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THE USE OF 3D PRINTING IN MILITARY APPLICATIONS

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WYKORZYSTANIE DRUKU 3D W ZASTOSOWANIACH WOJSKOWYCH

Abstract. *The paper presents the current potential of Additive Manufacturing (AM) in the production of devices, replaceable parts, construction infrastructure, medical materials, etc. The authors reviewed and analyzed the development trends in the use of additive manufacturing in technologically leading armies. The analysis of the available information shows that AM in military applications is mainly used in the production of spare parts for "aged" military equipment and for military equipment operated in conditions far away from the sources of supply with "original" technical material means. The aim of the article is to identify the level of development and application of AM technology in the military domain. The article concludes with the thesis that the introduction of AM technology to the logistic support of armed forces will increase its effectiveness, efficiency and resilience of the logistics supply chain, especially in the field of technical combat service support.*

Keywords: *additive manufacturing, AM technology, 3D printing, AM military applications, military logistics.*

INTRODUCTION

Additive manufacturing is a particularly dynamically developing technology in last period of time. The possibility of its use in the defense sector can significantly affect the production of components and parts which are in conventional way not possible or unprofitable for acquire. In addition, this technology also opens up completely new possibilities in terms of securing materials for the repair of military equipment, especially in the conditions of struggle carried out on the area of country or during operations and expeditionary missions.

Currently, in many armed forces (for example: USA, Great Britain, Germany) there is a trend related to the development of additive manufacturing technology using in field conditions to improve operational readiness of military equipment. Due to eliminate shortages of other equipment by producing it directly in field conditions or near the area where operations are carried out, as part of the so-called production on demand.[1]

Considering the dynamic growth of AM applications in the military domain, the aim of the research was to identify the level of development and application of AM technology in the military domain. On the basis of the defined purpose of the work, the research problem was defined as follows: does the current level and scale of the use of AM technology both in industry and in the military domain justify the implementation of this technology to the logistic support of the Polish armed forces.

1 METHOTOLOGY

The authors reviewed and analyzed the development trends in the use of additive manufacturing in technologically leading armies. The research problem was defined as follows: does the current level and scale of the use of AM technology both in industry and in the military domain justify the implementation of this technology to the logistic support of armed forces.

The research was conducted as a review of selected literature from the last 10 years. To define the analysis database, the following keywords were used, which are defined in the DIN standard ISO EN/ASTM 52900 to describe research related to AM: Additive Manufacturing, Additive Manufacturing, 3D Printing (in various variations). In addition, terms not listed in the standard have been added: Rapid Manufacturing, Direct Tooling, Direct Manufacturing, Direct Prototyping, Additive Repair and Reengineering. Based on this analysis, AM technology is presented in two areas: industrial and military. The conclusions from the literature analysis were supported by personal experience of the authors obtained during participation in thematic conferences, seminars and meetings.

2 LITERATURE REVIEW

Since additive manufacturing processes, were invented in the mid-1980s, there has being an upsurge in its use as an improving the speed of production, its flexibility and increasing the resilience of logistics supply chains to disruptions. Since then, hundreds of scientific studies have been published on general 3D printing as well (market and application domain) as on specific technical issues (material, machine and process, digital process chain, methodology). Publications devoted to the possibility of using AM technology in the military domain remain in the vast minority.

[1] The European Military Additive Manufacturing Symposium

AM has the potential to "reduce lead time, cost, material waste and energy usage" (Wu, B., Myant, C., Weider, S. Z., 2017). Industries that may benefit from these advancements include aerospace, automotive, energy, biomedical (Kluczyński J., Śnieżek L., Grzelak K., 2016) and military (Bird, D. T., Ravindra, N. M., 2021; Ficzere, P., 2022; Forecasting Change in Military Technology, 2020–2040). Moreover, AM offers a variety of potentials and advantages, such as the freedom of design, ease and unfettered form of creation (François, M., Segonds, F., Rivette, M., Turpault, S., Peyre, P.; Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T. Q., Hui, D., 2018; [2]), which is seen as an enabler for light weighting (Gibson, I., Rosen, D., Stucker, B., 2015), part consolidation (Yang, S., Tang, Y., Zhao, Y. F., 2015) or function integration (Gorn, M., Cerwenka, G., Gralow, M., Emmelmann, C., 2019).

Significant advantages of 3D printing are small-scale production and facilitating the production of personalized and custom products, as well as low cost of production and less dependence on expensive and dedicated tools (Durakovic, B., 2018, Wu, B., Myant, C., Weider, S. Z., 2017). Reverse engineering and 3D printing techniques may be used as a way of supporting the servicing of production machines (Loska, A., Palka, D., Bień, A., Substelny, K., 2022). Due to its relatively high resistance of the production chain, AM technology can be used in crisis situations (Wysoczański, A., Kamyk, Z., Yvinec, Y., 2021).

