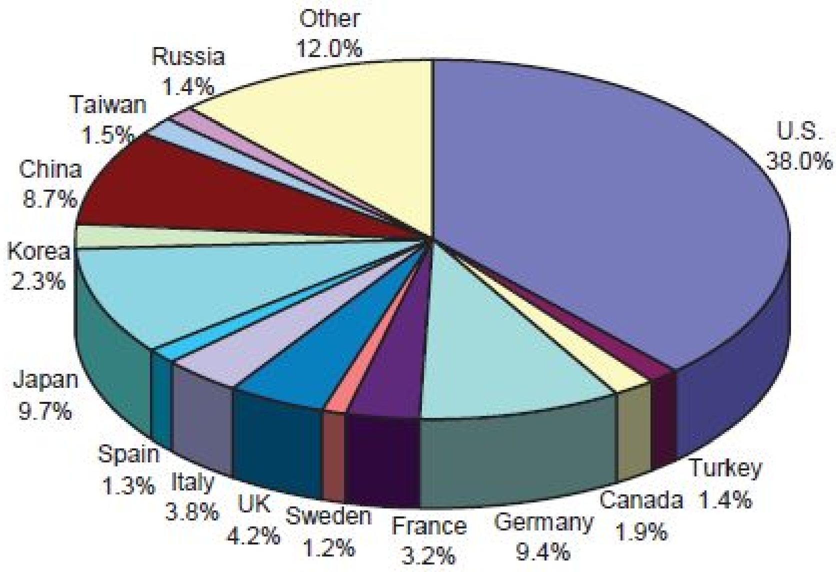


Figure 3.7 Installations by countries (Source: Wohlers Associates, Inc.)

From these 2 pie charts, we can easily find where consumers locate in general. As the most developed country on the earth, the US with no doubt, owns the latest technologies, has the most well-known companies and the biggest domestic market. It is and it will be the most important market for AM. In Europe, Germany, France, UK, Italy will lead the European market. Asia, a region which has the highest economic growth rate, attracts big companies from North America and Europe to invest in the future. Countries such as China, Japan and Korea, have a very good industrial foundation. Meanwhile, they also have a big population with an economic base to support a growing market.

3.2.3 Why consumers choose 3D printers

3D printers can be divided into 2 kinds, desktop and industrial-grade. The reasons why consumers buy these 2 kinds of printers are different.

Industrial-grade printers, just as the name shows, are for industrial demands. In section 2.1, we listed the advantages of 3D printing. Consumers buy printers to improve properties of parts, reduce the cost of production, realize the friendly-environmental goals, etc. Producers, with the aim of increasing revenues, intend to invest more to do R&D to sell new printers with lower price and better function. Here perceptual maps can be introduced to help producers satisfy consumers' demand. When doing the market analysis, producers need to list the properties that consumers take into consideration. Then the most two important properties should be discussed. For industrial-grade printers, we choose price and quality as the most important properties. Then we can start to draw the perceptual map with price and quality in xy directions. Figure 3.8 contains 3 brands in the perceptual map, brand A, B and C. Here we imagine that brand C performs best in the market, with lower price and higher quality. Brand A and Brand B need to take actions to modify the characteristics of printers so that their position in the perceptual map can move. The destination of using the perceptual map is that Brand A and Brand B can move towards Brand C. Brand C may be a real competitor in the market, or it can also be a target brand that is set by the company. When the brand launched by the producer reaches the target position in the perceptual map, the product will satisfy consumers' demand in both price and quality and perform one of the best in the market.

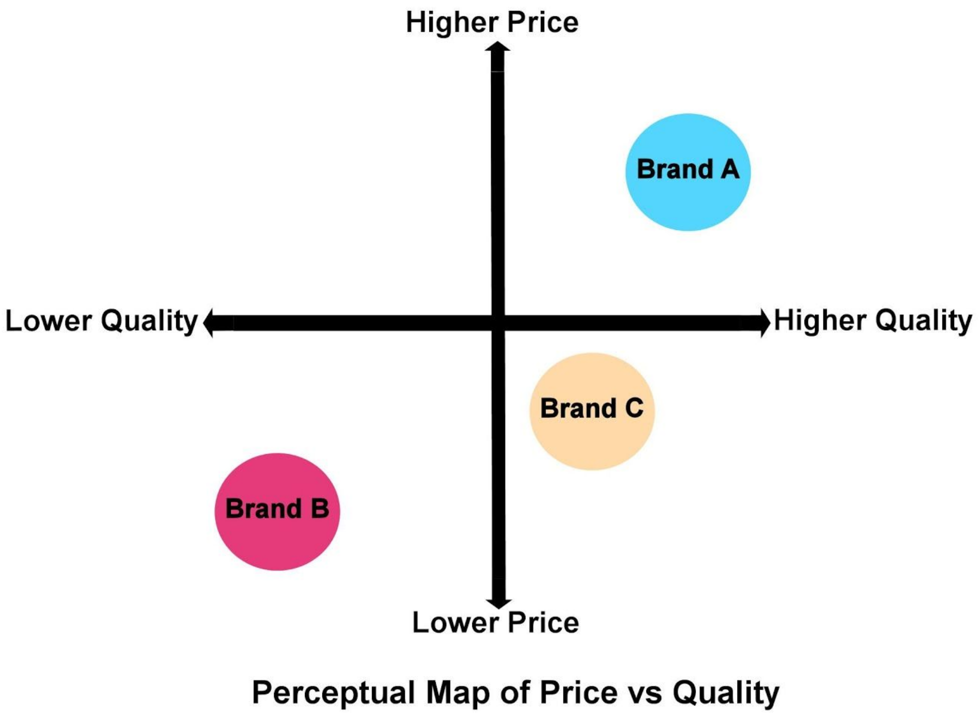


Figure 3.8 Perceptual map of price & quality

On the contrary, those who buy desktop printers are individuals who have a desire to print DIY objects. Consumers install desktop printers at home, design the structure of the object and then print directly in their rooms. To this group of consumers, producers tend to change consumer behaviour to grasp potential consumers. When 3D printers were not in the market, people didn't have the demand for 3D printers. However, when 3D printers entered the market, producers needed to create the demand. A perceptual process (Figure 3.9) illustrates how the producer creates a demand for consumers. The specific stimulus (sights, sounds, smells, etc...) stimulates the sensation of the consumer. Then producers can give meanings to this sensation. With several cycles, consumers will gradually form the perception of this stimulus. Desktop printers as a stimulus, stimulates the sensation of DIY. The producer intends to interpret how desktop printers help consumers create their own objects. Then consumers will tend to view desktop printers as a new way to support people's crazy ideas. In the end, a totally new demand which doesn't exist before is created by the producer.

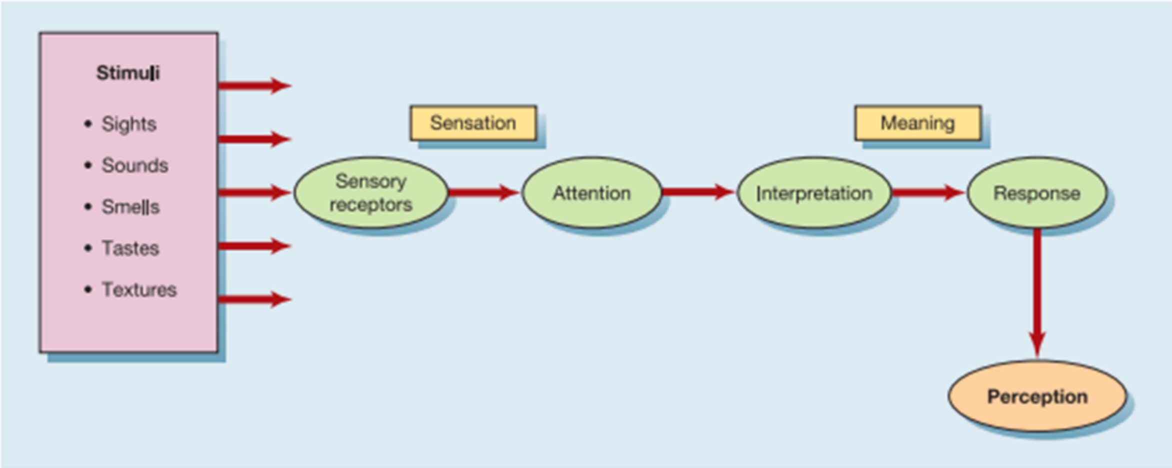


Figure 3.9 A perceptual process

3.3 Price

Price is a very important concept in the market. The market price reflects interaction between supply and demand. According to Wohlers Report 2015, industrial-grade and desktop printers were divided by price. Industrial printers were those that sold more than $5000, while desktop printers were those that sold less than $5000. Basically, industrial-grade printers are more expensive than the desktop due to the better performance. Price plays a very essential rule in the printers market. On the one hand, producers need to cautiously set the price. Higher price brings more profit but consumers become less. Lower price attracts more consumers but profit will shrink. On the other hand, consumers' preference for printers might not only be influenced by the price. Reputation, brand awareness, quality also influence consumers' choice.

3.3.1 Factors affecting price

The accuracy of the printer affects the price of the printer. The accuracy of a 3D printer is largely determined by the manufacturing and assembly accuracy of the printer itself. Vibration during the working process of the machine will seriously affect the printing accuracy. If high accuracy is required, the materials available for the printer will be different. Normally the higher accuracy of the printer, the higher price will be set.

The region of the producer will influence price also. With the same performance, printers produced in China normally are cheaper than that of Europe and the US. On the one hand, consumers have stereotypes that American and European products are of high quality. They think that they pay more and will get better products. Take a double blind test for example, consumers declared that they prefered coca cola to pepsi. However, during the double blind test for pepsi and coca cola, consumers prefer pepsi when they don't realize which they are drinking. The price of coca cola is more expensive than pepsi, in the double blind test, consumers feel that pepsi is better. In reality, consumers still think coca cola is the best. On the other hand, American and European producers normally not only invest in R&D, they also build brand awareness, including public relations, sponsorship, advertising, etc. These marketing communication events cause price premiums.

The printer that can print larger size takes a higher price. This is because the 3D printer has higher requirements for design, materials, structure, technologies.

