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Application of 3D printing technology in the military

Khan Rajib Hossain[1, *] ,Md. Mahfuz Ahmed Shishir[2], Shafinur Rashid[2], Md. Hasnain Ahmed[2], Abul Basher[2], Rakib Hasan Risad[2], Anik Chandro Paul[2]

[a] *State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, China.*
[b] *Department of Applied Chemistry and Chemical Engineering, Rajshahi University, Rajshahi 6205, Bangladesh.*

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ABSTRACT

An innovative and revolutionary piece of technology, 3D printing has the potential to have substantial military applications. More and more things can be created with 3D printing as the technology advances. This article introduces 3D printing technology in the military and discusses how it impacts military equipment's maintenance, support, and development. It also briefly describes the concepts, fundamental principles, and applications of 3D printing equipment and printing materials and their development prospects in modern information warfare. Although 3D printing has unique advantages and has been applied in many fields, its development is restricted by many factors. The main reason is that the independent manufacturing technology is still insufficient, there are few optional materials, and the product accuracy is inadequate, resulting in short strength, low quality, and limited types of printed products. Although some products can meet emergency needs, their reliability is difficult to meet practical requirements, and independent manufacturing, in the true sense, cannot be realized. In the future, the rapid development and application of 3D printing still need to be broken through artificial intelligence and material technology.

1. Introduction

Rapid prototyping is a specialty of 3D printing [1]. From the computer-created three-dimensional digital model, it produces numerous layers of plane slices. The 3D printer can bond sand, metal, ceramic, powder, liquid, or filamentary materials [2]. According to slice graphics, composite materials are stacked into a finished object one layer at a time. This technology incorporates state-of-the-art technological knowledge in several areas, including chemistry, digital modeling, computer technology, electromechanical control, and material science. It is a wide range of application application technique with cutting-edge materials. Traditional production methods (usually referred to as "subtractive manufacturing") cannot manufacture shapes with the same precision as 3D printing technology. It can detect the formation of the net shape early on, significantly decreasing the additional processing required later on and preventing data leakage and the need for outsourcing processing. Additionally, the cycle and expense of single-piece trial and small-batch production are lowered due to the significantly decreased manufacturing preparation and data conversion time. It is best suited for creating new goods and making parts in small batches out of a single piece. These benefits have made 3D printing popular. It has been extensively employed in a variety of fields, including architecture [3], industrial design [4], jewelry [5], footwear [6], fashion [7], automobiles [8], aerospace [9], medicine [10], education, geographic information systems [11], and many other industries [12]. The application of 3D printing in the military has many potential benefits, including creating custom items, customizing them, using digital components, streamlining the supply chain, and increasing the variety of available materials. Regular people can use this technology to create some intricate and unique shapes that are impossible to create using handwork or conventional molds, based on specific data files combining the culinary expertise and

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∗ Corresponding author. e-mail: liza2019@lzu.edu.cn
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artistic talents of engineers, instrumentation specialists, and designers. In the military field, not to be outdone, countries worldwide are actively developing and applying 3D printing technology, and remarkable application results have emerged in many areas. After nearly 30 years of development, 3D printing has been widely used as an advanced manufacturing technology in aerospace, vehicle manufacturing, biomedicine, precision instruments, daily consumption, and other fields. Countries worldwide are working hard to develop and use 3D printing technology in the military, and there have been a lot of successful applications at home and abroad.

2. Three-Dimensional Printing Technologies and Materials

Although the idea of 3D printing dates back to the 1970s, the first experimental tools only became available in 1981. Due to the advancement of rapid prototyping technology, Hideo Kodama [13] made the initial effort at 3D printing. In addition to developing the SLA (stereolithography/light-curing) 3D printing technique, which uses ultraviolet light to polymerize photosensitive resin, he was the first to explain the layer-by-layer printing manufacturing process. A few years later, Alain Le Méhauté, Olivier de Witte, and Jean-Claude André, a trio of French engineers, were interested in light-curing technology but gave it up because there were no practical commercial applications. SLA technology is also used in this attempt at 3D printing. Charles Hull [14] of the United States, who was also interested in this technique, submitted the first patent for SLA (light-curing) in 1986. In 1988, he formed 3D Systems, and the SLA-1, the company's first commercial product, was made available.

Many incremental techniques came into use gradually. The gradual processes' main differences are the lamination method and the materials used. Some functions layer by melting or softening the material, such as selective laser melting (SLM) or direct metal laser sintering (DMLS), selective laser sintering (SLS), fused deposition modeling (FDM), or fused filament fabrication (FFF). Some processes use different techniques to process liquid materials, such as stereolithography (SLA). Under Layered Object Manufacturing (LOM), raw materials (paper, polymers, metals, etc.) are sliced into layers for reassembly. Each incremental process has advantages and disadvantages, so some companies began to supply powder and polymer raw materials for different process options. Other companies sometimes create long-term basic models from standard, off-the-shelf receipts. When choosing a 3D printer, the primary considerations are printing speed, printer price, printing prototype price, printing material selection, price, and color rendering ability. The most commonly used materials for FDM 3D printing are ABS, PLA, and their various blends. More advanced FDM printers can also print with other specialized materials that offer excellent heat resistance, impact resistance, chemical resistance, and rigidity. SLS has a more limited range of material options than FDM and SLA, but the materials available have excellent mechanical properties and strength comparable to injection molded parts. The most commonly used material for selective laser sintering is nylon, a famous engineering thermoplastic with excellent mechanical properties. Nylon is lightweight, strong, flexible, and resistant to impact, chemical corrosion, high temperature, UV rays, water, and dust.

2.1 Features of 3D printing technology

The advantages of 3D printing through traditional model processing and manufacturing [15] are as follows: High precision is present in the printed parts. It is possible to adjust the accuracy of popular 3D printers on the market below 0.02 mm. This precision is adequate for most product needs. The production method is straightforward, and the product development cycle is brief. The technology behind 3D printing eliminates the traditional processes of mold design and manufacture. The production cycle is significantly shortened, the manufacturing process is made more straightforward, and mold-making costs are reduced since it immediately acquires genuine parts from the 3D model data of CAD software. One can achieve personalized manufacturing. Computer modeling is typically used to develop 3D prints. The ease with which the size, shape, and proportion may be adjusted in real-time substantially facilitates customizing items. However, computer modeling can create some curves that conventional methods cannot accept, giving 3D-printed objects a unique appearance—various production materials. A 3D printing system can typically print with many materials, including metal, stone, plastic, etc., to accommodate the demands of multiple industries. Some complicated sections can be finished. It fills in the gaps left by outdated processing technology.