In order to determine the main advantages and disadvantages of AM, measures (benchmarking) should be used that will enable comparison, in key correlating measures with classical production (economic, social and environmental). Thanks to them, manufacturing companies using AM technology have the ability to reliably determine the suitability of each additive manufacturing technology in accordance with their business goals (Kai, D. A., Pinheiro de Lima, E., Wesley, M., Cunico, M. W. M., Gouvêa da Costa, S. E. 2026). AM technology is an extremely complex process of the design process and the importance of pre-processing and post-processing activities cannot be underestimated in this complex process of 3D printing (Vayrea, B., Vignata, F., Villeneuvea. F., 2012).

Before AM technology becomes dominant in mainstream manufacturing, a number of process and material challenges need to be overcome. As these are overcome, there will be other challenges such as standardization, inspections, business models, and of course unexpected consequences (Lyons, J.G., Devine, D.M., 2019).

One of the most important aspects of introducing 3D printing technology into production is the expected reduction in production costs. In the available studies, there is no unequivocal answer to the question whether AM is cheaper than classical methods of production (turning, milling, forging, welding) (Laureijs, R E., Roca, J. B., Narra, S. P.,

[2] How are Different Branches of the US Military using Additive? Available at: https://markforged.com/resources/blog/how-are-different-branches-of-the-us-military-using-additive [25 April 2023].

Montgomery. C., Beuth, J.L., Fuchs, E. R. H., 2017). The financial advantages of AM are achieved in the case of prototyping and unit production. Classic methods of large-scale production still turn out to be cheaper.

As COVID-19 pandemic has disrupted the supply chain around the globe, AM technology has come to the fore as one of the most reliable technology to improvise many medical devices (Arora, R., Arora, P. K., Kumar, H., Pant, M., 2020).

AM is seen as a high tech in all areas of military technology.[3] AM technologies can hold great potential for enhancing defense capabilities, such as logistical support to forces deployed in remote or enemy environments. The time between failures and recovery of platform availability, the transport and storage of significant quantities of spare parts can be reduced, with associated cost reductions, reducing the logistical footprint of the operation (Ficzere, P., 2022).

3D printed sensor technology offers high-performance features as a way to track individual warfighters on the battlefield, offering protection from threats such as weaponized toxins, bacteria or virus, with real-time monitoring of physiological events, advanced diagnostics, and connected feedback (Bird, D. T., Ravindra, N. M., 2021).

3 INTRODUCTION TO 3D PRINTING TECHNOLOGY

Despite the fact that three-dimensional (3D) printing technology was invented quite a long time ago, its significant development and commercialization took place at the beginning of the 21st century. The beginnings of 3D printing date back to the 70s of the last century, and Charles Hull is considered the inventor of 3D printing, who patented this invention in 1984. Over the last few years, there has been a significant development of 3D printing technology and it has recently begun to be perceived as a flexible and powerful technique that can be used both in the advanced manufacturing industry and for home use (Grochala, M., Boratyński, W., 2019).

Process 3D is definied as a printing of the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology. In turn, the process itself additive manufacturing (AM) is a mechanism of joining materials to make objects from 3D model data, usually layered. In the literature on the subject, we can also meet such terms as: [4]

- additive fabrication,

[3] Forecasting Change in Military Technology, 2020–2040 [online]. Available at: https://www.brookings.edu/research/forecasting-change-in-military-technology-2020-2040/ [18 May 2023].
[4] Standard Terminology for Additive Manufacturing Technologies. ASTM F2792-12a [online]. Available at: http://web.mit.edu [24 March 2023].

– additive processes,
– additive techniques,
– additive layer manufacturing,
– layer manufacturing,
– freeform fabrication.

The idea of additive manufacturing (3D printing) was and is based on the creation of three-dimensional objects using special printers. A prerequisite for this type of additive manufacturing (AM) is having a three-dimensional computer design. The 3D (Fig. 1.) printer is a kind of device which allows you to create (by printing) objects with precisely defined shapes in the appropriate technology with using different, relevant for its filaments.