Also the more complex technologies that are applied, the higher price will be set. Usually 3D printers can be divided into FDM, SLA, SLS printers. FDM technology is currently the most used technology with the lowest cost. The principle is very simple. It is mainly to melt the material and stack it layer by layer until it is finally formed. SLA technology is mainly to focus a specific intensity of laser on the surface of the 3D printing material to solidify and shape it. Therefore FDM printers are cheaper than SLA and SLS in the market.

3.3.2 Average selling price

In this section, only industrial AM systems are discussed, desktop printers are not taken into calculation. Figure 3.10 gives a line chart that shows ASP value from 2001 to 2014.

Figure 3.10 ASP of industrial AM systems (Source: Wohlers Associates, Inc.)

From 2001 to 2010, ASP of AM systems has declined from $117700 to $62600 This is because some AM machine models that have been introduced in recent years are less expensive than established models, so one would expect the downward trend to continue. From 2010 to 2014, the ASP increased from $62600 to 87100. One reason for the increase is that high-end AM systems, including expensive machines that produce metal parts, were selling well. Another reason is that machines at the low end of the industrial system segment ($10000 to $30000 products) were not as selling well in recent years due to the growth and popularity of the under $5000 desktop 3D printers. Together these factors have caused the ASP of industrial systems to increase. This trend was impacted some by relatively strong sales of systems at the low end ($5000 to $10000) of the industrial system cost spectrum in 2014.

3.3.3 E-commerce

E-commerce is a popular platform for producers to sell printers to consumers. In e-commerce platforms, price is transparent. Consumers can set a range of requirements, such as price, region, sales, etc. Then the platform will provide optimal results to consumers. For 3D printers, it's the best solution. One reason is that physical retailers have high fixed costs. Also producers need to pay the rental payment every month, they need to hire salesmen and pay them salaries. Another reason is that consumers lack the understanding of the product. The transaction will be done only when consumers enter physical retails and make decisions to purchase. However, via the e-commerce platform, producers only need to spend money on building e-shops. When consumers have an interest in 3D printers, they can search information from the Internet. It's not necessary for consumers to drive their cars or take the bus from their home to physical retailers. So nowadays, when we search 3D printers in Google, a lot of information about products will be recommended to us.

The online retailer Amazon has started offering 3D printers and 3D-printed products. It also established a dedicated category team and brought the team at Mixee Labs on board. Amazon is interested in customization, and is offering the capabilities of several 3D printing, design, and custom product services. The degree of interest by such a larger retailer validates this market space and could lead to exposure to many new customers.

Alibaba is a Chinese business-to-business portal that sells products directly from factories and distributors in China. The site has significantly reduced the cost of 3D printers, filament, and parts such as stepper motors, bearings, and electronics. Through Alibaba, normally consumers can find cheap options from a large range of suppliers, especially for desktop printers.

3.4 Conclusions

With the development of equipment and materials, global 3D printer manufacturers are promoting final product modeling and mass production in the fields of aviation, aerospace, automotive, medical, household appliances, metal molds, etc., centered on Europe and the United States. The demand for high-end equipment, especially high-end 3D printers using metal as a material, is growing significantly.

In recent years, the source of manufacturing competitiveness is not traditional factors such as quality, price, and delivery time, but is turning to whether it can bring added value to the market through “commodities”. 3D printers can mold complex-shaped objects into "one body", but the design that can be completed by making full use of this feature remains to be "excavated."

With the continuous advancement of technology such as the automation and monitoring of modeling and material exchange, and the modeling of large objects, 3D printers have begun to be integrated into manufacturing plants. The software and hardware costs of 3D printers, the time cost of printing, and the cost of repairing equipment and replacing parts are relatively low. Although compared with other types of machine tools, 3D printers show disadvantages in terms of accuracy, and need to be improved in terms of printing speed, material plasticity and manipulation. As a complement to existing technologies, 3D printers are advancing the development trend of the trinity of equipment, materials and software, and their uses are expanding, and the 3D printer market is continuing to grow.

4.Chapter4: AM in aerospace sector

In section 2.6.2, we discussed that 3D printing is used in the aerospace sector from a market perspective. In this chapter we will talk about the current status and future trends of 3D printing in aerospace.

4.1 Introduction to aerospace sector

Aerospace is the human effort in science, engineering, and business to fly in aeronautics (Figure 4.1) and astronautics (Figure 4.2). Aerospace organizations research, design, manufacture, operate, or maintain aircraft and spacecraft. Aerospace activity is very diverse, with a multitude of commercial, industrial and military applications.

Figure 4.1 Aeronautics

Figure 4.2 Astronautics

Aerospace manufacturing is a high-technology industry that produces "aircraft, guided missiles, space vehicles, aircraft engines, propulsion units, and related parts". Due to the need to expose materials to extreme environments in aerospace, there are high requirements for materials. Aerospace materials cover a wide range, including aluminum alloys, titanium alloys, magnesium alloys and other light alloys, ultra-high-strength steels, high-temperature titanium alloys, nickel-based superalloys, and intermetallic compounds.

4.2 Current status of AM in aerospace

As a typical representative technology in the manufacturing of the third industrial revolution, the development of 3D printing has always attracted wide attention from all over the world. The metal 3D printing technology is regarded by experts in the industry as a highly difficult and high-standard development branch in the 3D printing, and it has a pivotal position in industrial manufacturing. Nowadays, industrial manufacturing companies all over the world are vigorously researching and developing metal additive manufacturing technology, especially aerospace manufacturing companies, and they are not hesitating to spend a lot of financial and material resources to increase research and development to ensure their technological leadership.

4.2.1 Application advantages of 3D printing in aerospace

As the shining jewel in the crown of the industry, the aerospace manufacturing field integrates all the high-tech technologies of a country. It is a back-up support area where the national strategic plan can be implemented and the political situation can be displayed. As a brand-new manufacturing technology, metal 3D technology has outstanding application advantages in the aerospace field and obvious service benefits. Mainly reflected in the following aspects:

4.2.1.1 Shorten the development cycle of new aerospace equipment

Metal 3D printing technology greatly shortens the manufacturing process of high-performance metal parts, especially high-performance large structural parts.

In traditional manufacturing, the development process of a mechanical product usually has five stages.

1.First of all, the company’s product planning department came to a conclusion after market research, that a certain product has great market demand. The conclusion will list the functions, main materials, parameters, target cost, and target time to market, etc. The R&D department will do a feasibility analysis after receiving market demand. This analysis includes technical feasibility, cost, patent risk, etc.

2.After completing the planning stage, it will go to the design stage. Product design will be based on product requirements and feasibility analysis. After the design is completed, the technical staff will check, ask questions and explain the solutions.
3.After the design is completed, a professional mold design engineer will design the corresponding mold, which is used to produce target products. This stage normally is longer than the second stage, because more details need to be taken into consideration. Mold design engineers need to consider not only products feasibility, but also production feasibility. This stage also contains mold making.
4.Then the R&D department conducts product trial production, and then goes to the production line to allow employees to participate in the product assembly. Through trial production, the existing problems of the product are exposed for subsequent rectification.
5.After completing the first 4 stages and solving the problems exposed, the last stage will start. At this stage, basically the entire company has been mobilized, and personnel in R&D, material control, procurement, engineering, production, quality, finance, business, etc. departments are all performing their duties, continuously making orders on time and quality.
In 3D printing, it’s not necessary to use mold to produce target products, they are just printed by 3D printers. So the third stage can be eliminated, also the other stages can be simplified to some extent. Therefore AM technologies can shorten the development time of a new aerospace innovation project.
FC-31 (Figure 4.3) is China's first fighter jet that uses 3D printing to manufacture integrated wings and mid-fuselage. More than 100 parts of the aircraft are manufactured by 3D printing. It is reported that its development time is shorter than the time required to rely on traditional manufacturing in the past.

Figure 4.3 Shenyang FC-31

4.2.1.2 Improve material usage rate

Most aerospace fields are using expensive materials because they have very high requirements for material properties. Traditional manufacturing, take CNC for example, is a subtractive manufacturing. Whether it is cutting or milling, it is accompanied by huge material consumption. Normally, the manufacturing, from rod-shaped or square raw materials to final products, wastes more than 90% of raw materials. The huge waste of materials also means that the machining procedures are complicated, because the losses caused by the simple procedures are less than the complex procedures. Meanwhile the production time is long. Metal 3D printing, as an additive manufacturing, wastes much less. There are 3 main steps in 3D printing, including design, build and post-processing. When building the object, the waste is mainly concentrated on supporting materials (Figure 4.4). 3D printing builds the object layer-by-layer, so the layer that is going to be printed, needs something to support, otherwise the layer will fall down. These support structures will become useless after building, which causes waste. The waste also appears in the post-processing. In general, the usage rate of 3D printing materials has reached 60%, which is much higher than traditional manufacturing.