2.2 The principle of 3D printing technology

The three-dimensional design model on which 3D printing is based is discretely divided into many layers of plane slices by software [16]. Then, the ceramics, powder, liquid, or filamentary metals, and materials like polymers and cell tissues are layered and bonded one layer at a time before being superimposed to create a tangible product. The main piece of 3D printing equipment is the 3D printer. It is a sophisticated mechatronics system that combines computer, control, and mechanical technology. It primarily consists of subsystems like a numerical control system, an injection system, and a molding environment. It also includes a high-precision mechanical system.

In contrast to traditional manufacturing, which uses "subtractive manufacturing technology" [17], 3D printing uses the additional principle of "layer-by-layer superposition [18]" (Fig 1). Standard tools, fixtures, and machine tools are no longer necessary. Shortening the processing cycle, increasing the rate at which energy and raw materials are utilized, lowering the environmental impact, and enabling the design and manufacture of products with complex structures can successfully integrate design and manufacturing—the uniformity of the density of molded goods.

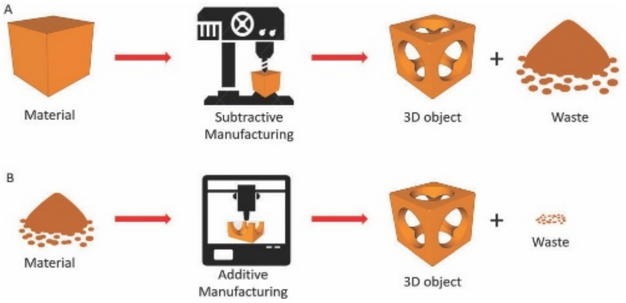


Fig 1. Manufacturing methods: additive versus subtractive. (A) To create the final 3D product and a sizable amount of residual material, material-removing machines treat a block of material with a digital design in subtractive manufacturing. (B) In additive manufacturing, a beginning material is processed by a 3D-printing device, which deposits precisely the necessary amount of material layer by layer until the final 3D product is formed.[18]

2.3 3D printing technology steps

As demonstrated in **Fig 2**, assist designers in creating 3D digital models of products using computer modeling software and then automatically analyze the printing process using the model. Then, press the "print" button, and the 3D printer can print them out. Although the materials used in 3D printing differ from those in traditional printing, the basic concept remains the same. While traditional printing employs "ink," 3D printing uses raw materials that must be qualified in terms of their physical and chemical qualities, be VAT, such as plastics, metals, ceramics, sand, etc.

2.3.1.Three-dimensional design: The steps in the 3D printing design process are: First, create a model using computer modeling software; then, "partition" the developed 3D solid model into layer-by-layer pieces, or slices, to direct the printer as it prints layer by layer. 3D design software is the data source of 3D printing, and the models required for 3D printing are created by 3D design software [19]. Domestic 3D design software includes autodesk maya, autocad, cinema 4d, solidworks, blender, rhinoceros, fusion 360, tinkercad etc. Although there is much special software for 3D printing, more intuitive, simple, and practical special software for 3D printing has yet to be developed.

*2.3.2 Slice processing***:** Similarly, to the laser forming technique, 3D printing creates 3D solids by layering, processing, and superimposing molding. Each layer's printing is divided into two stages. Before spraying a layer of special glue on the area that needs to be produced, the printer first reads the cross-sectional information in the file [20]. The sticky droplets are tiny and challenging to disperse. Spray a homogeneous powder coating next; when it comes into contact with the adhesive, the powder will instantly solidify and connect, but the region without glue will stay loose. The physical model will be "printed" by alternating glue and powder layers. After printing, the model can be "planned" by removing the loose powder, and any leftover powder can be recycled.

2.3.3 Finish printing: 3D printer resolution is adequate for most applications; however, it can be difficult on curved surfaces, producing jagged pictures. You can use the current 3D printer to create significantly larger objects and slightly surface polish them to create "high-resolution" objects with smooth surfaces. [21-22]

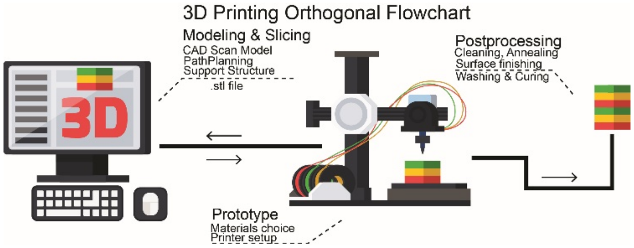


Fig 2. Process schematics of 3D printing process. (CAD-Sliceing-Prototype-Finishing).

2.4 Types of 3D Printing Technology

2.4.1 Stereolithography (SLA) Technology

The basic idea behind this technique is to pattern single-layer materials by focusing "light" at a focused wavelength and intensity on the surface of "photo-curable material" (**Fig 3**) [23]. The material used is liquid photosensitive resin [24]. It is characterized by fast forming speed, relatively high precision, and an excellent shape surface. It is mainly used to create several molds and models. The principles of stereolithography (SLA) and digital light processing (DLP) 3D printers are the same. They are irradiated with ultraviolet light to cure the photosensitive resin, but the working methods and processes are different.

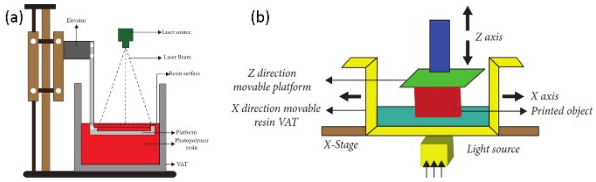


Fig 3. Scheme of the (a) Stereolithography (SLA) and (b) Digital light Processing (DLP) 3D printing technologies are

gradually belonged to the Vat Photopolymerization category of 3D printing. [23]

2.4.2 Fused Deposition Modeling (FDM) Technology

The principle is to melt the filamentary material into a liquid through the extrusion head of the heater [25]. The micro-spray head moves in the x-y plane, coats the molten material on the formed "work, " and completes the production of a graphics layer after cooling (Fig 4a). The materials used are filamentous (paraffin, metal, engineering plastics, low melting point alloy wire) [26]. It is characterized by easy use and maintenance, low cost, and high speed, and the complex prototype can be formed in only a few hours and is mainly used for plastic parts, casting wax patterns, samples, or models.

