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3D Printing in Defense

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Abstract:

3D printing, also known as additive manufacturing, is a process of creating three-dimensional objects by adding material layer by layer based on a digital model. It has come a long way since it was first developed in the 1980s. As in other industries, 3D printing is making its case within defense and military fields. The technology is revolutionizing the way militaries around the world procure and maintain their equipment. As 3D printing took off in recent years in the defense sectors additive manufacturing companies have been working to drive economies of scale. The military can benefit from 3D printing since the military personnel are exposed to all sorts of environments around the globe. This paper takes a look at how the defense industry has embraced 3D printing.

Keywords: 3D printing (3DP), additive manufacturing (AM), 3D printing in defense.

INTRODUCTION

Traditionally, a printer is used at home or in the office to print out text and images on paper. This conventional printer prints in a flat two-dimensional (2D) space using the dimensions length and width. A three-dimensional (3D) printer uses length and width but also adds depth to the print. A 3D printer has more manufacturing capacity than a traditional manufacturing machine. It is regarded as a disruptive technology that will change manufacturing. It has been used for decades in the automotive and aerospace industries. The 3D printer is also used by hobbyists, small businesses, creatives, manufacturers, architects, and most importantly contractors to instantly create a variety of products.

The field of defense technology is constantly evolving, and one groundbreaking innovation that has emerged in recent years is 3D printing. This technology has the potential to transform the way missiles are produced. The promise of cost reductions in the production of tools and components for military equipment, to design flexibility and on-demand, on-site manufacturing, 3D printing allows military pundits a lot of liberty. Figure 1 shows how the world's largest concrete 3D printer constructs barracks for the US Army in Champaign, Illinois [1].

The military has always been on the cutting edge of technology, and 3D printing is no exception. The US military has been involved with additive manufacturing technology since 2012 when 3D printers were first deployed in the field by the Army, Navy, and various DoD contractors. 3D printing is being used by military units from different countries around the world. They are creating everything from replacement parts for critical vehicles, ships, and aircraft as well as new designs for safety equipment. It is critical for them to develop the right equipment for defense purposes, a matter of life and death in the battlefield.

The use of additive manufacturing has expanded through medical devices, aerospace, automotive engineering, fashion, construction, and other fields. Numerous 3D printing companies offer ready-made menus of different materials and techniques. Several aerospace and defense companies have already adopted this technology in their operations. The advancement of 3D printing within aerospace and defense is in large part driven by key industry players, including GE, Airbus, Boeing, Safran, GKN, Stratasys, Latécoère, and Moog Aircraft Group. Although the USA pioneered the adoption of 3D printing in defense, the list of countries incorporating this technology continues to grow. Several nations, such as the USA, UK, Spain, Canada, Australia, and France have significantly invested in the use of additive manufacturing for the development of military equipment, vehicles, and weapons. They are pouring billions into 3D printing and related technologies.

WHAT IS 3D PRINTING?

3D printing (also known as additive manufacturing (AM) or rapid prototyping (RP)) was invented in the early 1980s by Charles Hull, who is regarded as the father of 3D printing. Since then it has been used in manufacturing, automotive, electronics, aviation, aerospace, aeronautics, engineering, architecture, pharmaceutics, consumer products, education, entertainment, medicine, space missions, the military, chemical industry, maritime industry, printing industry, and jewelry industry [2]

A 3D printer works by "printing" objects. Instead of using ink, it uses more substantive materials–plastics, metal, rubber, and the like. It scans an object–or takes an existing scan of an object–and slices it into layers, which can then convert into a physical object. Layer by layer, the 3D printer can replicate images created in CAD programs. In other words, 3D printing instructs a computer to apply layer upon layer of a specific material (such as plastic or metal) until the final product is built. This is distinct from conventional manufacturing methods, which often rely on removal (by cutting, drilling, chopping, grinding, forging, etc.) instead of addition. Models can be multi-colored to highlight important features, such as tumors, cavities, and vascular tracks. 3DP technology can build a 3D object in almost any shape imaginable as defined in a computer-aided design (CAD) file. It is additive technology as distinct from traditional manufacturing techniques, which are subtractive processes in which material is removed by cutting or drilling [3].