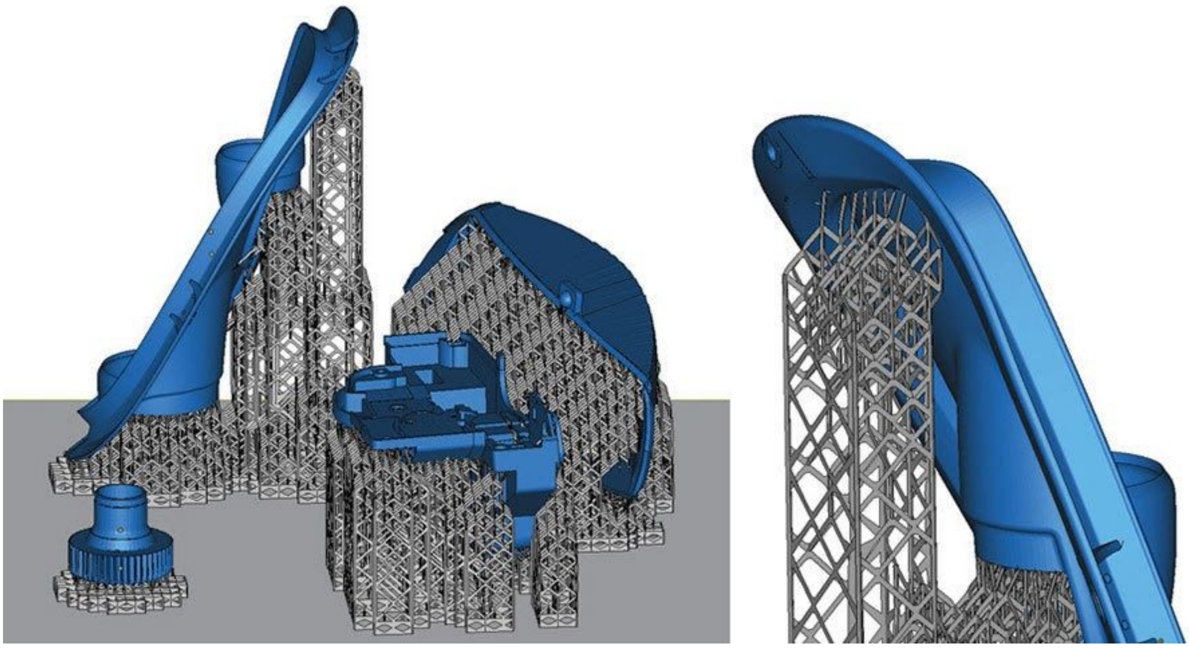


Figure 4.4 Support materials in 3D printing

4.2.1.3 Optimize parts structure and reduce weight

For aerospace weapons and equipment, weight reduction is its eternal theme. Weight reduction can not only increase the flexibility of flight equipment during flight, but also increase the load capacity, save fuel, and reduce flight costs. However, traditional manufacturing has already maximized the weight reduction of parts, and it is no longer realistic to further use the spare capacity. The application of 3D technology can optimize the structure of complex parts, and under the premise of ensuring performance, the complex structure is transformed and redesigned into a simple structure, thereby reducing weight. Moreover, by optimizing the structure of the parts, the stress of the parts can present the most reasonable distribution, reduce the risk of fatigue cracks, and increase the service life. Figure 4.5 shows an example of how a part has been redesigned to function by altering the part's topology. The topology of the part has been modified to meet existing structural performance requirements, and optimized to reduce the overall weight of the part.

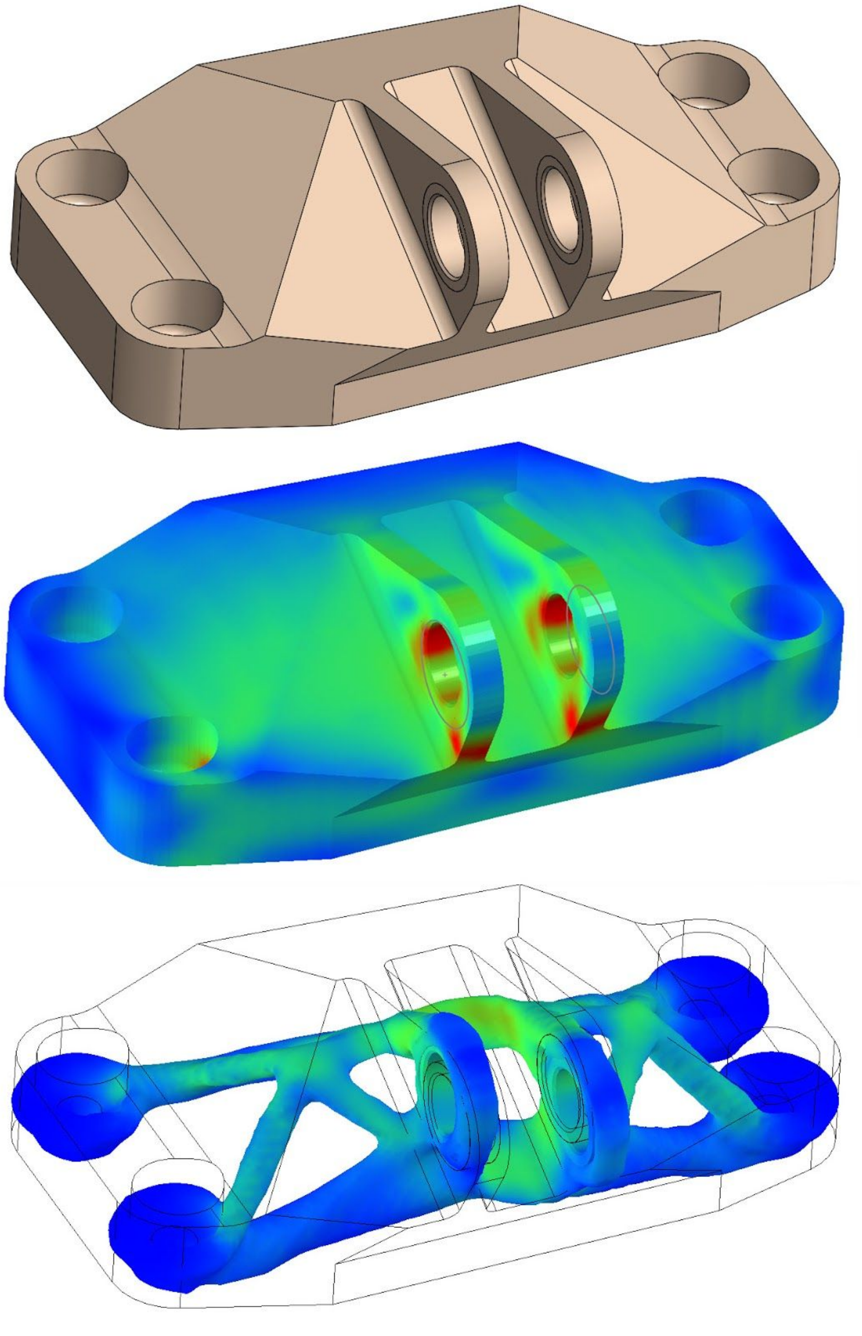


Figure 4.5 Topological optimization

Both performance and cost are key parameters when deciding if AM is appropriate for part fabrication and large-scale production of a specific part. In terms of design, factors that directly affect the cost of producing a metal AM part are:

1.Overall part volume and weight

2.The AM system selected for the printing process

3.The required secondary operations needed to transition an “as printed” part to a finalized form that meets geometric, surface and performance specifications

Topological optimization is a process that focuses on the modification of the topology or surface of a structure by altering that surface using a predefined objective along with applied design constraints. Typically, with metal AM part design, the objective of a topological optimization is to reduce part weight/volume with the constraint that the part not yield or fail under the part’s prescribed operational requirements (Francis H. Froes & Rodney Boyer, 2019). Figure 4.6, a part, after topological optimization, the volume decreases from 263346 cubic mm to 97884 cubic mm, the mass decreases from 2.06 kg to 0.766 kg, which is a reduction of 62.8%. From this example, we can see, by topological optimization, metal 3D printing can optimize structure and reduce the part’s weight and volume obviously.

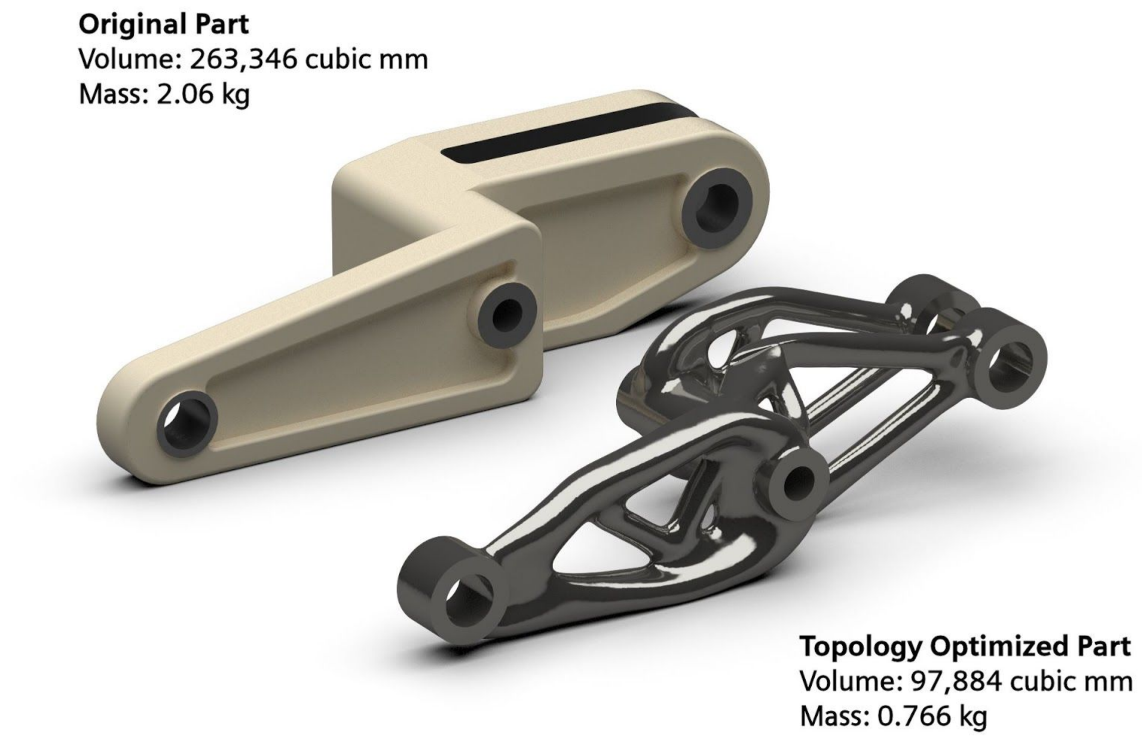


Figure 4.6 A topological optimized part

4.2.1.4 Repair forming of parts

The applications of the maintenance and repair operations benefit aerospace, where a structure or part is repaired using AM when it has incurred some sort of damage to one of its components that is not easily repaired and replaced using traditional manufacturing. Rather than scrapping the entire part or structure, AM material can be added to the damage site as replacement material reattaching a new component to the structure, and then performing any necessary secondary operations needed to return the overall part or structure to operation (Francis H. Froes & Rodney Boyer, 2019).

Take the high-performance integral turbine blade (Figure 4.7) disc part as an example. When a blade on the disc is damaged, the entire turbine blade disc will be scrapped, and the direct economic loss value is a huge amount. Traditional manufacturing makes this loss may be irreversible. However, based on the characteristics of 3D printing layer-by-layer manufacturing, we only need to treat the damaged blade as a special substrate, and perform laser three-dimensional forming on the damaged part to restore the shape of the part. The performance meets the requirements of use, even it’s higher than the performance of the substrate. Due to the controllability of the 3D printing process, the negative impact of its repair is very limited.