2.4.3 Laminated Object Manufacturing (LOM) Technology

The cross-sectional contour line data that the computer was able to retrieve (Fig 4b) shows how the laser cutting system functions. It uses the laser to cut the inner and outer outlines of the workpiece from the thin material coated with hot melt adhesive [27]. The feeding mechanism superimposes a new sheet of paper after cutting one layer. A sticking and pressing tool is used to adhere the sliced layers together. Paper, metal foil, plastic film, ceramic film, and fiber paper covered with heat-sensitive glue are the materials employed [28]. Its dependable performance, strong model support, affordability, and efficiency stand out. It is mainly used to swiftly create wooden casting molds, models, or samples of new products.

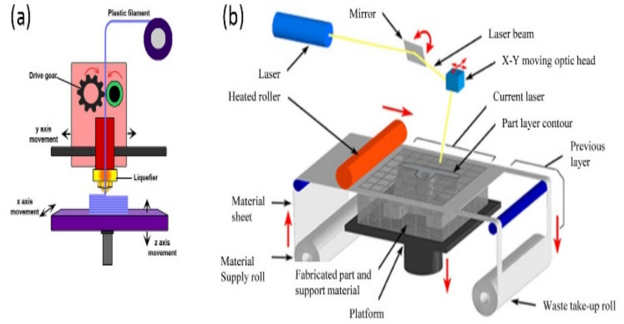


Fig 4. (a) A fused deposition modeling process schematic shows how the platform descends layer by layer along the z-axis as the print head travels in the x-y plane [29], and (b) A typical laminated object manufacturing (LOM) method is shown [30].

2.4.4 Powder-based Technology

The general idea is first to spread a layer of powder, then use a nozzle to spray adhesive onto the area that needs to be formed, let the material powder bond to create the cross-section of the part, and then repeat the powder spreading, spraying, and bonding process, layer by layer, to obtain the final artifact (Fig 5a) [31]. Powder materials, such as ceramic, metal, and plastic powders, are employed [32]. Its quick forming speed, lack of a support system, and ability to produce items with color printing—currently challenging with other technologies—make critical applications in the professional area possible.

2.4.5 Selective Laser Sintering (SLS) Technology

The idea is first to apply a coating of powder material and then use laser beam control to selectively sinter it until it reaches the melting point (Fig 5b) [33]. The sintered part solidifies to form a pattern and then repeats the powder spreading and sintering process until the entire process is completed. The model takes shape. The materials used are metal powder materials (Ni-based alloy mixed with copper powder, Ti, Fe, Cu powder, etc.). It is characterized by good precision and relatively high strength, and the most crucial advantage lies in producing metal products [34]. They are mainly used in high-end manufacturing fields.

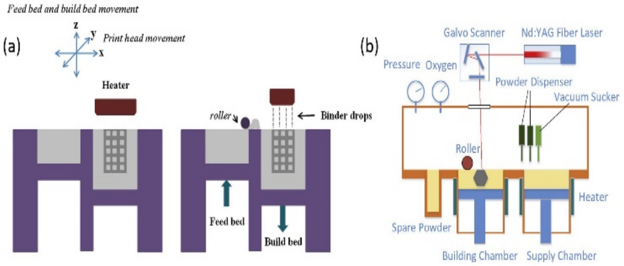


Fig 5. (a) Schematic for a 3D printer that use an inkjet printing technology based on powder, [35] and (b) Multiple material Selective Laser Sintering (SLS/SLM) system schematic diagram [36].

