3D Printing – Revolutionising Military Operations

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Abstract:

3D Printing has proven to be an innovative and revolutionary piece of technology with potentially significant applications for the military. In this essay, the author explores its technology, applicability and challenges before proposing a framework for our army to undertake 3D Printing. Firstly, he gives a brief overview of the technology behind the printing process and the various printing methods. Next, he highlights the abundance of possible military applications of 3D Printing, including the production of military equipment both during peacetime and on the battlefield for immediate use. Other uses include protective armour for soldiers, prosthetics, surveillance tools and even food. However, given the nascent stage of technology, there are challenges that need to be addressed such as Intellectual Property rights, liability, occupational health and safety, cost and quality standards. The author concludes by suggesting a framework to mitigate these challenges, which includes creating a task force to study the feasibility of this technology and disseminate 3D Printing-related knowledge. There is no doubt that the prudent use of 3D Printing technology will yield innumerable benefits for our army.

Keywords: 3D Printing; Invention; Technology; Military Applications; Quality

INTRODUCTION

> *"3D Printing is already shaking our age-old notions of what can and can't be made."*
>
> *– Hod Lipson, Associate Professor of Mechanical Engineering, Cornell University*[1]

It has often been said that necessity is the mother of invention. This leads us to see inventors as problem-solvers, doing what they do to overcome problems and challenges. However, this is not always so in the modern world. Instead, invention seems to be the mother of necessity, where new products can create needs that we have never felt before. The long lines that accompany each iPhone release are evidence of this. Throughout history, we have seen many daily necessities that originated from military inventions, including Global Positioning System (GPS) technology, microwave ovens and the Internet. However, we now see an innovative and game-changing technology from the manufacturing industry that could become a necessity for the military—Additive Manufacturing (AM), or commonly known as 3D Printing.

3D Printing, which manufactures a 3D solid object from a digital model, is a form of Rapid Prototyping (RP) technology that enables speed-to-market. 3D Printing is currently used to produce a plethora of commercial and industrial products and can potentially have significant military applications. Lieutenant Commander Michael Lienza from the United States (US) Navy was enticed by the

technology after personally seeing how one broken part could hold an aircraft back from a combat mission and affect military readiness. He said, "For the Navy, the technology promises to shift inventory from the physical world to the digital one...instead of actual parts, a ship might carry 3D Printers and bags of various powdered ingredients, and simply download the design files needed to print items as necessary."[2] With its potential to be a game changer for the military, this article thus explores its technology, applicability and challenges before proposing a framework for the military to undertake 3D Printing.

3D PRINTING TECHNOLOGY REVOLUTION

> *"We have 3D printing, a machine which can print spare parts, print models, print toys, print pistols, print body parts, organs; print things which can make a difference to our lives."*
>
> *– Prime Minister Lee Hsien Loong*[3]

The increased competition of manufactured products in the world has made it vital for new products to reach the market as early as possible.[4] 3D Printing, which manufactures a 3D solid object from a digital model, is one such method to enable speed-to-market. Although it was initially used for the purpose of RP during the early 1990s, advances in technology have allowed further applications in the area of industrial manufacturing, aerospace engineering as well as biomedical replacement. Industry interest in 3D Printing has grown with increased support from the private sector, while the Singapore government has also announced the allocation of S$500 million over the next five years to boost capabilities in advanced manufacturing, with 3D Printing a key area.[5]

Printing Process

3D Printing is the process of building a three-dimensional solid object from a digital model. The printing process is akin to that of printing a typical document, in that it requires an input file (3D model) and a printer. The 3D models of the object to be printed would firstly need to be created either through Computer-Aided Design (CAD) programmes or 3D scanners. The 3D Printer subsequently builds the component by adding successive layers of material, based on the layers defined by the file. However, due to the quality of printed components and the support structures that may be built as part of the manufacturing process, there is a need to perform additional post-processing on the 'printed' product to ensure usability. There may also be a further need to subject the produced part to testing and qualification to ascertain that the part produced conforms to its