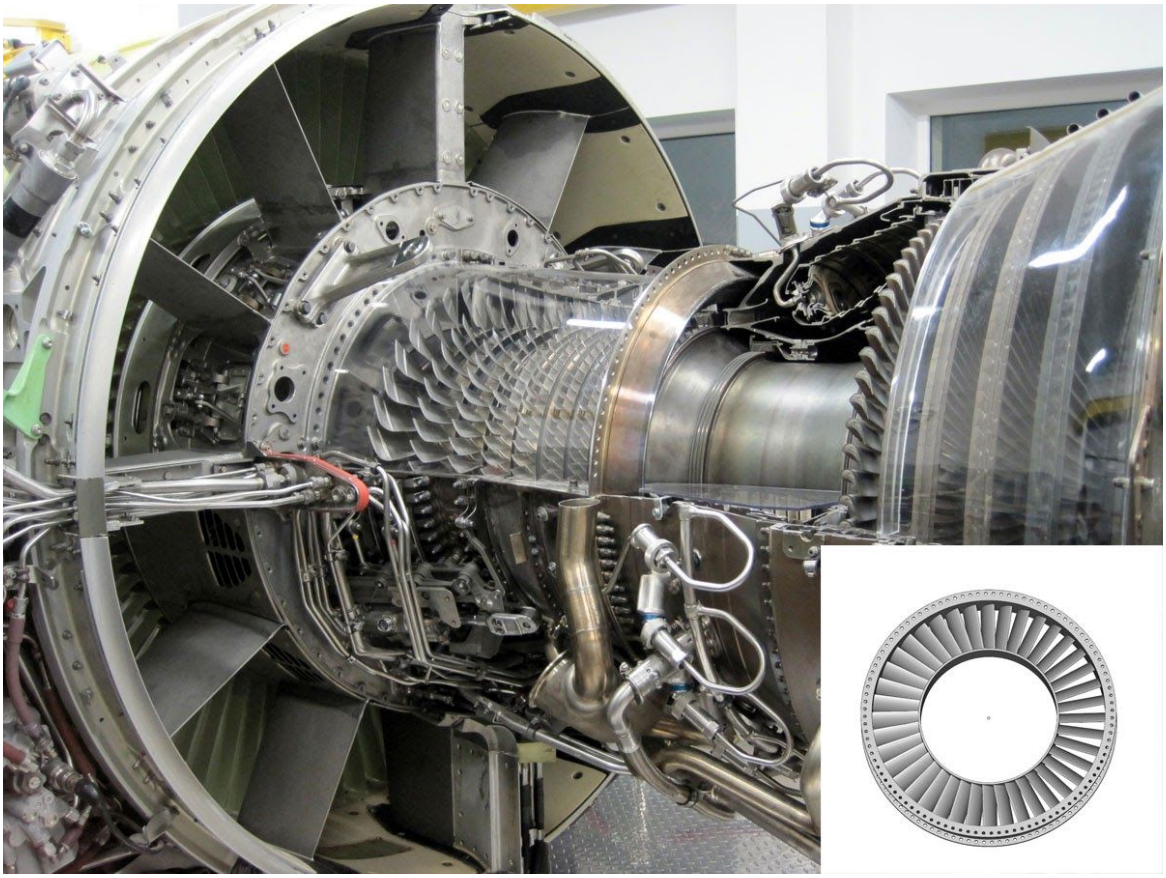


Figure 4.7 Turbine blade

4.2.1.5 Match with traditional manufacturing

Traditional manufacturing technology is suitable for mass production, while 3D printing technology is more suitable for the manufacture of personalized or refined structural products. Combining 3D printing technology with traditional manufacturing technology and taking advantage of each, make manufacturing technology more powerful.

For example, for parts that require high-quality performance on the surface but ordinary performance inside, traditional manufacturing techniques can be used to produce inside parts, and then laser three-dimensional molding technology can be used to directly shape surface parts on these inside parts, thus giving birth to the parts with high surface performance and ordinary inside performance. This saves the complexity of the process and reduces the production process. This complementary production combination has important practical application value in the production and manufacturing of parts.

Furthermore, for parts with simple external structures but complex internal structures, when traditional manufacturing techniques are used to manufacture complex internal structures, the process is cumbersome and the subsequent processing procedures are complex, which causes production costs and enlarges the production cycle. By adopting traditional manufacturing technology externally and 3D printing technology internally, only a small number of subsequent processes can be used to complete the product manufacturing, which shortens the production cycle, reduces costs, and gives play to the perfect match between traditional and 3D printing technologies. The combination of manufacturing achieves mutual complementarity.

In general, in the aerospace field, 3D printing and traditional manufacturing are combined to achieve 1+1>2.

4.2.2 Application of 3D printing titanium alloy

Titanium alloy has many advantages such as low density, high specific strength, wide operating temperature range (-269~600℃), corrosion resistance, low damping and weldability. It is the best material for aerospace to reduce weight and improve overall performance. Since the 1990s, with the rapid development of computer technology, laser direct manufacturing technology has gradually become a research focus in the manufacturing field. There are two methods in the laser direct rapid prototyping technology that can be used to directly manufacture metal parts, selective laser melting (SLM) technology and laser engineered net shaping (LENS) technology.

4.2.2.1 Landing gear

As one of the most critical sections of aircraft, landing gear systems bear a heavy load. Literally, all the weight of an airplane, fighter jet or helicopter is supported by the landing gear during taxi, landing and takeoff. Figure 4.8 is a landing gear. It's made of 3D printed titanium alloy. It can withstand high-impact loads because of the good mechanical properties of titanium alloys.

Figure 4.8 Titanium alloy landing gear

4.2.2.2 Bracket

For the first time, Airbus completed the installation of 3D printed titanium alloy brackets on the A350 XWB series mass-produced passenger aircraft. The bracket made using 3D printing is part of the aircraft engine pylon, which links the aircraft wing and engine nacelle (Figure 4.9).

Figure 4.9 Titanium alloy bracket between the aircraft wing and the engine nacelle

4.2.3 Conclusions

AM is transforming all segments of the aerospace industry, including commercial and military aircraft, space applications, as well as missiles systems. Such transformation is due to the unique ability of AM to produce parts with complex designs, reduce manufacturing costs (material waste, assembly due to part consolidation, and the need for tools and fixtures), and fabricate parts with premium materials with small production runs and short turnaround times. AM allows the realization of advanced part designs that provide additional space, multifunctional parts, multimaterial parts, part consolidation, and parts that are difficult to machine. The capability of AM to fabricate freeform designs makes it very suitable for the aerospace industry (Joel C. Najmon et al., 2019).

4.3 AM future trend in aerospace sector

Using 3D printers to make parts in aerospace is not cheap, but this has not stopped aircraft and jet engine manufacturers from castings to 3D printing. In this part, we will discuss the future trend of AM in the aerospace sector to see how it will go.

4.3.1 Aerospace 3D printing technique trend

In the future, 3D printing combined with Artificial Intelligence, Internet of Things, big data and blockchain will promote the development of aerospace.

4.3.1.1 AI

Artificial Intelligence (Figure 4.10) is a form of intelligence displayed by machines, sometimes called machine intelligence.

Figure 4.10 Artificial Intelligence

This kind of machine can obtain information by itself, reason and analyze it and draw conclusions autonomously (imitating human learning thinking) to perform advanced tasks. These machines that use AI mimic the intelligent behavior of humans. The AI automation process can be implemented autonomously in many different stages. The operation of the 3D printer itself is a relatively complicated process, and the addition of AI can greatly help it improve, thereby making this new technology more efficient.

Using AI in the 3D printing software may help design the best model. Generally, in order for the designed model to be 3D printed, technicians must use 3D printing modeling software to process the 3D printing model. These 3D printing modeling programs will increasingly include AI factors to help people create the best 3D printing models.

3D printing can use AI for defect detection. General Electric's (GE) Lab in New York began to develop a computer vision technology that can find micro cracks in machine parts. In the 3D printer printing process, AI will also learn independently. It can analyze the problems found during the printing process and continuously improve the quality control of 3D printed parts.

Obviously, AI can be integrated into the design of 3D printing factories and thus change the future of manufacturing. AI Build is a London-based company that has developed an AI-based automated 3D printing platform with a smart extruder that can detect any problems. It can also make autonomous response decisions. It is a large 3D printer that uses industrial robots and machine learning software. The use of robotic arms and automatic arms that can determine and print feasible parts without any problems is a real revolution.

In aerospace, we can see that in the future, 3D printing combined with AI, can not only help us design the best model, but also detect defects with high efficiency.

4.3.1.2 IoT

The Internet of Things (Figure 4.11) describes the network of physical objects “things”, that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet.