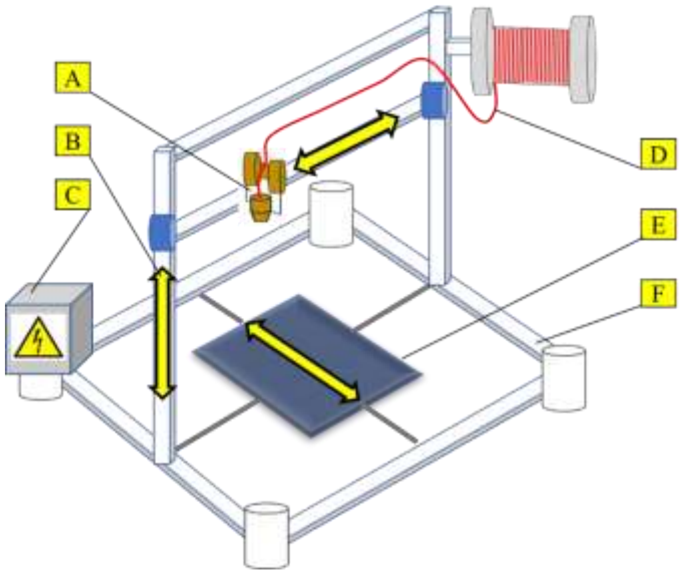


Figure 1 Schematic diagram of the 3D printer with its essential components.
Source: own study G. Stankiewicz.

The 3D printer is built from a number of different elements. Each of them is responsible for the implementation of specific functions (tasks), which is presented below:[5, 6]

A. The print head is the part through which filament enters, melts and then takes the shape of the object that needs to be printed. It consists of two parts, the cold end and the hot end. The cold end is present at the top of the print head, and it is cold, as the name suggests. The filament enters through this end and goes down towards the hot end. A motor is attached with the print head, which allows the filament to travel from the cold end to the hot end. A feeder system can also be referred to as the cold end, which is present on top of the print head. The filament is fed into the print head through this part. There are two types

[5] 3D Printers components - how 3D printers work [online]. Available at: https://solectroshop.com/en/blog/3d-printers-components-how-3d-printers-work-n40 [17 April 2023].
[6] Parts of a 3D Printer [online]. Available at: https://3dinsider.com/3d-printer-parts/ [23 April 2023].

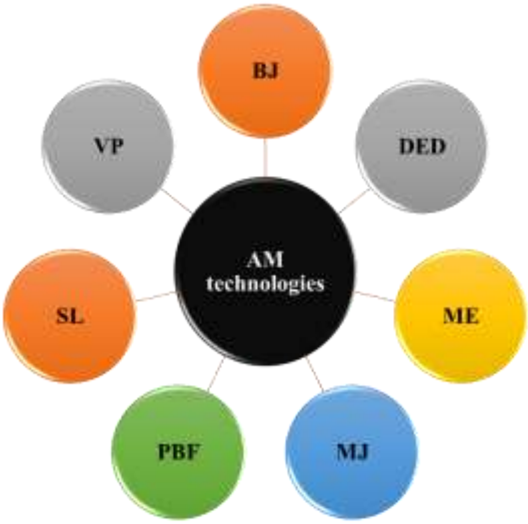
of extruders; single and dual. Single extrusion means you can use only one type of filament while printing your 3D object, that means there is only one nozzle present. On the other hand, dual extrusion means you can use two filaments together while printing your 3D object. Having two filaments means there are either two nozzles present in one printer head, or there are two different printer heads each having a different type of filament. The filament is the material used to print objects on a 3D printer. It's the equivalent of the ink used on a regular office 2D printer. It comes in a spool, which is loaded into the spool holder of the 3D printer, with the end of the filament inserted into the extruder. There are different kinds of filaments, each with their own properties and pros and cons.

B. The motion components of a 3D printer include all such parts that move inside it, in the x, y and z directions, and contribute towards the printing process. The print bed and print head move on the instructions of the controller board, to create a 3D printed object.
C. The power supply unit supplies power to the entire 3D printer. It is the most important part of the printer because without this, none of the other components can function. It can either be mounted on the frame of the printer or reside as a separate unit housed inside a box.
D. The most important component of the 3D printing process is the filament. It is the raw material required for printing three-dimensional objects, analogous to ink cartridges in the traditional inkjet/laser printers. Filaments come in many colors and materials, so you can choose one according to your needs. They are made of materials that easily melt and take the shape of the object that needs to be printed.
E. The print bed is the place where the final 3D object is formed. The filament material is deposited here, just like ink is placed on a piece of paper in the traditional 2D printers. Print beds come in two varieties – heated and non-heated. A heated print bed decreases the temperature difference between the hot filament material and the print bed. This improves the print quality and decreases the chances of warping. As the name suggests, the print bed surface is the top layer of the print bed. It makes it easy to remove the object after it is printed, and saves it from sticking to the print bed. A good printing bed surface must allow the printed object to stick onto its surface properly, and avoid warping issues, which occur when the inner layer of the object remains hot while the outer layer has cooled down.
F. The frame is the chassis of the 3D printer. It holds the other components together and is directly responsible for the stability and durability of the machine. These days, 3D printer frames are made of either different materials like for example acrylic or metal.