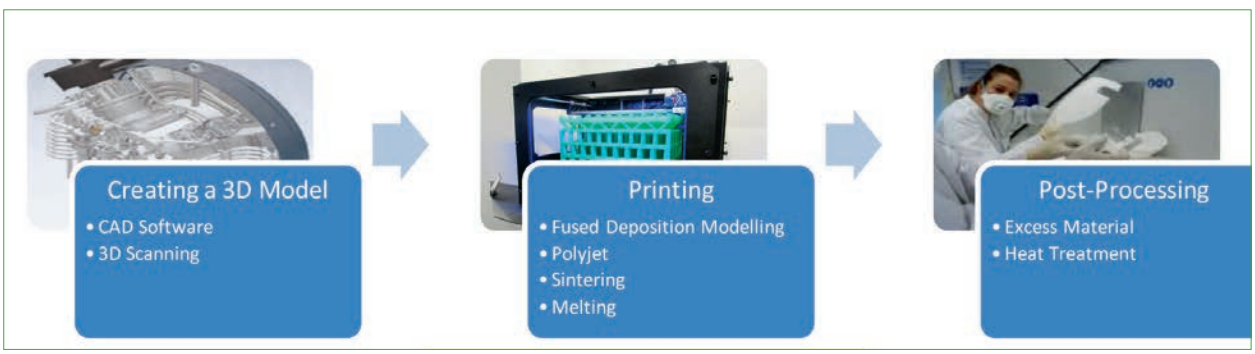


Figure 1: Additive Manufacturing Process.

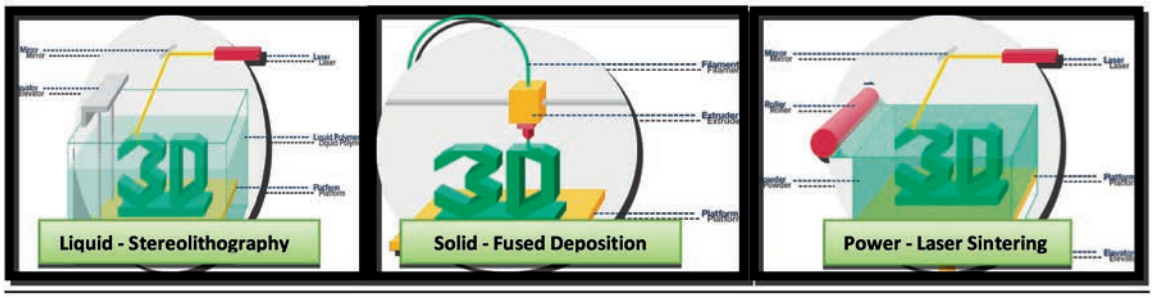


Figure 2: 3D Printing Methods.

requirements. It typically consists of three processes which are illustrated in *Figure 1*.

Printing Methods

There are several categories of 3D Printing methods currently available in the market, with each differing in the way it produces the layers of materials to be added and types of materials that are suitable for them. They are typically classified by the material that the prototype is built with and are broadly categorised into: (1) liquid based; (2) solid based; and (3) powder based. Examples of 3D Printing systems under each category are shown in *Figure 2*.

POTENTIAL MILITARY APPLICATIONS

Imagine an operation in which you are a lone soldier tasked to capture a terrorist in a building. You first despatch your 3D-printed drone to scan

Figure 3: Potential 3D Printing Military Applications.[6]

the building. Upon confirmation of the terrorist's location, you enter the building and engage your target. As you move towards him, he shoots at you. However, your 3D-printed armour is able to protect you and fully absorbs the shock. You are then able to counter him with your 3D-printed gun and take him down. As you head back, your vehicle breaks down. However, you are able to turn it around by printing the malfunctioning part, using your portable 3D Printer. While the depicted scenario is hypothetical, 3D Printing may potentially fulfil the following military applications shown in *Figure 3* and elaborated in the following paragraphs.