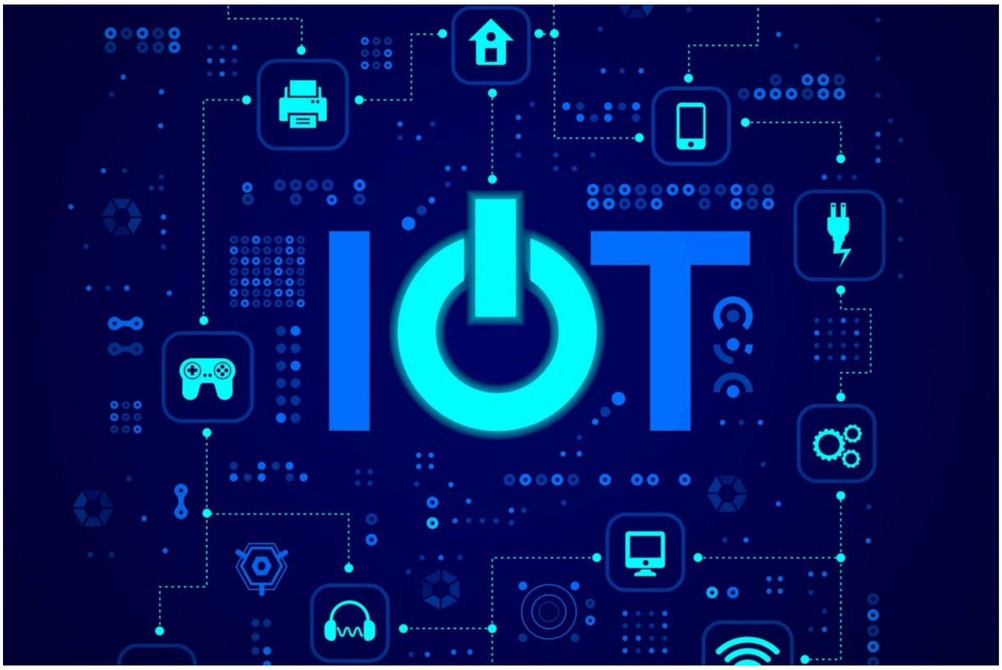


Figure 4.11 Internet of Things

Connecting the Internet of Things and 3D printing makes the production process more efficient for companies than ever before. The combination of the Internet of Things and 3D printing is two-way. One direction is that the implantable sensors and other monitoring devices made by 3D printing technology are directly "embedded" into the product as a manufacturing technology to directly connect with the Internet of Things. Another direction is to feed back a large amount of big data accumulated by the Internet of Things to the 3D printing manufacturing system to achieve more lean production and supply chain management and product design more suitable for user needs.

3D printing technology is playing an increasingly important role in aerospace. The Internet of Things can also play an important role in aerospace. By connecting monitoring results to big data analysis, it ensures efficient quality control. By placing sensors, collecting and analyzing manufacturing information, real-time detection of production problems, the technology can also be used for specific purposes, such as analyzing temperature and structural integrity, which helps to improve the quality of production in the manufacturing workshop.

So combined with IoT, 3D printing can completely change the way of monitoring process, analyze and improve product quality.

4.3.1.3 Big data

Big data (Figure 4.12) is a field that treats ways to analyze, systematically extract information from, or otherwise deal with data sets that are too large or complex to be dealt with by traditional data-processing application software.

Figure 4.12 Big data

3D printing currently has the problem of slow printing speed and difficulty in mass production. Big data can provide a solution for distributed manufacturing. The concept of distributed manufacturing is that the unit time consumption of product production becomes insignificant. For example, 10000 distributed manufacturing sites produce a single product, which has the same capacity as 10000 products manufactured in a manufacturing plant. And the former one, which is 10000 distributed manufacturing points, doesn't require inventory and logistics links. To create a distributed manufacturing site, one of the core problems to be solved is to have a designer platform based on huge design works. This must be based on the technology provided by big data.

With the help of big data, in the future 3D printing can break the technological monopoly. Aerospace companies can not only rely on a few monopolistic manufacturers, but also find the suppliers they need in small companies to reduce costs.

4.3.1.4 Blockchain

A blockchain (Figure 4.13), originally a block chain, is a growing list of records, called blocks, that are linked using cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data (generally represented as a Merkle tree). By design, a blockchain is resistant to modification of the data.

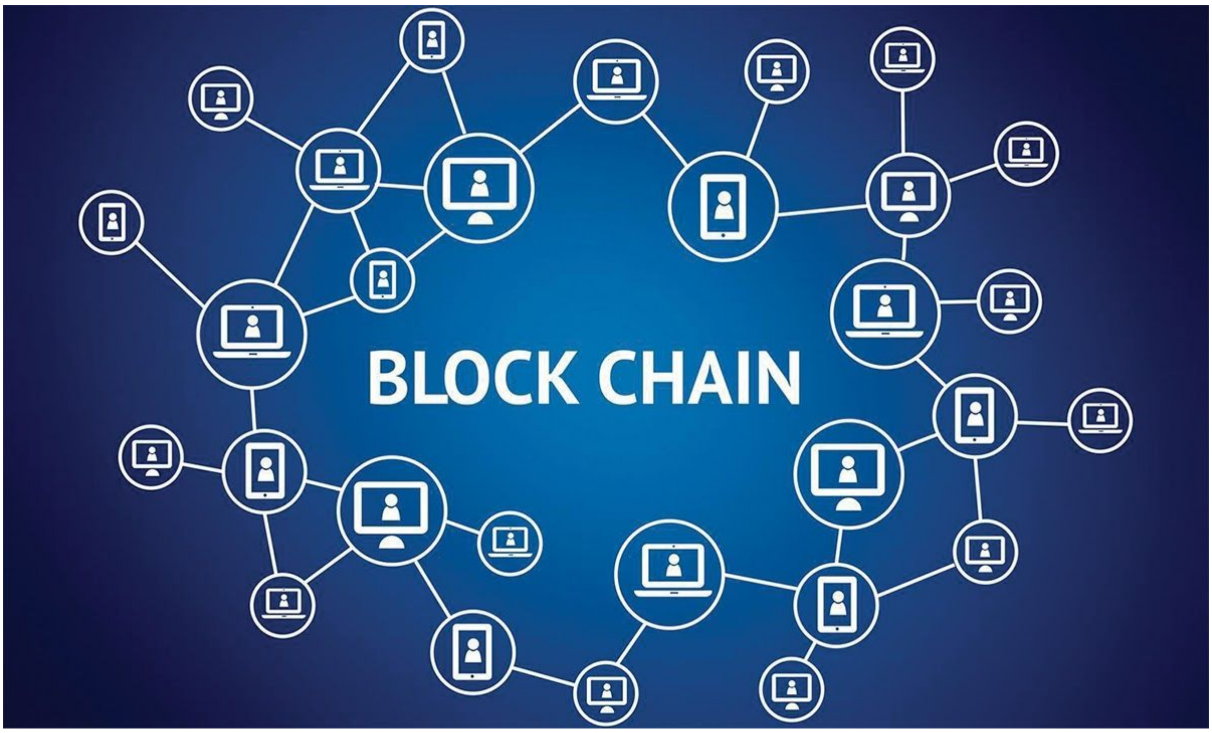


Figure 4.13 Blockchain

In the field of aerospace, due to the frequent involvement of company trade secrets and military secrets of various countries, there is an increasing demand for network security. However, 3D printing has serious security issues. On the one hand, the aircraft design may be stolen. On the other hand, the product may be deliberately printed to hide defects and built-in faults.

Blockchain can effectively handle this problem. The working principle of the blockchain is to create a distributed, encrypted ledger between any number of participants. The ledger can be used not only to verify identity, but also to verify the status of any particular mission. This means that every entity participating in any stage of 3D printing knows what other entities are doing in a safe way at all times. Since the blockchain is decentralized, meaning that no entity owns it, stealing or modifying 3D printed documents from the blockchain has nothing to do with metering.

Although cyber attacks against 3D printers are mainly limited to research laboratories, as more and more printers are connected via the Internet of Things, and more and more companies trust 3D printers with sensitive documents and information, 3D printers will only become targets that are more attractive to Hackers. Therefore, combined with blockchain, 3D printing can bring a technological revolution to aerospace while protecting intellectual property rights.

4.3.2 Aerospace 3D printing market trend

Currently, the aerospace industry accounts for more than 15% of the 3D printing market, with a market size of 1.8 billion US dollars. In the next few years, the aerospace 3D printing market will continue to grow at a rapid rate, and the market size is expected to grow to 5 billion US dollars by 2025. Aircraft and engine manufacturers are eagerly relying on this technology to develop lightweight components.

The aerospace 3D printing market is subdivided into hardware, software, materials and services by vertical type. Due to the use of multiple materials to print engines and structural components, the service sector is expected to witness the highest growth in the aviation 3D printing market during the forecast period. In addition, in the next few years, the development of new materials for 3D printing components to withstand high temperatures and extreme environments may increase the demand for 3D printing materials. Major aircraft manufacturers such as Boeing and Airbus are accelerating the adoption of this technology to achieve faster production processes, reduce waste and shorten the supply chain.

According to downstream applications, the aerospace 3D printing market can be divided into civil aviation, military aircraft and spacecraft, among which civil aviation is expected to become the fastest growing field in the next few years. GE Aviation Group has begun mass production of engine components using 3D printing technology. Rolls-Royce started to manufacture 3D printed parts for its engines (including Trent). Other major engine OEMs are also working hard to develop 3D printed parts. In addition, the increase in passenger traffic has created higher demand for new aircraft. Airlines require light aircraft to increase their profitability. Large airframe manufacturers are increasingly committed to the development of advanced technologies, including 3D printing, in order to develop lightweight parts at a faster rate.

According to the type of printing products, the aerospace 3D printing market can be subdivided into engine components, structural components and space components. The market is expected to continue to grow due to the increase in aircraft deliveries and the increase in the application of light materials, and the development of high-precision parts in a shorter time.

From a global perspective, North America is the largest market for aerospace 3D printing. The aerospace industry in North America is relatively developed, with many aerospace equipment manufacturers, parts and components companies, and OEM companies. The 3D printing industry in the region is also developing rapidly, and it is in a global leading position for the application of 3D printing in aerospace.

Currently, the main global aerospace 3D printing companies include 3D Systems Corporation, EnvisionTEC GmbH, EOS GmbH, GE Aviation, Hoganas AB, Materialize NV, Oerlikon Group, Renishaw plc, Stratasys Ltd., Trumpf Group, etc.

4.4 Conclusions

Compared to automotive and orthopaedics, aerospace is an industry that cost is not so important. This gives enough space for 3D printing. With its characteristics different from traditional manufacturing, 3D printing has been widely used in aerospace. At present, on the one hand, 3D printing needs more applications in aerospace. On the other hand, when these applications gradually become mature, we hope the cost of these applications can be reduced, so that related technologies can also be used in other commercial fields. The future trend of 3D printing in aerospace is to combine other advanced technologies to maximize the benefits of technology.

5.Chapter5: Case study: Desktop Metal

At present, new and old companies in the global 3D printer field coexist, with fierce competition in the market. Established 3D printing giants such as EOS, SLM solution and 3D Systems have led the development of the industry in the early stage. With patent advantages, they have more than ten or even twenty years of technology accumulation and already have a high market share and customer awareness. They have set a barrier for new entrants. However, Desktop Metal (Figure 5.1), a company that was just founded in October 2015, has achieved the valuation of $1.5 billion (Amy Feldman, 2019). How did Desktop Metal grow in just five years? What is its external environment? What are its internal conditions that give it an advantage? How does it make the right business strategies to achieve success? In this chapter, we will do a case study about Desktop Metal to analyze how it can stand out from a bunch of established companies.