2.5 Polymer materials for 3D printing

The most significant types of polymer materials for 3D printing include photosensitive resins, thermoplastics, and hydrogels. However, other polymer materials, such as starch, sugar, and chocolate, can also be used. Photosensitive resin is one of the earliest materials used in 3D printing [37–39]. It is appropriate for stereolithography (SLA) equipment. To achieve curing, auxiliary substances like leveling agents and polymerization inhibitors can undergo polymerization processes under specified light (often UV light). Photosensitive resin is a classic substance. Similar-principled photoresists, photocurable coatings, and photocurable inks have been extensively used in producing electronics, holographic imaging, adhesives, printing, and medicinal treatments. Photocuring technology is regarded as an environmentally friendly green technology in the coatings industry due to its benefits, including quick curing times, superior curing results, reduced pollutants, and energy savings. The resin used in 3D printing, whose formula is distinct from classic photocurable coatings and inks in terms of composition, has a typical cured thickness of >25 µm, much more than conventional coatings' coating thickness which is typically <20 µm. Free radical polymerization and cationic polymerization are two possible divisions of the polymerization system [40-41]. There are differences between the active groups used and the polymerization method. While cationic polymerization uses the epoxy groups in the photosensitive resin for polymerization, free radical polymerization uses the unsaturated double bonds in the photosensitive resin. The cationic polymerization system has no oxygen inhibition effect, and the curing shrinkage is minimal or nonexistent. The free radical polymerization system has a quick curing speed and low raw material cost. Still, there is a certain amount of oxygen inhibition in the air, affecting the curing and part performance. The photosensitive resin used in 3D printing is primarily a free radical polymerization technique since shrinkage is particularly sensitive to moisture, and the cost of raw materials is expensive. The photosensitive resin mainly uses the acrylate free radical polymerization method for 3D printing. Commercial acrylates come in various forms, and the formulation must be altered to suit different requirements. The following characteristics are typically necessary for photosensitive resins used in 3D printing: stable performance before curing, and typically no curing is required when exposed to visible light; fast reaction speed, as the higher reaction rate can achieve high-efficiency forming; moderate viscosity to match the recoating requirements of light-curing forming equipment; After curing, the material has a minimal amount of shrinkage, which reduces deformation and internal stress during the forming process. It also has a sufficient amount of mechanical strength and chemical stability. In some unique applications, additional specifications may exist, such as low or no ash requirements for photosensitive resin used in casting, no injury to the body requirements for resin used in orthopedics, or implant qualities like biodegradability or toxicity. The industry today offers a variety of photosensitive resins that may satisfy the needs of various sectors. The most popular 3D printing materials are thermoplastic polymers. For 3D printing, common thermoplastic polymers include ABS (acrylonitrile-butadiene-styrene), PLA (polylactic acid), nylon/polyamide (PA), PC (polycarbonate), PS (polystyrene), PCL (polycaprolactone), PPSF (polyphenylsulfone), TPU (thermoplastic polyurethane), and PEEK (polyether ether ketone). The shape of the material used varies depending on the 3D printing technique [42]. Filaments are used in fused deposition modeling (FDM), and powder is used in selective laser sintering (SLS). Since most of the regularly used polymer raw materials in the industry are primarily grains, the silk or powder materials must go through secondary processing, raising the cost of 3D printing consumables. Several organizations are using granules as the primary material for 3D printing equipment. Below, several representative materials are introduced. The most commonly used FDM consumables are PLA and ABS, particularly well-liked due to their affordable pricing [43]. Although ABS is a standard technical plastic with outstanding mechanical qualities, the rigorous 3D printing environment can cause it to warp and emit an unpleasant odor. The plastic PLA is environmentally benign, biodegradable, and prints well. It is a popular thermoplastic polymer for 3D printing and is utilized in many areas, including education, healthcare, construction, and mold making. Furthermore, PLA has strong biocompatibility, and it can be changed by adding hydroxyapatite to create scaffolds for tissue engineering. One of the significant consumables of SLS is PA, a semi-crystalline polymer that may produce high-density and high-strength parts following SLS forming. The PA used in SLS is typically manufactured by low-temperature pulverization and must have good sphericity and particle size uniformity. By incorporating inorganic components such as glass beads, clay, aluminum powder, carbon fiber, etc., PA composite [44] powder can be made. To suit various criteria, adding these inorganic fillers can greatly enhance specific performance characteristics, such as strength, heat resistance, electrical conductivity, etc. A thermoplastic with a low melting point is PCL. The primary applications of PCL filament [45] are in 3D printing and textile engineering. Due to its low forming temperature (80–100 °C), it provides a high level of safety. It is important to note that PCL can be used as a material for tissue engineering scaffolds in biomedicine and has excellent biocompatibility and degradability. Doping nano-hydroxyapatite and other materials can also enhance mechanical characteristics and biocompatibility. Additionally, the shape memory effect that PCL materials offer has some potential for 4D printing [46]. Thermoplastic TPU has a high degree of flexibility. It features an extensive, adjustable hardness range, some wear resistance, and grease resistance. It is ideal for producing industrial parts, individual consumer goods, and shoe materials. Complex porous structures that are challenging to fabricate using conventional forming techniques can be created with 3D printing technology, giving the parts distinctive and customizable mechanical properties of the rubber. The porous structure TPU insole manufactured using the SLS technique now meets market performance and service strength standards [47]. PEEK is a semi-crystalline polymer with a high melting point (343°C), excellent mechanical properties, and excellent biocompatibility. It is currently hot, researched 3D printing material. Young's modulus of pure PEEK is 3.86±0.72GPa. It can reach 21.1±2.3GPa after carbon fiber reinforcement, which is the closest to Young's modulus of human bone. It can effectively avoid the stress shielding and loosening of human bone after implantation of ideal orthopedic implant material. PEEK implants manufactured by 3D printing technology can meet the personalized implant customization needs of patients with different conditions [48]. At present, domestic 3D-printed PEEK implants have achieved good clinical results. Hydrogel is a polymer structure with a cross-linked three-dimensional network, which can absorb and retain a large amount of water (up to 99%). According to different polymer sources, it can be divided into the natural hydrogel and synthetic hydrogel. The former, such as gelatin, agar, and sodium alginate, have high swelling properties and relatively poor mechanical properties, which limit their application range. In the latter, due to the adjustable composition, structure, and cross-linking degree of the hydrogel, the properties of the synthetic hydrogel can be adjusted in a wide range; at the same time, the synthetic hydrogel has good repeatability and can be used for large-scale Therefore, it has received extensive attention from researchers at home and abroad. Traditional hydrogels have been widely used to manufacture contact lenses and wound repair. Hydrogel has broad application prospects in this field as an ideal material for tissue engineering. In addition, a hydrogel can also be used as a sensor material, which takes advantage of its swelling behavior and diffusion coefficient that changes with the surrounding environment. The formation of traditional hydrogels mainly relies on molds, which cannot produce complex structures; the use of 3D printing technology to form hydrogels can not only realize the manufacture of complex shapes but also the manufacture of complex pores and even gradient structures, making 3D printed hydrogels have performance not available with traditional manufacturing methods [49]. In addition, living cells can be added to the hydrogel, making it possible to 3D print human organs. The 3D printing methods of hydrogel include photocuring and Direct Ink Writing (DIW) (Fig 6) [50]. The hydrogel components used for photocuring are similar to photosensitive resins, including solvents, monomers, crosslinking agents, photoinitiators, etc. Inorganic fillers can be added to achieve the regulation of hydrogel properties. Direct ink writing is a more popular form of 3D printing hydrogels. When printing, the hydrogel is injected into the syringe, and the computer is utilized to regulate the syringe's movement and extrusion by the planned structure. The extruded hydrogel heals in response to environmental factors, including temperature, moisture, pH, light, etc. To successfully print 3D objects, it is typically necessary for the hydrogel's curing speed to be quick enough or for its rheological qualities to meet the condition of no deformation during printing. There are a few commercial hydrogel printing materials, most of which are in the laboratory development stage.