For many years, the additive manufacturing industry suffered from lack of categories of grouping AM (3D) technologies, which made it challenging educationally and when communicating information in both technical and non-technical settings[7]. Nowadays we have

[7] Standard Terminology for Additive Manufacturing Technologies. ASTM F2792-12a [online]. Available at: http://web.mit.edu [24 March 2023].

differnt possibility for division of technologies which are used in additive layer manufacturing. They are for example connected with materials which are using in this kind of production. Below (Fig. 2.) Authors presented one such divisions.



BJ	binder jetting	an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials
DED	directed energy deposition	an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited
ME	material extrusion	an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice
MJ	material jetting	an additive manufacturing process in which droplets of build material are selectively deposited
PBF	powder bed fusion	an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed
SL	sheet lamination	an additive manufacturing process in which sheets of material are bonded to form an object
VP	vat photopolymerization	an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization

Figure 2 AM technologies
Source: own work by G. Stankiewicz by on the basis of: [8, 9]

Nowadays the AM technology has different areas of using (Fig. 3.). Key applications for 3D printing include:

- production process in industry - 3D printers deliver inter alia rapid tooling and replacement parts to maintain the production lines. Sometimes AM applications are used to creation of small batch the end-use products to speed up time to market of a product. This offers greater flexibility, enabling businesses to run small batches of goods without the risks involved of manufacturing a larger batch. There is also scope for “printing on the spot” and creating products for the customer while they wait,
- prototyping - low-cost and a lot of types of materials and short lead times make AM technology ideal for the iterative design process. 3D printed prototypes can be both visual (parts that look like a finished product) or functional (parts that are capable of being tested in real conditions),
- science and education - AM equipment and materials enables a variety of education applications – from engaging younger students with basics to providing research labs to work on engineering projects and develop skills in the much modern conditions.

[8] An Introduction to Additive Manufacturing (Also known as 3D printing) [online]. Available at: https://additivemanufacturing.com/basics/ [23 April 2023].
[9] Standard Terminology for Additive Manufacturing Technologies. ASTM F2792-12a [online]. Available at: http://web.mit.edu [24 March 2023].

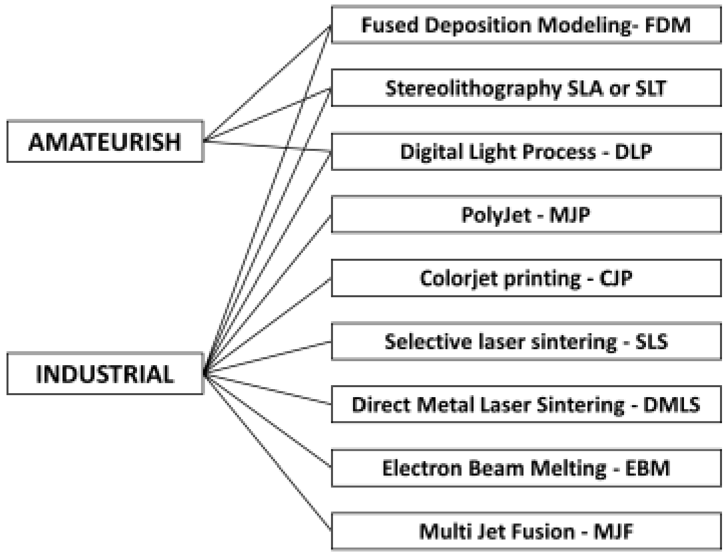


Figure 3 Areas of application of individual 3D printing technologies
Source: own work by G. Stankiewicz by on the basis of: (Ślusarczyk, P., 2017).