Figure 5.1 Desktop Metal logo

5.1 Desktop Metal background

An introduction of Desktop Metal's background will be given in this chapter, including history and products.

5.1.1 History

At the time of its founding, the company was developing a process for metal 3D printing that would be fast and small enough for office settings. The company's intent was to create a metal 3D printer that would "churn out parts more quickly" and be "much cheaper, smaller, safer and easier to operate" than alternatives on the market (Jeff Bauter Engel, 2017). By October 2015 the company had only 11 employees. From 2015 to 2016, the company received a total of $97 million investment. The capital was used for research and development, with plans to begin selling the first product later that year in a variety of industries.

The company revealed two distinct metal 3D printing systems in late April 2017: a studio model and a production model.The Studio System, safe for office settings, is designed for rapid printing and the production of small volumes, while the latter is intended for high-speed production of parts. Both systems include a printer, furnace, and cloud-based software to operate the machines, with the ability to print several hundred alloy types.

By early 2018 the company had been granted two patents for separable support and an interface layer, with around 100 patents pending for around 200 inventions.

In January 2019, Desktop Metal raised an additional $160 million in funding, resulting in a valuation at $1.5 billion. By May 2019, the company employed around 300 people, mostly engineers, with the machines made through contract manufacturing. It also had a sales channel distributed in 48 countries. In June 2019, the company began shipping to Europe. By 2019, the company had raised $437 million from investors, and was one of only three 3D printing unicorns. In November it introduced a system for metal job shops and a system using fiber placement.

5.1.2 Products

Desktop Metal launched its first two products in April 2017: the Studio System, a metal 3D printing system designed for engineers and small production runs, and the Production System, intended for manufacturers and large-scale printing.

The Studio System (Figure 5.2) leverages Bound Metal Deposition technology - a process based on MIM (metal injection molding) in which loose powders and dangerous lasers are eliminated in favor of bound metal rods - to shape parts layer-by-layer.

Figure 5.2 Studio system printer

In 2019 the company introduced the Shop System (Figure 5.3), a metal binder jetting printing system designed for machine and metal job shops, as well as Fiber (Figure 5.4), a continuous carbon fiber printer using automated fiber placement technology (AFP) to make parts.

Figure 5.3 Shop system printer

Figure 5.4 Fiber printer

Also Desktop Metal developed Live Parts, an AI software for users to automatically generate printable object designs. The program allows users to input specifications for an object, then creates a computer model which can be printed using any 3-D printing system.

5.2 External analysis

When Desktop Metal was founded, it faced a mature market, with a lot of companies competing with each other. Meanwhile, many countries realized that it’s important to invest in the 3D printing industry, which means more and more new entrants join every year. The external environment for Desktop Metal is optimistic, but still it needs to face the fierce competition in the market environment.

5.2.1 PESTEL

PESTEL analysis is a simple and widely used tool that can generally describe a framework of macro-environmental factors in a company’s business environment.

5.2.1.1 Political

At present, a lot of countries in the world have shown sufficient support for the 3D printing industry.

In 2013, US President Barack Obama emphasized the importance of 3D printing technology in his State of the Union speech, hoping to promote the development of the US 3D printing industry. Then the US government established the "America makes" alliance in Youngstown, Ohio. The alliance promotes 3D printing technology through conferences, training, and project solicitation. The alliance members include universities, research institutions, public institutions and private companies.

The UK has released policies to promote the development of 3D printing and additive manufacturing since 2007. In 2013, the British government added 3D printing to the teaching curriculum of junior and senior high schools.

The Chinese government has also been releasing relevant policies in recent years to promote the development of the 3D printing industry in order to promote industrial upgrading. It’s obvious that 3D printing companies can develop faster with the help of relevant government policies.

5.2.1.2 Economic

Desktop Metal was founded in 2015, the domestic economy of the United States was recovering from the 2008 economic crisis at that time.

The United States GDP grew by 2.6% in 2015, an increase of 0.2 percentage point from 2014. The unemployment rate in the United States fell to 5.0% in October 2015, maintaining a continuous downward trend since October 2009. In October 2015, the number of

unemployed people in the United States fell to 7.91 million, and the number of employed people increased by 1.86 million in the same period. The US employment conditions continue to improve and the unemployment rate continues to fall. However, at the same time, the world economy slowed down in 2015, and the road to global recovery was bumpy and difficult. This shows that the U.S. economic recovery has a good foundation.
In a better economic situation, it's easier for Desktop Metal to grow.

5.2.1.3 Sociological

Nowadays, people are more receptive to new ideas. Additive manufacturing, as a new method of manufacturing, attracts a large number of enthusiasts. News about 3D printing is endless, pistols produced by 3D printers, first villa built by 3D printer, etc. There are already thousands of 3D printed works in the world, from simple artwork to complex customized products, from medical organs to precision mechanical parts. People design original products, print them at home using 3D printers, and then share on the Internet, which accelerates the spread of the concept of 3D printing among the public. 3D printers seem to be omnipotent and change the way people think of manufacturing. The society is very optimistic about 3D printing, although the application range of 3D printing is much smaller than traditional manufacturing.

5.2.1.4 Technological

Currently, the R&D focus of 3D printing lies in the development of materials and optimization of manufacturing processes. As is illustrated above, the relevant technologies update frequently, which offers a chance to Desktop Metal. When 3D printing just entered daily life, it was an expensive method of manufacturing. The materials cost high and manufacturing speed was extremely slow compared to traditional manufacturing. With the development of technologies, more materials are verified that can be used, new methods are designed to produce in a fast and high-efficiency way. Big companies, such as 3D Systems and EOS, hold related patents which are barriers to new companies. Frequent upgrading technologies provide new companies with a challenge that new companies can occupy new market segments.

5.2.1.5 Environmental

The waste slag, waste water and waste gas generated by the cutting, calcination, welding, grinding and other processes used in traditional manufacturing production are extremely serious environmental pollution. Compared to traditional manufacturing, 3D printing is an environmentally friendly manufacturing process. There are 5 main reasons:

1.Zero waste of resources: 3D printing consumables are made directly from raw materials, the accessories of specific shapes can be formed at one time. Compared with traditional cutting, assembling 3D printing can be described as zero waste of resources.
2.Green printing consumables: The PLA consumable used by the 3D printer is a new type of renewable biodegradable material, which is made of starch raw materials proposed by renewable plants (such as corn, cassava, etc.). It has good biodegradability. It can be completely degraded by microorganisms in nature under specific conditions after usage. This process will finally produce carbon dioxide and water. It is recognized as an environmentally friendly material.
3.No waste pollution: The 3D printed products are melted and sprayed out by the high temperature generated by the power source and stacked layer by layer, so that this process can reduce noise and chemical pollution.
4.Low time cost: In the production of customized parts and small batches of complex objects, 3D printing requires less production equipment, time and production costs from design to molding, and usually only takes a few hours or days to complete.
5.Extend product life: 3D printing technology can make it easier for people to produce replacement parts, thereby extending the service life of the entire product and avoiding it being thrown away when parts fail.

5.2.1.6 Legal

Combined with design software and appropriate raw materials, 3D printers can produce clothes, shoes, footballs, cakes, guns, houses, and even human organs. However, it also brings many new challenges to the determination of patent infringement.

The core of patent protection is to determine whether the alleged infringing method or product has infringed the patent right. Patent is to protect industrial methods or industrial products. Since 3D printing adopts a layer-by-layer stacking method, which is different from the traditional manufacturing of products by cutting raw materials or moulding, unless the patented method itself involves 3D printing methods, 3D printing will hardly infringe on the patented methods. Most of the cumulative technologies of 3D printing have been applied for patents. Therefore, anyone other than the right holder must obtain a license in advance to use these technologies for commercial purposes, otherwise they may be suspected of infringement. 3D printing materials may also have a certain degree of particularity. Related technologies such as the development of additive manufacturing materials are also applicable to the patent law. 3D printing may also involve trademark infringement. If a registered trademark is used in goods without the permission of the trademark owner, the goods are counterfeit and the trademark will also be infringed.

Generally speaking, the key points of 3D printing are printing technologies and printing models. Technical issues are generally adjusted by patent law, and there is not much dispute.

5.2.2 Competitors analysis

The main competitors that Desktop Metal needs to face are 3DSystems, stratasys, EOS, etc… Also there are international competitors from Europe and China. Considering Desktop Metal located in the US, 3DSystems could be one of its biggest competitors.

3D Systems, headquartered in Rock Hill, South Carolina, is a company that engineers, manufactures and sells 3D printers, 3D printing materials, 3D scanners, and offers a 3D printing service. Chuck Hull, the CTO and former president, invented stereolithography in 1986. The company creates product concept models, precision and functional prototypes, master patterns for tooling, as well as production parts for direct digital manufacturing. It uses proprietary processes to fabricate physical objects using input from computer-aided design and manufacturing software, or 3D scanning and 3D sculpting devices. 3D Systems' technologies and services are used in the design, development and production stages of many industries, including aerospace, automotive, healthcare, dental, entertainment and durable goods.

3DSystems manufactures stereolithography (SLA), selective laser sintering (SLS) color-jet printing (CJP), fused deposition modeling (FDM), multi-jet printing (MJP) and direct metal printing (DMP). Each technology takes digital input from three-dimensional data to create three-dimensional parts through an additive, layer-by-layer process. The systems vary in their materials, print capacities and applications.

3D Systems is a closed-source company, using in-house technologies for product development and patents to protect these technologies from competitors.

For the full year 2019, the company reported GAAP revenue of $629.1 million compared to $687.7 million for the prior year. Printer revenue decreased 24.3 percent, again due to the delay in factory metals printing shipments, timing of large enterprise customer orders and the softer macro industrial environment. Materials revenue decreased 0.6 percent, healthcare solutions revenue decreased 3.5 percent including a large enterprise customer and increased 9.8 percent excluding this same customer, on demand services revenue decreased 13.5 percent and software revenue decreased 2.7 percent. The company reported full year 2019 GAAP loss of $0.61 per share compared to a GAAP loss of $0.41 per share in the prior year, and non-GAAP loss of $0.08 per share compared to non-GAAP earnings of $0.15 per share in the prior year.