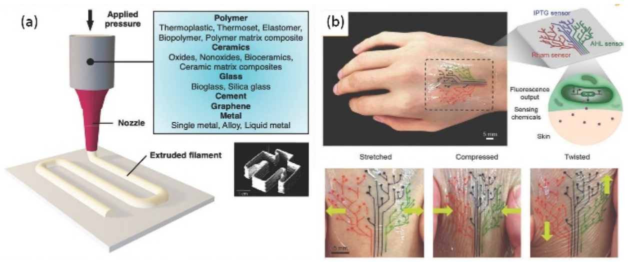


Fig 6. Ink rheology and Direct ink writing (DIW) technology. (a) DIW process depiction in a schematic. The method has drawn a lot of interest since it can handle the broadest variety of materials for creating intricate, multifaceted 3D constructions. One of Cesarano's initial experimental constructs created at Sandia National Laboratory is seen in the inset. The structure was a 20-layer "Thunderbird" built of aluminum oxide that had been sintered "crack-free" to 96% of theoretical density, and (b) Design for the 3D-printed living tattoo that resembles a tree and is used to detect chemicals on human skin (top). Different-colored hydrogels depict the many cell types that are encapsulated, the living tattoo on the skin in various states (center), including stretched (left), compressed (middle), and twisted (right). [50]

2.6 Metal materials for 3D printing

The metal additive manufacturing industry has developed significantly. As an essential material in 3D printing [51-52], metal materials have broad application prospects in industries such as automobiles, molds, energy, aerospace, and biomedicine. Metal materials for 3D printing [53] often come in powder and wire forms. The most popular material for 3D printing is powder, which can be used in a variety of techniques, including laser selective laser melting (SLM), laser engineered net shaping (LENS), and electron beam melting (EBM); wire material is suitable for arc additive manufacturing (also known as wire and arc additive manufacturing, or WAAM), among other techniques [54]. The metal powder must fulfill specific criteria to comply with the 3D printing process requirements. The fluidity of powder is one of the important characteristics of the powder. All 3D printing processes that use metal powder as consumables involve powder flow during manufacturing. The fluidity of metal powder directly affects the uniformity and uniformity of powder coating in SLM and EBM. The powder feeding stability in LENS, if the fluidity is too poor, the printing accuracy will be reduced, or even the printing will fail. The fluidity of the powder is affected by many aspects, such as powder particle size, particle size distribution, powder shape, absorbed moisture, etc. Generally, to ensure the fluidity of the powder, the powder is required to be spherical or nearly spherical, with a particle size of more than 10 to 100 microns; too small a particle size will easily cause powder agglomeration, while too large a particle size will lead to a decrease in printing accuracy [55]. In addition, to obtain denser parts, it is generally desirable that the bulk density of the powder is as high as possible, and it is easier to obtain a high bulk density with graded powder than with powder with a single particle size distribution. Atomization is the primary procedure used to prepare metal powder for 3D printing. The primary atomization techniques are those that use gas and water. The powder created by gas atomization offers superior purity, less oxygen content, controlled powder particle size, cheap manufacturing cost, and high sphericity compared to the powder made by water atomization, high performance, and a unique alloy powder preparation technology's primary development path. The metal wire utilized in 3D printing is identical to the wire used in conventional welding. Theoretically, 3D printing can employ any metal that can be melted under technological conditions. Wire material manufacturing has a far more developed manufacturing process and cheaper material costs than powder materials. Metal materials for 3D printing can be classified as iron-based alloys, titanium-based alloys, nickel-based alloys, cobalt-chromium alloys, aluminum alloys, copper alloys, and precious metals, depending on the type of material used. An earlier and more in-depth investigation of metal materials for 3D printing was done with iron-based alloys. Tool steel, 316L stainless steel, M2 high-speed steel, H13 die steel, 15-5PH maraging steel and other iron-based alloys are some of the more widely used materials. The iron-based alloy is particularly well suited for mold making because it is inexpensive, has high hardness, good toughness, and is easy to machine [56]. An important use for iron-based alloys is the 3D printing of conformal water channel molds. Specially shaped water channels are challenging to process using conventional methods, but 3D printing can precisely control the cooling channel layout to match the cavity's geometry, effectively reducing product defects and lengthening mold life. Due to their extremely high specific strength, outstanding heat resistance, corrosion resistance, and good biocompatibility, titanium and titanium alloys have emerged as desirable materials in the domains of medical equipment, chemical equipment, aerospace, and sports equipment. However, titanium alloy is a common material that requires more work. The high stress, high temperature, and severe tool wear during processing constrain the broad application of titanium alloy. Manufacturing titanium and titanium alloys are a specialty for 3D printing [57]. First, titanium does not readily react with oxygen, nitrogen, and other elements when 3D printing is taking place in a protective atmosphere, and the localized fast heating and cooling of the micro-area also restricts the volatilization of alloying elements; The second is that because, to the high utilization rate of powder or wire materials, complicated shapes can be produced without cutting, resulting in no harm to raw resources.

3. The application of 3D printing technology in the military field

3D printing technologies in the military play a key role by allowing parts to be manufactured quickly and locally and supporting military readiness on the battlefield. China's first aircraft carrier, the Liaoning carrier-based J-15 [58], was the first successful plane to fly from October to November 2012 and is widely used in 3D printing technology. It manufactures the main bearing part out of titanium alloy, including the entire nose gear, and its research and development time is only three years. The development cycle is shortened with 3D printing technology, and participation is not unrelated. In addition, China is developing the J-20 [59] and J-31 [60] 3D printing technologies, which are also used. Researcher at the University of Illinois, USA A 3D miniature curved antenna has been printed. Weihang Magnetoelectric Co., Ltd. of Shenzhen in 2013, the Hilbert satellite GPS antenna was created using 3D printing technology (Fig 7). It worked better than the four-arm spiral antenna. In April 2015, NASA used 3D printing to make the first full-size copper-alloy rocket engine parts [61]. It saved money on the original manufacturing costs. The Chongqing Institute of Green and Intelligent Technology and the Space Application Center of the Chinese Academy of Sciences were set up in April 2016. As the china's first space-on-orbit 3D printer, astronauts can use the machine to print parts in a weightless environment. It can do more flexible experiments on the space station and reduce the number and types of materials kept there. This saves money and makes the station less reliant on supplies from the ground.

Fig 7. (a) The constructed views of the antenna prototype show the antenna construction as (a) made and coated half sections and assembled. [62] (b) EOS produced a baseplate with an all-in-one design for Inconel 718 printing utilizing selective laser melting (SLM), (c) Flex joint of the RS-25 [63] (d) the SuperDraco engine from SpaceX [64] (e) Chinese satellites carried two examples of continuous fiber-reinforced 3D printed parts: a honeycomb structure and a logo for China Aerospace Science and Technology Group Co., Ltd. [65] (f) gradient background for a SpaceX suit 3-D IMPRESSION HELMET The 3-D printed helmet's personalized padding provides valves that control the pressure systems in the suit as well as microphones for communication. Doug Hurley and Bob Behnken in their SpaceX spacesuits [66].