3D printing has started breaking through into the mainstream in recent years, with some models becoming affordable enough for home use. Many industries and professions around the world now use 3D printing. It plays a key role in making companies more competitive. The gap between industry and graduating students can be bridged by including the same cutting-edge tools, such as 3D printing, professionals use every day into the curriculum. There are 3D printed homes,

prosthetics, surgical devices, drones, hearing aids, and electric engine components. As shown in Figure 2, 3D printing involves three steps [4]. A typical 3D printer is shown in Figure 3 [5].

3D PRINTING IN ARCHITECTURE

While there are now several different types of AM, each forms an object in the same basic way: A programmed machine adds material, layer by layer, until a three-dimensional object is formed. Few technologies are as vigorously hyped throughout the military as additive manufacturing, for good reason: The ability to produce components on demand, at the point of need, will transform logistics, reduce material waste, and enable customization, all at a fraction of the costs and times involved in the manufacturing process than traditionally techniques. New designs can be prototyped and tested rapidly, without having to stand up production lines or create expensive tooling.

Contrary to traditional manufacturing methods, 3D printing offers flexibility and responsiveness, particularly in addressing the needs of the aerospace and defense sectors.

The beauty of additive engineering, design, and manufacturing products is the fact that you have that vital thread from when you first start designing the part, analyzing it, doing topology optimization, light-weighting, printing, finishing and inspecting. While much of the world continues to think of AM technology as a convenient way to make sturdy plastic objects from 3D printers, military personnel at all levels have been pushing its limits far beyond what most imagined possible. The selection of available 3D printable materials for aerospace and defense applications ranges from engineering-grade thermoplastics to metal powders. Speed of use and versatility sum up what makes additive manufacturing different. When there is a need to build something state-of-the-art we do that and are comfortable with the risk. Manufacturing parts through a 3D printer can cut down on time and cost in comparison to ordering specialized parts.

APPLICATIONS

There are countless ways in which the military is using 3D printing to improve the workflow of their service members. Defense professionals have also been using 3D printing to create bunkers, vehicle hide structures, bridges and buildings in various locations around the world to serve to support and house military personnel and machinery at bases as well as in the field. All branches of the US military (the US Army, Air Force, Navy, and Marines) use 3D printing. They are exploring more efficient and effective ways to 3D print anywhere in the field whether on board a ship at sea or at a remote base camp. Some of the common applications of 3D printing in defense industry include the following [8,9]:

1. *Prototyping:* The ability to 3D print a prototype and make adjustments in a matter of minutes is crucial. A prototype can be printed multiple times to the same specifications. Military prototypes can be 3D printed quickly and cheaply. 3D printing technology is being used by the military to create prototypes and design new equipment. Additive manufacturing is an ideal solution for creating quick concept models and prototypes. It is widely used in the defense industry to rapidly produce prototypes without the need for expensive tooling. Design concepts, as well as validation testing, can be done much faster, thereby shortening the product development cycle. For example, 3D printing has made manufacturing weapons become easier, as shown in Figure 4 [10].

2. *Replacement Parts:* Perhaps the most crucial advantage of choosing 3D printing technology over traditional manufacturing techniques lies in spare parts production, enabling highly efficient maintenance and repair of military defense systems. Since the average lifespan of an aircraft can range between 20 and 30 years, making maintenance and repair become important functions in the industry. Now, cut down production time from weeks, and even months, to a matter of hours. The defense industry relies heavily on spare and replacement parts. 3D printing becomes a viable option, as it facilitates the cost-effective and relatively quick production of parts and tools on

demand, helping to maintain an aging fleet without having to order a spare part or to return to a port. As replacement parts can quickly run out of stock, 3D scanning techniques can be used to reverse engineer an available part, which then can be easily replicated via 3D printing. Figure 5 shows 3D-printed spare parts [11], while Figure 6 portrays solder making repair incorporating 3D-printer parts [12].