5.2.3 Porter Analysis

Porter's 5 Forces framework (Figure 5.5) is a method for analyzing competition of a business. It draws from industrial organization (IO) economics to derive five forces that determine the competitive intensity and, therefore, the attractiveness (or lack thereof) of an industry in terms of its profitability. Porter's five forces include three forces from 'horizontal' competition – the threat of substitute products or services, the threat of established rivals, and the threat of new entrants – and two others from 'vertical' competition – the bargaining power of suppliers and the bargaining power of customers.

Figure 5.5 Porter’s 5 Forces framework

5.2.3.1 Bargaining Power of Suppliers

The suppliers can be divided into 2 categories, materials suppliers and software suppliers. 3D printing materials are mainly divided into two types: metal and non-metal materials. The materials that 3D printing equipment can use are relatively limited, so the production and sales of materials are mainly determined according to the needs of 3D printing equipment. At present, the 3D printer operating software on the market is usually developed by the equipment manufacturers themselves, and the 3D modeling software that needs to be used in the design stage has also been developed. Therefore, companies that focus on the development of 3D printing software are mainly devoted to data processing, optimizing 3D design, and better adapting to 3D printing technology. At the same time, some large software development companies have begun to try to establish an open source 3D printing

software platform, aiming to attract more software developers to carry out more in-depth software optimization and development on this platform.
Bargaining power of suppliers is different in desktop and industrial printers. Desktop printers suppliers have weak bargaining power, while industrial printers suppliers have strong bargaining power. This is because desktop printers consume less materials and industrial printers consume more.

5.2.3.2 Bargaining Power of Buyers

In the 3D printing field, there are many companies, for example 3DSystems, EOS, etc. These companies produce 3D printers that use different materials, such as composite, polymer, ceramic, metal. Desktop Metal only focuses on metal and composite 3D printers, mainly metal 3D printers. In terms of the metal printing market, it can be discussed in two fields, industrial market and desktop market. In the industrial market, Desktop Metal needs to face the competition of EOS. EOS is a German company, which was founded in 1989. It is the world's leading metal 3D printing manufacturer. In 2018, the revenue of EOS was $400 million, the profit was more than $40 million, the profit margin was 10%. The bargaining power of buyers is high, Desktop Metal may use cost leadership or product differentiation to take more market share from EOS. In the desktop market, currently it’s still not clear. Consumers may consider their choices based on printer prices, consumables, and printer performance. Generally speaking, buyers have bargaining power on Desktop Metal, which also promotes its continuous development.
In general, the overall buyer's bargaining power is not strong. Buyers’ bargaining power of industrial printers is lower than that of desktop. This is because there are more companies that produce desktop printers in the market.

5.2.3.3 Threat of New Entrants

The leading 3D printing manufacturers, like 3DSystems and EOS, have a history of more than 30 years. Desktop Metal was just founded in 2015, it’s so incredible that it has grown exponentially in the past few years and has quickly developed to a level that keeps pace with these leading companies. Desktop Metal was a true threat of new entrants to those established companies, so are other new entrants. In the 3D printing field, new entrants could grow quickly with the help of investments from investors and latest technologies. Desktop Metal and other companies need to register patents to protect technologies and set industry standards to raise barriers to new entrants.
Generally speaking, industrial printers have less new entrants, while desktop printers have more new entrants.

5.2.3.4 Substitutes

Substitutes to 3D printers are other manufacturing machines, such as computer numerical control(CNC). Take CNC for example, it has the advantages of high accuracy and high speed. 3D printing can shorten the process from design to mass production and satisfy the demand of DIY. At present, CNC has a much bigger market share in the industry compared to that of 3D printing. When customers make a decision, they need to consider both cost and quality. 3D printing is facing a challenge that we all need to solve, the cost is still high, mass production is still in theory. If investors still can't see the possibility of completing the industrial revolution after a large amount of investment, investment fever will drop, investment will flow into other areas. That is to say, high cost and difficulty of mass production will cause the threat of substitutes.

In general, there is no obvious threat of substitutes, it complements and coexists with traditional manufacturing .

5.2.3.5 Rivalry

Industrial printers are in the blue ocean competition. Currently, few companies provide industrial printers because the barrier is high for new entrants. Industrial large-size 3D printers mainly include FDM and SLA models. Both of them, the more expensive industrial SLA printers are more advantageous in terms of printing speed and molding accuracy. SLA is the earliest rapid prototyping manufacturing process. It is printed by moving the optical axis. In theory, it can be made to a large size. However, because the SLA industrial model adopts the forward swing resin cylinder to have the same depth as the workpiece height, the molding space must be filled with resin material, which also means that the equipment must be very large. At the same time, every time the material is changed, the entire cylinder must be emptied. SLA model consumables are liquid photosensitive resin, which has the characteristics of fast curing, high molding accuracy, good surface effect, easy post-processing, etc. Therefore, we can see that the technical threshold of SLA industrial equipment is relatively high, and there are few equipment manufacturers.

Desktop printers are in the red ocean competition. Compared with industrial printers, desktop printers have less requirement for technologies and materials. For new entrants or those small companies, they prefer to sell desktop printers. There are many companies competing in this segment, the competition is gradually moving towards cost leadership.

5.3 Internal analysis

In this part, SWOT analysis and VRIO framework will be included in internal analysis.

SWOT analysis, which is a list of strengths, weaknesses, opportunities and threats, is helpful to conduct in-depth and comprehensive analysis and positioning of competitive advantage before formulating development strategy.
VRIO, which is a framework consisting of value, rare, imitation and organization, is used as a framework in evaluating just about all resources and capabilities of a firm, regardless of what phase of the strategic model it falls under.

5.3.1 SWOT analysis

Strengths: 1)The process for metal printing is fast and small enough for office settings 2)It's much cheaper, smaller, safer and easier to operate 3)Enough investment 4)Cooperation with Ford, BMW and other companies 5)It has a sales channel distributed in 48 countries 6)It developed an AI software for users to automatically generate printable object designs	Weaknesses: 1)It was founded in October 2015, it has insufficient industry experience 2)Few products with high market share 3)Not too many latest technologies
Opportunities: 1)Online channel 2)New trends in consumer behaviour 3)Globalization	Threats: 1)Fierce competition 2)Technologies are not widely promoted

5.3.2 VRIO

Through the internal analysis, the goal is to find Desktop Metals core resources, which presents Desktop Metal with a competitive advantage. The analysis' scope is to understand how these resources are utilized and how they create value for Desktop Metal. The VRIO framework has been chosen as the instrument to dissect Desktop Metal. Resources are divided into two categories, tangible and intangible.

5.3.2.1 Tangible resources

Tangible resources are physical items including cash, inventory, machinery, land or buildings. These items can be easily liquidated and have a set value. Here only financial resources and physical assets will be included.

5.3.2.1.1 Financial resources

Desktop Metal is an unlisted company and therefore not able to raise funds and capital through the sale of its securities. Fortunately, Desktop Metal is a “unicorn”. By 2019, the company had raised $437 million from investors. With the help of a large amount of investment, Desktop Metal has developed rapidly in just a few years. Recently, it will list on the New York Stock Exchange in a merger with Trine Acquisition Corp., a special purpose acquisition company led by former cable exec Leo Hindery Jr. and HPS Investment Partners. The public listing and a total of $575 million in new funds from the transaction will give Desktop Metal the firepower to expand aggressively (Amy Feldman, 2020).

The resource is not rare in the industry as many competitors have capital to take advantage of opportunities or can raise it at will. Desktop Metal does however have a considerable advantage compared to the lesser competitors and new entrants, as they are rarely backed with the kind of capital that Desktop Metal is in possession of.

5.3.2.1.2 Physical assets

Desktop Metal's core products, which are studio systems, shop systems and fiber, are produced in the US. Desktop Metal serves markets in 60 countries and parts are used in industries ranging from automotive, aerospace to consumer products. These products can meet the different needs of different customers. All these physical and technological resources are valuable and costly to imitate.

5.3.2.2 Intangible Resources

An intangible asset is an asset that is not physical in nature. Goodwill, brand recognition and intellectual property. Here patents, R&D, reputation, brand reliability and human resources will be included.

5.3.2.2.1 Patents

So far, Desktop Metal has obtained 2 patents and 52 applications to be approved. These 2 patents are "Fabricating an interface layer for removable support"(US9833839B2) and "Fabricating multi-part assemblies"(US9815118B1). Patent is not only to improve the efficiency of the enterprise, but also promote the sustainable development of the enterprise. Patents are important for Desktop Metal, they can help seize the market, set barriers to new entrants and avoid imitation. This resource is very valuable, the firm is able to capture the value produced by patents.

5.3.2.2.2 R&D

Due to a large amount of investment from investors, Desktop Metal is able to pay much more attention to R&D work.

In 2017 April, Desktop Metal was officially launched with the introduction of the Studio System, the world's first office-friendly metal 3D printing system, and the Production System, the world's fastest mass production printer.

In 2019 October, Desktop Metal introduces Fiber, the world’s first desktop 3D printer to fabricate high resolution parts with industrial grade continuous fiber composite materials used in automated fiber placement processes.
In 2019 November, Desktop Metal launches Shop System, the world’s first metal binder jetting system designed for machine shops and metal job shops.
We can see good returns from R&D. It’s a valuable resource because it brings core products to the market. This has also become a virtuous circle. Investment stimulates R&D, R&D brings good products, and good products bring a new round of investment.

5.3.2.2.3 Reputation, brand reliability

The expected valuation of Desktop Metal will be up to $2.5 billion if It is listed on the New York Stock Exchange in a merger with Trine Acquisition Corp. finally. As one of three “unicorn” 3D metal printer companies, Desktop Metal attracts attention from all over the world. To some extent, Desktop Metal represents the future of commercial 3D printing prospect. Although the history of the company is only 5 years, the brand has become a household name in the 3D printing industry. The products are favored by customers and the future prospects are coveted by investors. Thus this resource is for sure to give a competitive advantage to Desktop Metal. What’s more, in the short-term future, as the business expands, the company can invest more funds in brand building.