In 2013, the research team [67] demonstrated using 3D printing equipment and moon rock materials to produce related work, making the US "space manufacturing" program a significant step forward. In 2013, the European Aerospace Defense Group used 3D printing technology to manufacture micro-drone prototypes [68] and temporary parts for drones with thermoplastic materials. In 2012, a research team at Washington State University in the United States launched an exploratory project using 3D printing technology to produce metal and ceramic parts for small scientific research satellites. On a national security level, 3D printing is the new war environment (a too-empty environment) that provides technical support. U.S. Army Research Laboratory (ARL) developed 2017 a "Small On-Demand Unmanned Aerial Vehicle Manufacturing System" (ODSUAS) [69] that completes the entire process from design to manufacturing of drones in 24 hours. 3D-printed drones, with the highest flight speed of up to 55 mph, can monitor enemy movements on the battlefield and help with communications and the rapid delivery of military supplies, among other purposes. In March 2017, the 3D-printed grenade launcher RAMBO in the U.S. Army equipment research, development, and construction Cheng Center passed the test. In addition to springs and fasteners, RAMBO's parts are 3D printed using DMLS (Direct Metal Laser Sintering) technology [70]. Although its aluminum receiver and barrel require some processing after printing (the printing time of a person is about 70 hours, and the post-processing takes 5 hours), its entire manufacturing process is still much faster than traditional methods. In addition to the RAMBO ben Body, the researchers also tried to print its ammunition (shell) 3D and one M781 40 mm training wheel. Aerospace is one of the fields where 3D printing technology is widely used, and there have been many successful application cases. Lockheed Martin used Sciaky's 3D-printed titanium alloy parts on the aileron spar of the F-35 fighter jet and conducted flight test verification [71]. The two companies (British BAE & Lockheed Martin) also jointly developed the F-22 fighter's titanium alloy support, which passed the full-life spectrum fatigue test and load test [72]. The British Royal Air Force has successfully tested a Tornado fighter jet with 3D-printed metal parts. The 3D-printed parts include the radio shield of the cab, the landing gear protection device, and the air intake bracket (Fig 8) [73].

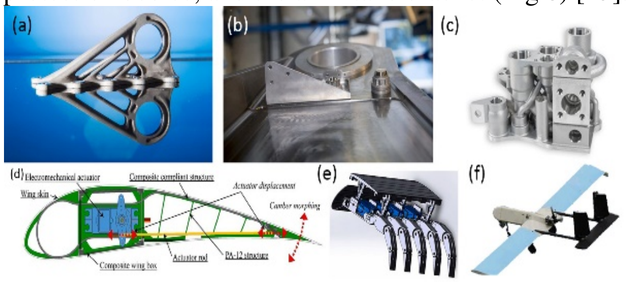
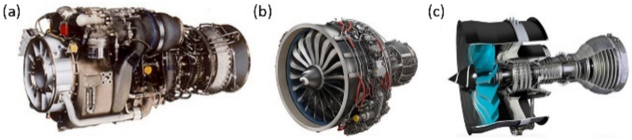


Fig 8. Illustrations of parts manufactured via additive manufacturing: (a) A 3D printed bracket installed on the Airbus A350 XWB [74] , (b) a 3D printed titanium bracket put on the Airbus A350 XWB pylon [75] (c) Installed on the A380 was a 3D-printed valve block that was ten components lighter and 35% smaller than the standard valve block [76], (d) AM applications for changing wings Green-colored, 3D-printed composite structure [77] (e) Adaptive wing segment constructed with 3D-printed parts [78] (f) 3D-printed UAVs with morphing wings that have been in flight [79].

3D printing has the advantages of speed, precision, customization, and less waste. The militaries of various countries favor it. It is considered one of the subversive military technologies of the 21st century, which will have an important impact on future warfare. Military experts generally believe that with the increasing maturity of technology, 3D printing may play a significant role in fostering the transformation of the military-industrial supply chain. Key components of printable core equipment in a report entitled "3D Printing: Advanced Manufacturing Technology Promotes Supply Chain Reform," the RAND think tank in the United States pointed out that 3D printing technology has entered a stage of rapid popularization in military, commercial, and civilian fields [80]. Statistics show that among all users involving 3D printing technology in 13 major countries around the world, the business volume of the military is growing at an average annual rate of 1.2%. Because of this, major military countries have started to make the necessary preparations recently to meet the demands of the rapidly spreading use of military 3D printing technology. The "Mobile Expeditionary Laboratory," based on 3D printing technology [81], is deployed to the frontier battlefield to study how to use 3D printing technology for equipment maintenance and support. As an illustration, the European Defense Agency launched a military additive manufacturing project at the end of 2016 to determine the viability of 3D printing technology in the military field and its potential positive impact. The current state of military 3D printing technology has seen extensive improvement. Some of the core equipment's essential parts can be safely sent to the 3D printer for processing. The precision and durability of the military parts produced with 3D printing technology are significant. Weight reduction increases the lethality and combat effectiveness of equipment and weapons. According to reports, British BAE Systems and Lockheed Martin both employ 3D printing to build vital components for the "Tornado" fighter jet and the F-35 fighter jet, which have passed flight test verification. Military supply chains can change. The report predicts that the development and acceptance of 3D printing technology will lead to significant advancements in the sector of military logistics. The first is that equipment support and maintenance speed has significantly increased. Weapons and equipment on the modern battlefield are at constant risk of harm due to the continuously changing battlefield conditions. Traditional support techniques frequently need to provide the necessary parts promptly, slowing down the rate at which damaged equipment may be repaired. If 3D printing tools are brought to the front lines, the process will move along much more quickly. According to reports, the US military's mobile 3D printing laboratory can quickly transform materials like aluminum, plastic, and steel into the parts they need on the battlefield in Afghanistan. In this way, the front line no longer needs traditional manufacturing and supply chains. Support, logistics, and repair speed will be greatly improved. Second, the development and acceptance of 3D printing technology will facilitate the development of "front-line" logistics assistance. In times of conflict, logistics support troops are typically found behind the lines of battle and bring weapons, ammunition, and other supplies to the front lines. However, their supply lines are susceptible to disruption. These issues are not present with 3D printing. With design drawings of weapons, suitable materials, and advanced printing equipment, soldiers can produce combat materials on the battlefield on demand and truly realize "front-line" logistics support. For example, suppose an outpost in a remote area urgently needs certain key components. In that case, the Air Force can airdrop polymer materials to it and transmit the printing drawing files through the network, and the 3D printer in the outpost can print out the required parts within a few hours. Cyber-attacks pose the greatest threat. Although 3D printing can be used to perfectly "manufacture" various military parts and even overall equipment, this does not mean the technology has become "perfect." 3D printing also has technical weaknesses and is vulnerable to cyberattacks. The essence of a 3D printer is another type of computer, so the security threats ordinary computers face, including viruses and network hackers, will also pose threats to 3D printers. Once a military 3D printer is hacked or infected with a virus, it will have serious consequences. Usually, hackers reprogram successfully hacked 3D printers to make the printed military equipment or parts defective, causing danger in use. For example, if the temperature of the printing material is raised or lowered slightly, its internal chemical structure will change. The printed product has no problems on the surface, but its strength is greatly reduced. If you print critical materials such as nuclear bomb launchers or submarine shells, the slightest change in strength or misalignment of parts will eventually pose a safety risk. In addition to the above problems, cyber attackers may use 3D printers to steal confidential information on military networks. Once an important piece of equipment information is stolen, the enemy will likely manufacture the same equipment or accessories for combat or training, eventually posing a threat to its side.