3. *Structural Components:* 3D printing can make a significant impact in the production of end parts for military equipment. The applications of additive manufacturing here vary, from complex brackets and small surveillance drones, to jet engine components and submarine hulls. The US Army has improved the impact absorption of the Army's combat helmet through 3D printing by incorporating advanced lattice geometries. Figure 7 shows a 3D-printed structural component [13].

4. *Metal 3D Printing*: Companies have used 3D print technology to print defense and military equipment in a variety of metals, irrespective of the complexity of the design. This is a huge shift from conventional manufacturing which rendered many complex designs useless due to its inability to produce it. Now, 3D print military weapons such as guns, rocket launchers, drones, and even missiles can be produced using 3D printing and materials such as steel, stainless steel, aluminum, titanium, nickel alloy, and cobalt chrome.

5. *Plastic 3D Printing:* Plastic 3D printing has proven itself to be critical for the purposes of prototyping, research and development, and restocking in defense. Military operations will be handicapped without supplies such as food, fuel for vehicles, ammunition and tools for repair and maintenance. Materials used include nylon, PC, and Alumide.

6. *Medical Supply:* Another area where the military is using 3D printing is to create medical supplies. This is especially important in combat situations, where time is of the essence. 3D-printed medical supplies can be produced quickly and easily in the field, which means soldiers can be treated faster and have a higher chance of survival in combat situations. Additive manufacturing can also play a key role in the military medical sector by providing customized implants, prosthetics, and medical tooling in the field.

7. *3D Printed Structures:* Defense professionals have also been using 3D printing to create bunkers, vehicle hide structures, bridges and buildings in various locations around the world to serve to support and house military personnel and machinery at bases as well as in the field. The military has partnered with civilian companies to start building 3D-printed barracks to house service members for training missions. They have also been using giant robotic 3D printing to create bunkers, vehicle hide structures, bridges and buildings in various locations around the world to serve to support and house military personnel and machinery at bases as well as in the field. Figure 8 is an example of 3D-printed building [14].

BENEFITS

3D printing has the potential to transform the defense industry, providing new ways to 3D print replacement parts on demand, while reducing production costs for tools and components, and enabling new design engineering possibilities. Other benefits of 3D printing in defense include the following [8]:

1. *Faster Product Development:* 3D printing significantly speeds up the design process, since it requires no tooling. It cuts down production time from weeks, and even months, to a matter of hours. In contrast, traditional manufacturing can take months to produce the necessary tools to create end parts and prototypes. The defense industry can capitalize the technology to bypass costly and time-consuming tooling, thereby reducing the time required for product development.

2. *Freedom of Design:* Designers now have the freedom to cut down on unnecessary features on equipment that drastically helps to reduce overall product weight. The defense industry can take

advantage of 3D printing's ability to produce freeform, optimized objects. Leveraging advanced design tools, design engineers can reduce the number of components in an assembly to just one, and thus greatly simplify the assembly process.

3. *Customization:* 3D printing offers the opportunity to create customized parts, tailored for specific functions. Soldiers can use 3D printing systems to manufacture customized parts on demand. Customizable 3D printable designs are vital to achieving greater levels of agility and flexibility within the military.

4. *On-Demand Production:* A major advantage of 3D printing is that it allows for on-demand manufacturing, which means that militaries can print the items they need when they need them, especially on the battlefield where time is often of the essence and sometimes lives are at stake. With 3D printing, the military can create the parts they need on-site whether that is on base, at the front lines, or at sea. Coordinating logistics and transportation makes up a significant part of any military budget. It is more cost-effective to print custom parts, tools, and spare parts near the point of use, a solution which additive manufacturing provides. This implies that soldiers in remote areas can also use 3D printing to their advantage.

5. *Waste Reduction:* 3D printing reduces material cost for the defense industry and also reduces the waste produce, thereby increasing material efficiency. As the making of defense products requires costly raw materials such as titanium, so when these raw materials are wasted the amount of money that goes in vain hampers budget of the company. Traditional methods of manufacturing defense products are not at affordable for majority of the companies but additive manufacturing definitely saves quite some amount of expenses.