5.3.2.2.4 Human resources

When the company was founded, there were 7 founders. These 7 founders were leaders in their respective industries before the company was founded. When they decided to create the company together, it was destined to be full of the integration of various technologies in the future operation of the company. By October 2015, the company had 11 employees.
If we only focus on the scale of the company’s recruitment, we may easily think that it is difficult for this company to grow quickly. But according to the investment the company received, we know that the rapid development of this company doesn’t depend on the company's employment scale.
As the company is committed to the development of the 3D printing field, most of the company’s employees have relevant background knowledge and are extremely adventurous. Meanwhile, the technology of the 3D printing industry is updated rapidly, it also has higher requirements for practitioners. Practitioners need to maintain a positive learning attitude at work.
If the New York Stock Exchange’s (NYSE) listing is completed in the fourth quarter of 2020, Desktop Metal will continue to expand its production scale in the future schedule and at the

same time need more employees to meet production needs. Being an important resource of the company, human resources will continue to inject fresh blood into the company.

VRIO	Value	Rare	Imitation	Organization
Financial resources	High	High	High	High
Physical assets	Medium	Medium	High	Medium
Patents	Medium	Medium	High	Medium
R&D	High	High	Medium	High
Reputation, brand reliability	Low	Low	Low	Medium
Human resources	High	High	Medium	High

5.4 Business analysis

In this part, we will analyze how Desktop Metal becomes a “unicorn” in metal 3D printing within 5 years. Which kind of strategy has it taken? Why does this strategy make sense?

5.4.1 Blue ocean

As we have talked about 3D printers, desktop printers are in the red ocean, while industrial printers are in the blue ocean. We all know companies should try to shift their business to the blue ocean. But it’s not an easy strategy. First, industrial printers have much higher requirements compared to desktop printers. Companies need to obtain relative patents and technology. The current status of 3D printers is still hard to satisfy industrial production demand. Therefore new entrants tend to produce desktop printers in the beginning stage. Meanwhile, they can accumulate experience through desktop printers and lay the foundation for the future production of industrial printers.

Desktop Metal launched its first two products in April 2017: the Studio System, a metal 3D printing system designed for engineers and small production runs, and the Production System, intended for manufacturers and large-scale printing. That is to say, Desktop Metal has both desktop printers and industrial printers in its beginning stage. It can quickly increase market share through desktop printers, also it can start a business about industrial printers in the blue ocean.

Red oceans represent all the industries in existence today, the known market space. In the red oceans, industry boundaries are defined and accepted, and the competitive rules of the game are known. Here companies try to outperform their rivals to grab a greater share of product or service demand. Blue oceans, in contrast, denote all the industries not in existence today, the unknown market space, untainted by competition. In blue oceans, demand is created rather than fought over. There is ample opportunity for growth that is both profitable and rapid.

Desktop Metal, with its Production System in the blue oceans, doesn’t need to consume too much energy in price wars. It has more energy to invest in new product development and marketing.

5.4.2 Public relations

Public relations (PR) is the practice of deliberately managing the release and spread of information between an individual or an organization (such as a business, government agency, or a nonprofit organization) and the public. The aim of public relations is to inform the public, prospective customers, investors, partners, employees, and other stakeholders, and ultimately persuade them to maintain a positive or favorable view about the organization, its leadership, products, or political decisions.

Desktop Metal is a company with a history of only 5 years. But if you search the company name on the Internet, you will find that the Internet is basically a positive view of Desktop Metal. It has established a good image and reputation among the public, which paved the way for Desktop Metal to obtain a huge investment. In this virtuous circle, Desktop Metal’s well-received investment has expanded its scale, and the expanded scale has brought a good corporate image to the public, and a good corporate image has brought the next larger investment. A good corporate image is also favored by consumers. Consumers are willing to take the initiative to learn about companies with a good image. Compared with other companies, consumers will be more patient when first contacting Desktop Metal.

5.4.3 Listed company

It’s reported that Desktop Metal prepares to be listed on the NYSE in 2020.

Listing on the regulated capital market can bring many benefits to the company. First it opens up a new direct financing channel. Companies can not only raise a considerable amount of capital when they go public, they can also refinance to raise capital after listing and use company stocks for mergers and acquisitions, etc. Public listing is the most attractive form of long-term financing for companies, which can fundamentally solve the company’s need for capital. Second, public listing can enhance corporate brand value and influence. Listings have strong brand communication effects. Public listings play a huge role in the brand building of companies, which directly enhance the company's industry reputation and will receive more attention. It will be easier for companies to attract new customers. Suppliers are more willing to cooperate with you and banks will give higher credit lines. Third, listing makes the company more attractive to employees. Listing on the exchange will make the company more attractive to high-quality employees (such as the CEO), which will help the company recruit satisfactory senior talent. In addition, after listing, the company's equity incentive plan will be more attractive to employees, which helps attract and retain the most talented employees. And when the company provides a share dividend plan to outstanding management employees, the company’s benefits will be linked to the benefits of corporate managers to increase the motivation of employees. Last but not least, listing enhances the company's competitive advantage. For companies with good performance, good growth, and integrity, their stock prices will remain at a relatively high level. Not only can they continue to raise a large amount of capital at a lower cost, continue to expand the scale of operations, but also they can use stocks as a tool for mergers and acquisitions to further cultivate and develop the company’s competitive advantages and competitiveness, enhance the company’s development potential and stamina, and enter the channel of sustained and rapid development.

If Desktop Metal is successfully listed this year, it will become an industry giant in the field of metal 3D printing in the near future.

Reference

Adilet Zhakeyev; Li Zhang; Jin Xuan. "*Chapter 13 - Photoactive resin formulations and composites for optical 3D and 4D printing of functional materials and devices*". Available at: <https://doi.org/10.1016/B978-0-12-816805-9.00013-2>

Ali Bagheri; Jianyong Jin. "*Photopolymerization In 3D Printing"*. Available at: <https://doi.org/10.1021/acsapm.8b00165>

Manyalibo J.Matthews; Gabe Guss; Saad A.Khairallah; Alexander M.Rubenchik; Philip J.Depond; Wayne E.King. "*Denudation of metal powder layers in laser powder bed fusion processes*". Available at: <https://doi.org/10.1021/acsapm.8b00165>

S. A. Uhland; R. K. Holman; M. J. Cima; E. Sachs; Y. Enokido. "*New Process and Materials Developments in 3-Dimensional Printing, 3DP™*". Available at: <https://doi.org/10.1557/PROC-542-153>

Xin Wang; Man Jiang; Zuowan Zhou; Jihua Gou; David Hui. "*3D printing of polymer matrix composites: A review and prospective*". Available at: <https://doi.org/10.1016/j.compositesb.2016.11.034>

Amy Feldman (2019, Jan 23). "*3-D Printing Unicorn Desktop Metal Grabs Another $160 Million As It Prepares To Ship Its Mass-Production Printers"*. Forbes, from https://www.forbes.com/sites/amyfeldman/2019/01/23/3-d-printing-unicorn-desktop-metal-raises-160-million-for-expansion/#16a32e083c04

Amy Feldman(2020, Aug 26). "3*D Printing Unicorn Desktop Metal To Go Public In Latest Deal With A Blank Check Company*". Forbes, from https://www.forbes.com/sites/amyfeldman/2020/08/26/3d-printing-unicorn-desktop-metal-to-go-public-in-latest-spac-deal/#38b8916167ac

Jeff Bauter Engel (2017, April 25). "*Desktop Metal, Backed By $97M, Unveils Its First Metal 3D Printers*". Xconomy, from https://xconomy.com/boston/2017/04/25/desktop-metal-backed-by-97m-unveils-its-first-metal-3d-printers/

Christian Weller; Robin Kleer; Frank T.Piller. “*Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited*”. Available at: <https://doi.org/10.1016/j.ijpe.2015.02.020>

Grandviewresearch.com. 2020. “*3D Printing Metal Market Size, Share | Industry Report, 2020-2027*”. Available at: <https://www.grandviewresearch.com/industry-analysis/3d-metal-printing-market>

Marco Savastano; Carlo Amendola; Fabrizio D'Ascenzo; Enrico Massaroni. “*3-D Printing in the Spare Parts Supply Chain: An Explorative Study in the Automotive Industry*”. Available at: <https://doi.org/10.1007/978-3-319-40265-9_11>

C.McAlister; J.Wood. “*The potential of 3D printing to reduce the environmental impacts of production*”. ECEEE Industrial Summer Study Proceedings, 2014

Simon Ford; Mélanie Despeisse. “*Additive manufacturing and sustainability: an exploratory study of the advantages and challenges*”. Available at: <https://doi.org/10.1016/j.jclepro.2016.04.150>

Cindy Kohtala. “*Addressing sustainability in research on distributed production: an integrated literature review*”. Available at: <https://doi.org/10.1016/j.jclepro.2014.09.039>

Thomas Duda; L. Venkat Raghavan. “*3D Metal Printing Technology*”. Available at: <https://doi.org/10.1016/j.ifacol.2016.11.111>

Mohd. Javaid; Abid Haleem. “*Additive manufacturing applications in orthopaedics: A review*”. Available at: <https://doi.org/10.1016/j.jcot.2018.04.008>

R. Leal; F. M. Barreiros; L. Alves; F. Romeiro; J. C. Vasco; M. Santos; C. Marto. “*Additive manufacturing tooling for the automotive industry*”. The International Journal of Advanced Manufacturing Technology volume 92, pages1671–1676(2017)

L. Jyothish Kumar; C. G. Krishnadas Nair. “*Current Trends of Additive Manufacturing in the Aerospace Industry*”. Advances in 3D Printing & Additive Manufacturing Technologies pp 39-54

Joel C.Najmon; Sajjad Raeisi; AndresTovar. "*2 - Review of additive manufacturing technologies and applications in the aerospace industry*". Additive Manufacturing for the Aerospace Industry 2019, Pages 7-31. Available at: <https://doi.org/10.1016/B978-0-12-814062-8.00002-9>

Wohlers Associates. "Wohlers Report 2015 - Additive Manufacturing and 3D Printing State of the industry". 2015.

Wohlers Associates. "Wohlers Report 2013 - Additive Manufacturing and 3D Printing State of the industry". 2013.