We should realize that in additive manufacturing the material properties are very important, because both the raw material has an impact (i.e. the chemical makeup of the polymer, the size and distribution of metal powder particles) and process parameters also have impact on the strength, ductility, porosity and surface finish of the final part. This brings new challenges unique to additive, but also opportunities. When the material properties are determined alongside the geometry, it becomes possible to intentionally and precisely control those properties in specific regions of the part to introduce properties such as porosity, or stiffness, or flexibility. The main classes of materials used (ways of use – Tab. 1.) in 3D printing today are: [10, 11, 12] (Gaweł, T. G., 2020)

- **Polymers** - in 3D printing can be used the popular plastics, including ABS and PC. The other structural polymers can also be used, as well as a number of waxes and epoxy based resins. Mixing different polymer powders can create a wide range of structural and aesthetic materials. The following polymers can be used:
  - ABS (Acrylonitrile butadiene styrene),
  - PLA (polylactide), including soft PLA,
  - PC (polycarbonate),
  - Polyamide (Nylon),
  - Nylon 12 (Tensile strength 45 MPa),

[10] About Additive Manufacturing [online]. Available at: https://www.lboro.ac.uk/research/amrg/about/materials/ [23 April 2023].
[11] Additive Manufacturing Materials [online]. Available at: https://www.additivemanufacturing.media/kc/what-is-additive-manufacturing/am-materials [04 April 2023].
[12] An Introduction to Additive Manufacturing (Also known as 3D printing) [online]. Available at: https://additivemanufacturing.com/basics/ [23 April 2023].

- Glass filled nylon (12.48 MPa),
- Epoxy resin,
- Wax,
- Photopolymer resins,

- **Metals** - a range of metals can be used, including a number of options suitable for structural and integral component parts. Common metals used: aluminum, titanium, stainless steel, Inconel and cobalt chrome, copper-nickel alloys. Metals for 3D printing are generally provided in wire or powder formats, but can also be mixed with other materials,
- **Composites** – this group combine different types of materials by what gaining ground in 3D printing. The composite might be created during the 3D printing process, or that process might begin with a material that already includes an additive,
- **Ceramics** - have low absorption and are difficult to print with laser-based systems. However, solutions relying on extrusion, material jetting and photopolymerization have been developed Ceramic powders can be printed, including:
  - Silica/Glass,
  - Porcelain,
  - Silicon-Carbide,
- **Sand** - even sand can be 3D printed through binder jetting to selectively “glue” the grains together, a technique that is quickly advancing for both prototype and production foundry molds as well as vacuum-form and other types of tooling, for example:
  - Polymer-metal composites, polymer-ceramiccomposites and fiber-reinforced composites,
  - Polymer composites, metal composites, metal-ceramiccomposites and fiber-reinforced composites,
  - Polymer composites, ceramic composites, metal-ceramic composites, fiber reinforced composites,
  - Composite with zirconia, alumina, calcium phosphate.

Table 1 Additive manufacturing process types and attributes, including example materials utilized in machines and typical ways of use

No.	Process	Group of Materials	Ways of use
1.	Vat Photopolymerization	Photopolymers	Prototyping
2.	Material Jetting	Polymers, Waxes	Prototyping, Casting Patterns
3.	Binder Jetting	Polymers, Metals, Foundry Sand	Prototyping, Casting Molds, Direct Part
4.	Material Extrusion	Polymers	Prototyping
5.	Powder Bed Fusion	Polymers, Metals	Prototyping, Direct Part
6.	Sheet Lamination	Paper, Metals	Prototyping, Direct Part
7.	Directed Energy Deposition	Metals	Repair, Direct Part

Source: own work by G. Stankiewicz by on the basis of: [Scott, J., Gupta, N., Weber, Ch., Newsome, S., 2012).

4 DEVELOPMENT AND UTILIZATION OF 3D PRINTING IN ARMED FORCES – SELECTED EXAMPLES

As mentioned above, 3D printing is increasingly used in almost all industries and beyond. The armed forces of many countries, based on the advantages of additive manufacturing technology, integrate 3D printing into their activities. The adopted solutions, which are still being developed, vary depending on the functioning of the armed forces of a given country and its technological potential. There are countries that have been using AM technology in the military sector for many years: the USA, Great Britain, Germany, Norway and Australia. There are countries that started their adventure with the use of 3D printing in the defence sector just a few years ago: Italy, Spain, the Czech Republic and Portugal. There are also countries that have not introduced AM technology to support the operations of the armed forces. These countries include, among others, Poland. The current state of development and the use of 3D printing in the armed forces of selected, technologically leading armed forces are presented below.