6. *Cost Reduction:* 3D printing eliminates the cost of tooling and setup. This makes the entire process way more economic and feasible. Not only does additive manufacturing makes the production cheaper, but it also saves ample of time. Reduced warehousing costs, higher customization, and feasibility make 3D printing the best fit for the defense industry.

7. *Weight Reduction:* Weight is one of the most important factors to consider when it comes to aircraft design. There are countless ways in which the military is currently working to make lighter weight and safer machinery, equipment and vehicles for use in combat as well as daily operations. It is not unusual for a single soldier to carry between 90 to 140 lbs worth of gear, including weapons, ammo, water, MREs, batteries, and personal protective equipment. Increased weight in transport vehicles, planes, and ships can decrease fuel efficiency and reduce maneuverability and speed. As a result, the military has a lot of interest in developing ways to lower weight without sacrificing performance. The US Army is investigating lightweight metals such as titanium, titanium alloys, and hybrid ceramic tile composites for their next-generation combat vehicles.

8. *Part Consolidation:* One of the key benefits of 3D printing is part consolidation: the ability to integrate multiple parts into a single component. Reducing the number of parts needed can significantly simplify the assembly and maintenance process by reducing the amount of time needed for assembly.

9. *Democratization:* The 3D printing technology has brought democratization.

It highlights that manufacturing homemade, illegal weapons has become more accessible. People for a very long period of time have not been able to manufacture craft weapons. The emergence of 3D printing technology changes everything. People could not manufacture weapons before, and now they can do it due to the 3D printing.

CHALLENGES

Although military prototypes can be 3D printed quickly and cheaply, wider implementation of additive manufacturing for the production of end parts still faces a number of challenges. As with any emerging technology, there are potential challenges related to security risks and vulnerabilities. Other challenges of 3D printing in defense industry include the following [8]:

1. *Quality assurance:* One of the main concerns for the defense industry is quality assurance, as all parts must adhere to stringent performance requirements. The military must be assured of the repeatability and accuracy of the 3D printing production process.

2. *No Standards*: Lack of standards also can be a problem. Speed of use and versatility sum up what makes additive manufacturing different. Currently there are no fully defined industry standards for 3D printed parts in the defense industry. It is crucial to establish a comprehensive set of standards to govern 3D printing processes and qualify printed parts. Materials must also be certified by a defined standard, increasing the developmental work required by DoD to leverage a still immature field to this task. Safety standards must be published and implemented.

3. *Skills Gap:* Although 3D printing has been used within the defense industry for a number of years, there remains an AM skills gap. Further training in the particularities of AM production, designing for AM, maintenance and supply chain management will be necessary to push forward the use wider use of additive manufacturing within the military. The US has been able to cultivate a strong academic foundation and attract global talent in AM, with the US commanding the largest share of the global industrial 3D printer market at 33%. While slightly trailing the US in academic impact, China has made significant strides in the commercial sector.

4. *Digital Security*: If the military is to use additive manufacturing for on-demand, localized production, it will be vital to ensure the security of the digital CAD files. This will require additional digital security measures to ensure files cannot be accessed externally, and digital supply chains remain secure. Ensuring the integrity of the 3D printing process and preventing the production of counterfeit components are crucial considerations in safeguarding national security interests.

These challenges stand in the way of unleashing the full potential of 3D printing for military use.

CONCLUSION

It has been predicted that the defense industry will expand it's arms towards 3D printing in the next 10 years. 3D printing has the potential to fundamentally change how parts are manufactured and delivered. This may have enormous implications for the future of the military supply chain. In an increasingly complex military landscape, 3D printing has the potential to meet key defense needs. The use of 3D printing in the military enables them to be more self-sufficient. With 3D printers, militaries can print replacement parts and components for their equipment, rather than having to rely on outside suppliers.

3D printing technology is revolutionizing the military industry by providing a way to quickly and cheaply produce spare parts, prototypes, and even entire weapons systems. In the future, 3D printing technology will become even more sophisticated and widespread. It will have a transformative impact on the way militaries operate [11]. The future of 3D printing for global militaries certainly looks bright. More information about 3D printing technology in the defense industry can be found in the books [15,16].