Figue 9. Military and civilian engines use AM technology: (a) GE CT7-2 engine [82] (b) CFM LEAP engine in airliner use [83], and (c) RR Advance3 [84].

3.1 3D printing military application status: (1) In 2012, the new electron beam 3D printing technology of Sciaky Company of the United States made an important breakthrough by having the ability to process large metal parts. The U.S. Department of Defense and Lockheed Martin plan to use it to produce titanium; high-quality parts and components made of high-value materials such as tantalum and incoloy all meet the requirements in the preliminary inspection. (2) 3D Systems' laser melting technology has made important progress, and the U.S. Air Force will develop 3D printers for printing F-35 fighter jets and other weapon systems on this basis. (3) The maturity of the space 3D printing technology of the American Space Manufacturing Company has reached level 6, and it can demonstrate models or prototypes in space. In November 2012, it won the second phase contract from NASA, raising the technology maturity level to 8, completing the existing system, passing the test and verification, and finally being able to apply to space station maintenance, upgrade and life extension, payload upgrade, and improvement, hardware space manufacturing, etc. In 2014, the first 3D printer was delivered to the International Space Station. (4) As early as 2002, the United States began to install laser-formed titanium alloy parts on fighter jets for testing. However, due to the inability to solve technical problems such as the deformation and fracture of titanium alloys in manufacturing, the United States can only produce small titanium alloy parts and repair the surface of titanium alloy parts. In recent years, the United States has actively researched the production of large titanium alloy parts by 3D printing technology. The U.S. military and military industry companies are cooperating with 3D printing technology companies such as 3D Systems and Sciaky to promote the application of large-scale titanium alloy 3D printing technology in the manufacture of fighter jets. (5) In 2013, the United States began to use 3D printing technology to mass-produce fuel nozzles for jet engines. In terms of using 3D printing technology to produce lightweight materials, the American "Solid Concept" company created the first 3D-printed metal pistol in 2013 that can constantly fire 50 bullets while remaining intact. (6) In terms of maintenance, the United States has begun to deploy maintenance support equipment based on 3D printing technology. The American military deployed two mobile expeditionary laboratories for equipment upkeep and support in July 2012 and January 2013. The mobile expedition laboratory is a 20-foot-long standard container that can be transported to any location by truck or helicopter, using 3D printers and computer numerical control equipment to process raw materials such as aluminum, plastic, and steel into required parts. This move can quickly generate needed parts on the battlefield and even quickly design and produce urgently needed equipment to achieve timely and accurate support. Additionally, the U.S. Army has developed a lightweight, inexpensive 3D printer that can be carried in a backpack to quickly and cheaply create replacement parts in the field.

Fig 10. Applications of additive manufacturing now and in the future in aerospace [42].

Rapid laser prototyping (3D printing) technology [85] has reached the world's leading level. The Beijing University of Aeronautics and Astronautics has mastered using laser rapid prototyping technology to manufacture complex titanium alloy components exceeding 12 square meters and has successfully applied it to developing weapons and equipment. The 3D printing technology of Beihang University and Northwest University has been successfully applied to the prototype manufacturing of several domestic aviation projects. The main windshield window frame and large central wing root rib of the large passenger aircraft C919 [86] independently developed by china, and the titanium alloy main structure of the new fighter jet under design are all manufactured by laser rapid prototyping technology. (9) According to reports, the research and development of the J-10 aircraft took nearly 10 years [87]. After using 3D printing technology, China launched the carrier-based aircraft J-15 within 3 years, directly entering the third-generation carrier-based fighter phalanx. In China's national defense technology and equipment, 3D printing technology has been fully used in the research and development of the J-20 stealth fighter and the J-31 fifth-generation fighter [60]. Some foreign media exclaimed that 3D printers are creating the "Chinese speed" of the Air Force's development. Accelerating the development and application of 3D printing technology is an effective way to compensate for the lack of china's current weapons and equipment design, manufacturing, and maintenance support capabilities, improve research and development efficiency, reduce manufacturing costs, and improve the timeliness and accuracy of maintenance support. China's 3D printing technology is in the leading position in the world in the laser forming of large and complex titanium alloy components. However, the overall level still has a lot of room for improvement. We should focus on the long-term development of weapons and equipment, make overall plans, gather all forces to promote the development and application of 3D printing technology [88], and provide technical support to " be able to fight and win wars." One is to take 3D printing technology as the key to the upgrading of manufacturing industry, integrate military and civilian resources, and develop with the strength of the whole country; the other is to address the current problems, strengthen the core technology research of 3D printing material technology, and change country's core key equipment. The third is to actively explore the application of 3D printing technology in the construction of weapons and equipment and to use the application to guide the development direction and focus of technology. Sophie Caulier et al. [89] examined consumers' sentiments regarding the meal in a real-world military context to develop further insight into the elements that can affect the acceptance of 3D-printed food. The findings indicated that consumers who consumed 3D-printed food regularly became more receptive to it, but they also indicated that other factors were also at play. The level of consumer control, desired level of customization, technological advancements, and applicability of 3D food printing technology are all factors in the success of 3D-printed foods. Identifying potential applications for the technology in the food production sector, the current study examined consumers' opinions of 3D food printing and samples of 3D-printed food in a real-world military setting. The authors primarily looked at the effects of increased knowledge of 3D food printing and frequent consumption of 3D-printed recovery snack bars on soldiers' perceptions of 3D-printed food and 3D food printing technology. The current study's focus was on internal and external factors that influence the acceptance of 3D printed food, including the importance of consumer empowerment, the level of customization that is wanted, the stage of technological development, and the applicability of 3D food printing technology.