4.1 3D PRINTING TECHNOLOGY IN THE US MILITARY

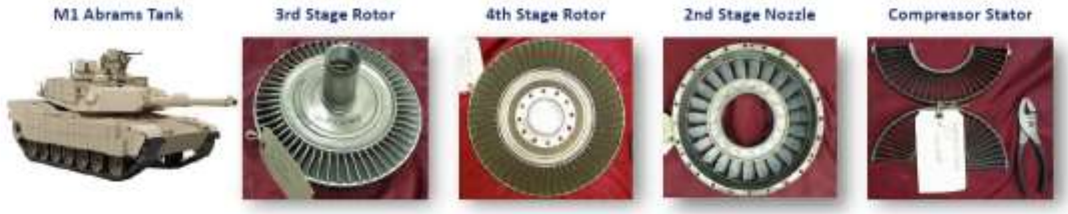
The US military has been using AM technology since at least 2012, when 3D printers were first deployed by the Army, Navy, Air Force and Marines. However, the wide use of 3D printing in the US military began in 2016. Since then, the military’s ongoing use of AM has grown significantly, evolving from basic prototyping to end-use parts in vehicles, planes, weapons, gear, shelters, and more. All of the US military branches using 3D printing technology. Additive manufacturing projects across the US military can be categorized into three basic areas: [13]

1. Maintenance and Sustainment:
   - manufacture of parts typically produced using conventional manufacturing,
   - AM repair of conventionally manufactured parts (Fig. 4.),
   - manufacturing aides for support to conventional manufacturing,
   - Prototyping for rapid innovation and reverse engineering.
2. Deployed and Expeditionary:
   - manufacturing of parts typically produced using conventional manufacturing,
   - AM repair of conventionally manufactured parts,
   - prototyping for rapid innovation and reverse engineering.

[13] Final Report. Department of Defense USA, Additive Manufacturing, Roadmap [online]. Available at: https://www.aimhigherconsortium.org/shared-files/1298/Final-Report-DoDRoadmapping-FINAL120216.pdf [18 May 2023].

3. New Part/System Acquisition:
- new parts/systems designed for AM and manufactured using AM,
- manufacturing aides for support to conventional manufacturing,
- prototyping for rapid part/system development.

Selected 3D printing applications across the US Military are presented below. In 2020, the U.S. Army needed more hatch plugs: devices mounted on combat vehicles to help soldiers see during low-light missions. The original vendor had discontinued the part, and the replacements would require a three-month lead time and cost $10K to produce. The Army used additive manufacturing to solve the problem. In a few short days, they 3D printed two versions of the part using different materials at a fraction of the cost.[14]



Material	Inconel 713	Inconel 713	Inconel 713	321 Stainless
New Cost	$ 8297	$ 5485	$ 6032	$ 910
Repair Cost	< $2,000	< $2,000	< 2,250	< $300
Savings/Part	> 75%	> 60%	> 60%	> 60%

Figure 4 Example: US Army repair of components from Honeywell AGT 1500 gas turbine engine
Source: [15]

The US Army in 2021announced that is going to build the world's largest metal 3D printer. The U.S. DEVCOM Army Ground Vehicle Systems Centre is working to build the printer with the help of ASTRO America, Ingersoll Machine Tool, Siemens, and MELD Manufacturing at Rock Island Arsenal – Joint Manufacturing and Technology Centre. The printer will be part of the Jointless Hull Project with the end mission being to print monolithic (one-piece) hulls for combat vehicles. When it was announced, it was estimated that the project would take around 14 months and the end printer would be capable of printing metal parts that are 30 feet long, 20 feet wide, and 12 feet high (Ficzere, P., 2022).

ITAMCO (Indiana Technology and Manufacturing Companies), has developed a runway for military expeditionary airfields using additive manufacturing. These runway mats are an essential component of Expeditionary Airfields (EAF). Their function is to be implemented on weaker ground surfaces to allow military aircraft to land and take off. Before that, a portable runway made of aluminium planks was used, but as it became outdated, the army needed to find an innovative solution. The M290 3D printer from the German company

[14] How are Different Branches of the US Military using Additive? [online]. Available at: https://markforged.com/resources/blog/how-are-different-branches-of-the-us-military-using [25 April 2023].
[15] OPTOMEC presentation, AM Village 2nd preparation meeting, Prague 12-13.04.2023

EOS was used to create a much lighter and more durable model for the U.S. Air Force's military equipment [9]. Moreover, the Airforce Lifecycle Management Center regularly uses 3D printing to manufacture obsolete parts for a number of legacy fighter jets including fleets of B-52s, the massive C-5M Super Galaxy, and the B-2 Stealth Bomber.