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Figure 1 World's largest concrete 3D printer constructs barracks [1].

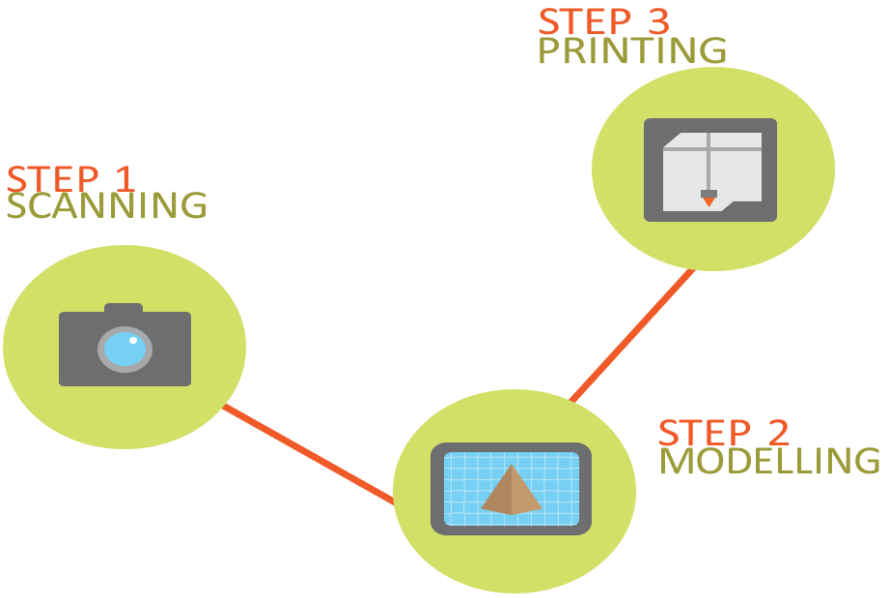

Figure 2 3D printing involves three steps [4].

Figure 3 A typical 3D printer [5].

Figure 4 3D printing has made manufacturing weapons become easier [10].

Figure 5 Army 3D-printed spare parts [11].