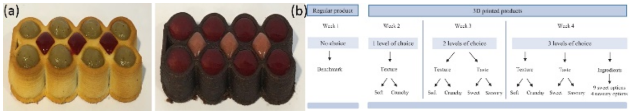


Fig 11. Illustrations of 3D-printed munchies; (a) a crisp vanilla cookie with kiwi and raspberry fillings; a chocolate biscuit with rhubarb and raspberry filling and a crispy texture, and (b) The degree of customization (weekly) was examined using repeated measures analysis to see if and how it affected participants' preferences for the 3D-printed snack bars (generally, in terms of appearance, flavor, and texture), as well as their perceptions of the value of customization and whether they were suitable for use in military applications.[89]

3.2 The impact of 3D printing technology on equipment development

From the drawings and molds to the traditional way of making parts, it has been hard to meet the needs of modern development, which is quick and changes often. Using 3D printing technology, researchers can direct the design to meet their needs, quickly print and test strategies, and make changes. Direct printing can also significantly improve designers' creativity, allowing all kinds of inventions to be less costly to put into practice so that more applications can be obtained. So, 3D printing breaks the old model for research and development and makes room for a new one. In the production and processing process, it can effectively solve the problems of long manufacturing cycles, large cutting volumes, many internal defects, complex mold processing, high costs, significant weight, etc., for a single or large number of pieces. Significantly, it reduces the quality of the structure. The processing advantages of some unique and complex parts are undeniable. Also, using 3D printing to make prototypes will lower the cost of prototypes and make their structure and functions more like the real thing for businesses that make equipment. The optical assembly of molded prototypes will give enterprises and industries more opportunities. In addition, 3D printing technology can fill the imagination of designers. The structure of weapons and equipment is more reasonable, and the function and design are further improved. More research, promotion, and use of 3D printing technology should go into developing equipment. It has a fundamental significance.

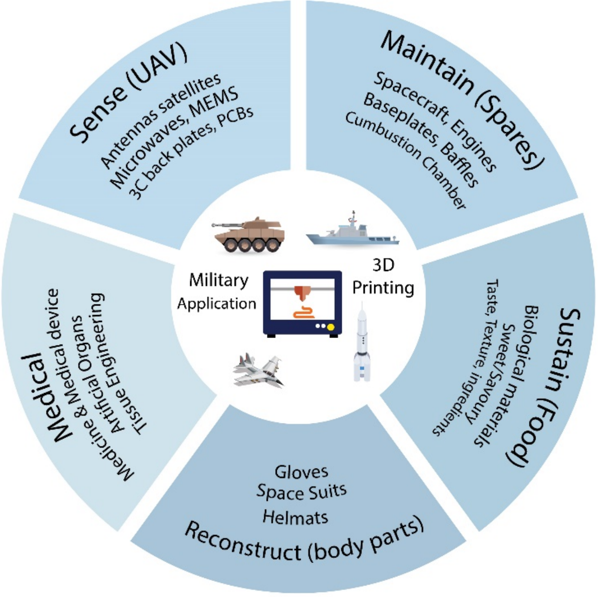


Fig 12. Applications for 3D printing in the military consequently and in the potential.

4. Conclusion

This article explored 3D printing technology and its potential military uses. In addition, it has outlined its difficulties and offered a plan for the military to use 3D printing. At present, 3D printing is in a stage of rapid development. In technology at the same level, 3D printing can already realize metal materials, polymers, and other materials. How 3D printing works and how well it works are similar to traditional manufacturing, and it can meet the needs of most non-industrial applications. With the continuous development of technology, the application field of 3D printing technology is deep. The degree is constantly expanding, and there are broad application prospects. But notice it quickly. We should also consider these advantages: differences, convenience, customization, and flexibility. Aware of its limitations, such as the accuracy of printing, surface quality, and so on. There is still a particular gap compared with traditional machining, especially in strength, stiffness, precision, and other military equipment with high requirements, while equipment costs are high and raw materials are expensive.

To improve the effectiveness of 3D printing methods, metal and ceramic molding procedures still need to be developed. Even higher standards are required for accuracy, strength, stiffness, and roughness in electronic devices. A slight adjustment can cause a significant change in the frequency, band, or loss. Materials for rapid prototyping, which have their drawbacks, are still under development. Few studies have concentrated on the electrical properties, although the mechanical properties have received much attention. A long-term goal is to increase additive manufacturing speed to quickly prototype massive, complicated structures. In conclusion, this study emphasizes how closely research and product development are related and how advancement in both areas is the only way to ensure the acceptance of 3D-printed objects.

Strategic agility, with its attributes of flexibility, adaptability, and speed, is used to meet the challenges of rapid and unexpected change. The same is true for operational agility, characterized by the fast generation of multiple response options to a given challenge and the ability to switch between different options to respond to emerging threats. Additive manufacturing (in the future referred to as AM, also known as 3D printing) technology was born at the right time, which can meet the needs of agility at the strategic and operational levels. In the long run, AM has the potential to be a game-changing technology that can maximize the use of multi-domain (land, air, sea, space, network) integration, resulting in immense flexibility. Face up to reality, the defense challenges of the 21st century cannot be solved by a single solution and can only rely on agility to provide multiple responses. Rapid change poses an insurmountable obstacle to those who lag and a lasting advantage to those who respond quickly. AM technology can guarantee agility. With quick and low-cost design and manufacturing, it can produce single or multiple prototype parts to meet mission needs, including on-site immediate repair and replacement parts. AM technology has the potential to support many defense-oriented missions while generating long-term cost-saving benefits.

Conflict of Interest Statement

The authors confirm that they have no known conflicts of interest that would have appeared to have an impact on the research presented in this study.

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