In 2017, additive manufacturing was used by the US Navy in order to create submarine parts. The US Navy and Naval Sea Systems Command (NAVSEA) are exploring ways to use AM to design, print, approve, and install critical or obsolete parts while at sea. This will allow crews to 3D print parts and tools on-demand to reduce part production costs and repair time. A recent example can be seen aboard the USS Tulsa where Navy sailors now have access to 3D printing technology and they are trained how to use it. The crew members were taught how to set up, operate, and maintain 3D printers. They were also taught computer-aided design techniques and how to use precision scanning equipment. Once at sea, they will have the opportunity to practice their new skills on the ship by 3D printing various components (Clemens, M., 2023). In 2022 the US Navy opened an Additive Manufacturing Center of Excellence in Virginia, where they hope to train young engineers on 3D printing technologies and to develop the use of the processes in order to scale them for big picture use.

4.2 3D PRINTING TECHNOLOGY IN THE BRITISH MILITARY

The British military, like the US military, uses 3D printing technology in all its military branches and in similar circumstances (the military forces of both countries are expeditionary in nature). Particularly noteworthy in the use of AM technology in the British Army is the production, using 3D printing, of replacement parts for military vehicles in service. UK defence supplier Babcock International Group has introduced its first 3D printed metal parts for the British Army's Titan and Trojan fleets. This marks the first time that a UK defence supplier has produced metal-based 3D prints to extend the operability of the service's armoured vehicles. The metal printed components form part of the fleets' periscope system, which enables the Titan and Trojan operators to have complete visibility of the surrounding environment. 3D printed metal parts for the British Army's Titan and Trojan fleets is a significant step forward in the use of additive manufacturing in the UK defence industry. It demonstrates the potential of 3D printing to address technical and commercial obsolescence, as well as the ability to rapidly manufacture parts to support operations.[16]

The British Army will deploy SPEE3D's metal cold-spray printing for unplanned repairs via the purchase of an XSPEE3D printer and a two-year contract to provide training courses for Royal Electrical and Mechanical Engineers. One feature that makes the XSPEE3D well suited to this application is that it's built into a customized shipping container that measures 20 feet

[16] British Army Gets AM Parts for Armored Vehicles, 12 Jan 2023 [online]. Available at: https://3dprinting.com/news/british-army-gets-am-parts-for-armored-vehicles/ [25 April 2023]

long, 8 feet deep and 8 feet high and contains both the printer and the necessary auxiliary equipment (Fig. 5.). It can produce parts as large as 1,000 mm x 700 mm and up to 40 kg in weight, with a deposition rate of up to 100 grams/minute via cold-spraying and it is compatible with a variety of alloys, including aluminium 6051, aluminium bronze and copper (Wright, I., 2023).

Figure 5 Containerised metal 3D printer
Source: [17]

The UK and US army have also collaborated in the use of 3D printing to improve battlefield capabilities, as part of what is known as Project Convergence. Thanks to this project the British Army were able to contribute towards the manufacture of replacement parts for the US army using a 3D printer. The U.S. Department of Defence via the Ukraine Security Assistance Initiative are to provide Ukraine with seven of WarpSPEE3D printers. These machines will be deployed near the frontlines, with a primary focus on the rapid production of critical repair parts for a variety of armoured platforms and aging military equipment systems. Making Ukraine the latest defence force to use SPEE3D technology to produce critical replacement “parts of consequence” in the field at the point of need.

Figure 6 Containerised metal 3D printer, Source:[18]

[17] SPEE3D Will Work With British Army To Develop Their Additive Manufacturing Capabilities [online]. Available at: https://www.spee3d.com/resources/?resource=brochures [28 April 2023] and Metal Parts on the Frontline: SPEE3D's Impact on Ukrainian Military Operations [10 October 2023].

[18] SPEE3D Will Work With British Army To Develop Their Additive Manufacturing Capabilities [online]. Available at: https://www.spee3d.com/resources/?resource=brochures [28 April 2023] and Metal Parts on the Frontline: SPEE3D's Impact on Ukrainian Military Operations [10 October 2023].

4.3 3DPRINTING TECHNOLOGY IN THE GERMAN MILITARY

The German Armed Forces started using 3D printing in their operations in 2016 initiating the research phase. This was followed by parallel activities in general 3D printing approach and the testing and trial phase. In 2020, the Customer Product Management Project was launched in the Bundeswehr and together with it the implementation phase was started. From 2023, the phase of using 3D printing technology in the German Armed Forces is being implemented. The multi-criteria approach to operational modelling of the use of AM in German Armed Forces and the time dependence of German Armed Forces activity in the AM field is presented in Fig. 7.