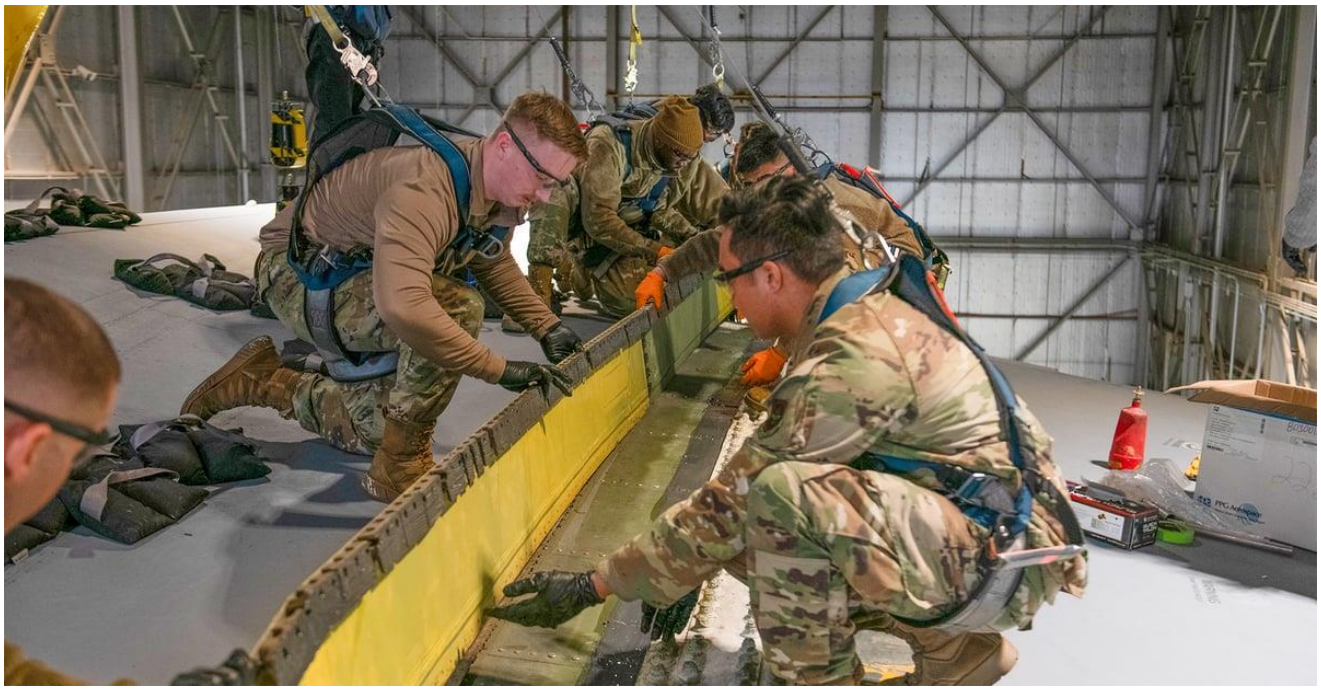

Figure 6 Solders making repair incorporating 3D-printer parts [12].

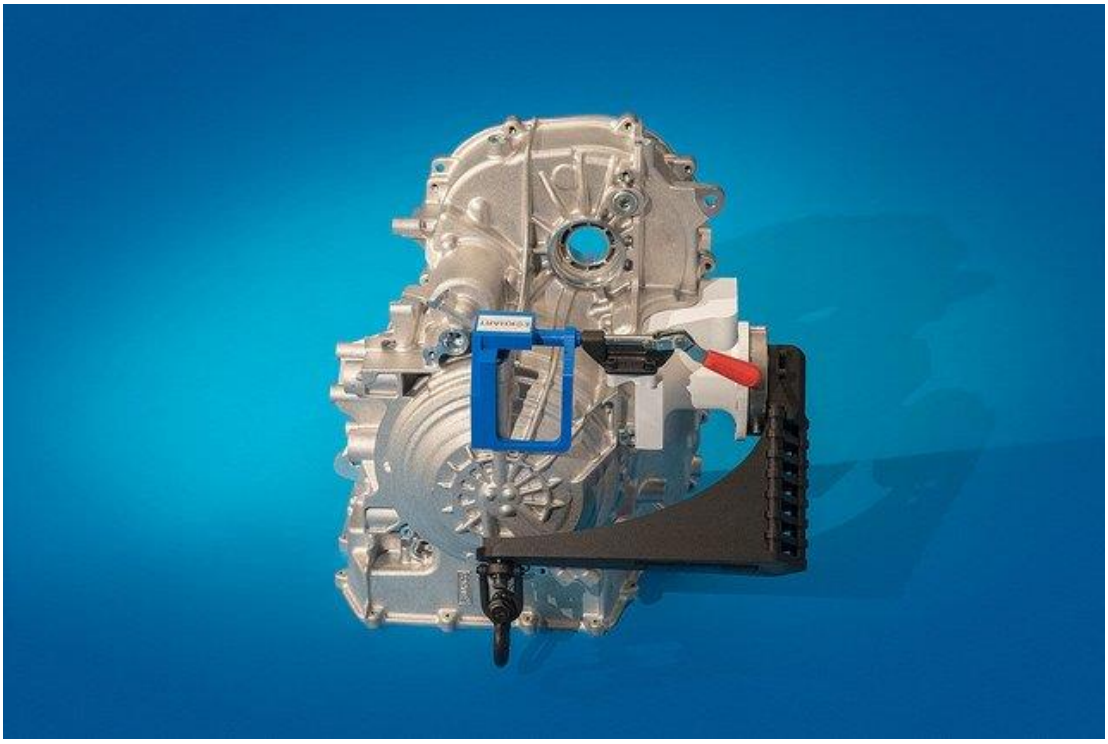

Figure 7 A 3D-printed structural component [13]

Figure 8 A 3D-printed building [14].