Maintain – Peacetime

3D Printing can allow Just-in-Time and on-demand production of prototypes for trial purposes, before full-scale production proceeds. Due to the low tolerances of the 3D Printing process, complex components that used to require difficult machining and assembling can be manufactured at once. This can potentially allow Military System Managers to rapidly develop and implement innovative solutions to platforms, boosting their performance and safety. It has been reported that parts manufactured through 3D Printing, including protective covers and support struts, have been used on the Royal Air Force's (RAF) Tornado fighter jets.[7] Furthermore, militaries with smaller fleets may face difficulties in prototyping potential modifications or parts to existing platforms, since minimum order quantities may not be met to be economical. 3D Printing can

Figure 4: A Complex Gear System Produced Using 3D Printing without supporting assemblies.

Display of one of the REF's Expeditionary Labs.[8]

Annette LaFleur, team leader for NSRDEC's Design, Pattern and Prototype Team.[9]

therefore help mitigate such potential difficulties through Just-in-Time and on-demand production. In addition, 3D Printing can overcome the issue of obsolescence which poses a challenge to the long-term maintenance of the military systems through on-demand manufacturing of obsolete components.

With the forward deployment of 3D Printers in the Area of Operations, it is possible for maintenance personnel to manufacture components for immediate use. This can thus help reduce the load that is carried by maintenance forces, which in turn reduces the logistics tail.

Maintain – Operations

Lastly, the on-demand nature of 3D Printing can be applied to the battlefield as well. With the forward deployment of 3D Printers in the Area of Operations, it is possible for maintenance personnel to manufacture components for immediate use. This can thus help reduce the load that is carried by maintenance forces, which in turn reduces the logistics tail. This concept has, in fact, been implemented by the US Army's Rapid Equipping Force (REF), through the deployment of their Expeditionary Lab-Mobile (ELM) in Afghanistan. The ELM is a 20-foot container equipped with a 3D Printer and other workshop equipment and has allowed the US Army to produce items from simple canteens to replacement parts.[10]

Protect

Researchers at the US Army Natick Soldier Research, Development and Engineering Centre (NSRDEC) are currently incorporating 3D Printing into the uniform design process. It is envisaged that 3D

Printing could play a major role in the production and advancement of the clothing and armour worn by soldiers, both on and off the battlefield. For one, there would be less stitching and seams required in garments. Clothing could be catered to the exact size of a particular solider, while design programmes could determine how to print each piece with the least number of seams and stitches as possible. Such an accomplishment could be a boost to the comfort of a soldier, especially during long, tough missions. Other potential applications could also include the printing of ballistic materials for armour, in precise shapes, making it less expensive and more efficient for a soldier's protection.

Reconstruct

In the past, soldiers who were wounded on the field would have to continue with a disfigured arm or face. Now with 3D scanning technology, the soldier can do a 3D scan before he or she is deployed. This would ensure all physical features are saved on file and should the soldier come back wounded, his 3D data can be extracted and used to build a prosthesis that is exactly how he used to look instead of sculpting.[11] Researchers have also been able to 3D print custom facemasks of a patient's face out of a material called Polycaprolactone (PCL). They are then able to generate skin over the custom mask by depositing a collagen-based wound matrix, allowing for the skin to grow in a pre-determined shape and thus producing a near-perfect fit for the patient.[12]