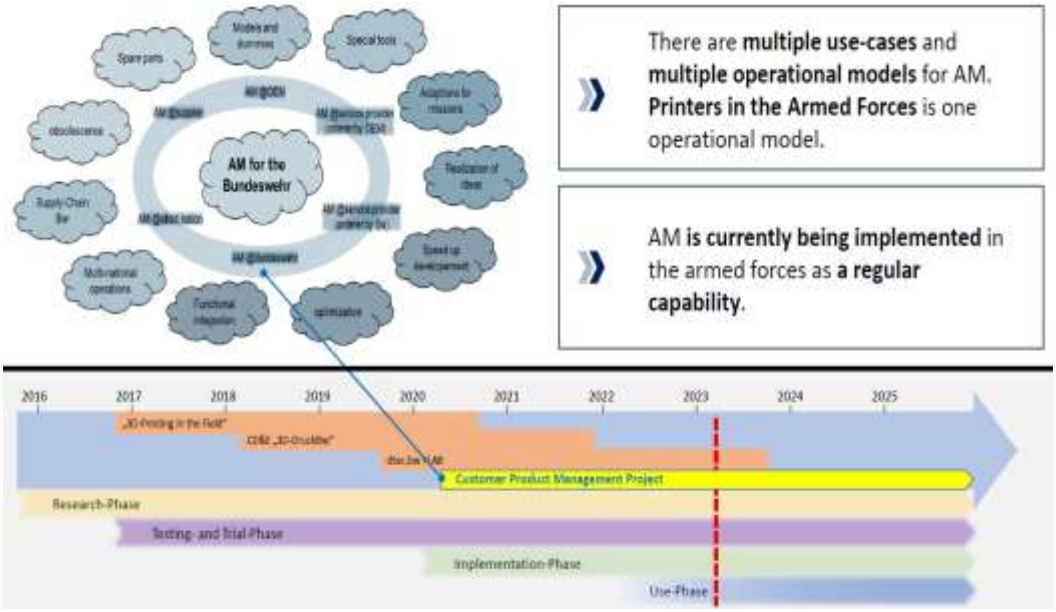


Figure 7 DEU activities in the field of additive manufacturing. Source: [19]

Activities of German Armed Forces in the field of 3D printing are accompanied, coordinated and supported by the 3D Center of Excellence for materials and constructions methods (WIWeB). In a pilot project, WIWeB has rebuilt a steel spare part for the Weapon System WIESEL. It is a part from the undercarriage and it is used to attach the track wheels to the tank hull.

In the framework of the dtec.bw-project FLAB-3Dprint a high tech laboratory was set up at the University of the German Armed Forces in Munich for intensive research activities in the area of additive manufacturing.3D printing was tested in action by German Armed Forces at a remote repair base in Mazar-e Sharif. During this test parts with low complexity can be constructed in the field by soldiers. The construction of complex parts was possible with reach back to experts from Germany.

[19] Bundesministerium der Verteidigung presentation, AM Village 1st preparation meeting, Ede, Niderlands, 22-23 February 2023.

The Luftwaffe has also been working with AM technology for some time and has already tested various use cases for practical application and made them suitable for small series production. More over, the AM technology was successfully tested on a seagoing unit. Among others things, test were run to determin how maritime specyfic environmental influences (e.g. sea state, vibratioons of the drivetrain, salty air) affect 3D printing.

4.4 3DPRINTING TECHNOLOGY IN THE PORTUGUASE MILITARY

The Portuguese army is constantly developing 3D printing technology capabilities. The latest project dedicated to additive manufacturing is the project titled Army Logistic Support Trough Additive Manufacturing (implemented in 2020 - 2023). The main goal of the project is the production of dual-use components (maintain and sustain operational capability focusing deployed contingents and support non-military entities). The project proposed a concept of logistic procedures using 3D printing technology in relation to all levels of logistic support. So far additive Manufacturing Capability implemented in the Maintenance Units (General Support Maintenance and Depot Maintenance) and Deployed Contingents (CAR & Romania).

CONCLUSION

The use of 3D printing technology, acquiring knowledge and practical experience in the field of this technology is especially important from the point of view of the functioning of the armed forces in the future, because additive manufacturing will certainly be one of the factors increasing the repair and maintenance capabilities of military equipment.

It should be assumed that certainly, in the foreseeable future, that armed forces will implement a variety of additive manufacturing techniques, equipment and materials in all its services. This will involve a number of procedural and organizational challenges concerning, for example, how to create databases with digital versions of components and parts, 3D scanning, creating mobile solutions, etc. In addition, attention should also be paid to the need to properly prepare personnel to operate 3D devices, as well as to perform activities as part of extensive programming using IT systems dedicated to additive manufacturing.

In the authors opinion, there is no doubt that the introduction of AM technology to the logistical support of armed forces will result in an increase in the effectiveness, efficiency and resilience of the supply chain, especially in combat service support.

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