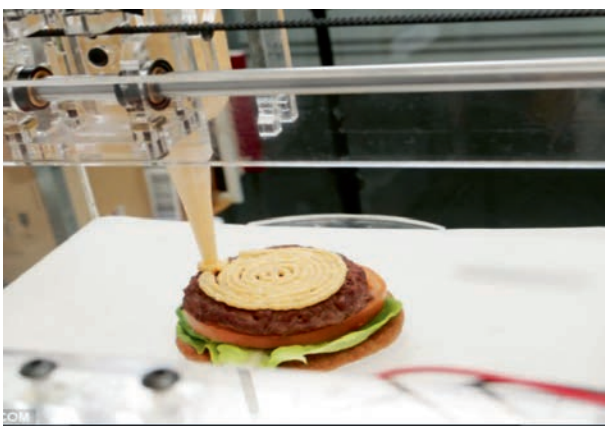
Sustain

Army researchers are currently investigating ways to incorporate 3D Printing technology into producing food for soldiers. Currently, most 3D Printing applications for food consists of a paste that comes out of a printer and is formed into pre-determined shapes. Food technologists at the US Army NSRDEC hope to create nutrient-rich foods that can be consumed in a warfighter's specific environment on or near the battlefield. Nutritional requirements could be sent to a 3D food printer so meals can be printed with the proper amount of vitamins and minerals, thus meeting the individual dietary needs of the warfighter.[14]

3D printed body parts created by researchers at Wake Forest Institute for Regenerative Medicine.[13]

Sense

The University of Maryland's Maryland Robotics Centre was contracted by the US Army to design the Robo-Raven as a surveillance tool that would blend



3D Printed Food.[15]

in with its surroundings. Robo-Raven is made of 3D-printed, lightweight and thermal-resistant plastic in addition to carbon fibre, foam and Mylar foil. Its 3D-printed components imbue the bionic bird with an agility that has been so similar to real birds that real birds of prey have actually attacked it.[16]

Robo-Raven in flight.[17]

POTENTIAL CHALLENGES

While 3D Printing promises many possibilities, there are challenges which need to be addressed as follows:

Legal Issues

Since 3D Printing can give the Army the means to manufacture components and parts that were designed, and possibly patented, by past suppliers, there is a valid concern over the issue of Intellectual Property (IP) rights infringement. In fact, at this current juncture, other governments such as the US and the European Union are still grappling with such an issue. This may necessitate the need for militaries to procure the rights to manufacturing data such as CAD files for their acquisitions. It has been assessed that 3D Printing may lead to widespread copyright theft, if printing any 3D item is as easy as downloading a song or movie illegally. Should a CAD file of a firearm be easily downloadable, it might potentially be a huge safety issue. Currently in the US, a handgun has been printed by a 3D Printer, assembled and successfully test-fired by a firearms manufacturer.[18]

Liability

Should a part that was produced by 3D Printing fail and result in damage or injury, it is unclear who will be held responsible: the 3D Printing machine Original Equipment Manufacturer (OEM), originator of Stereolithography (STL) file or personnel operating the machine. To mitigate the uncertainty in this area, it may be conservative to identify a group of personnel who are allowed to undertake the task of 3D Printing, as well as to establish a set of standards to govern the 3D Printing process. This also brings up the issue of the standards that should be used to test and qualify printed components. An effective initial proposal is to adopt the original testing requirements that were used during the manufacture process by the component OEM. Using the same qualification procedures, it will provide the assurance that the quality of the product from 3D Printing will be at least the same as that of the original.

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Occupational Health & Safety

Since 3D Printers make use of high voltage power supplies, hot surfaces and fine powdered materials, they can increase the risk of hazards to the health and safety of personnel operating them. A study in 2013 by the Illinois Institute of Technology reported that a small desktop 3D Printer had emission rates similar to that of a cigarette burning indoors. Therefore, the necessary safety infrastructure must

be established and safety codes adhered to, so as to minimise these risks. Studies have also shown that 3D Printing could create health problems if done in areas without proper ventilation due to the emissions from printing. The study results suggest that the printers which are using Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) polymers as plastic feedstock were 'high emitters' of ultrafine particles or UFPs, which can be deposited in the lungs and absorbed into the bloodstream.[19]

True Cost of Manufacture

Just as there is a Total Cost of Ownership (TCO) associated to every system, there is also a need to consider the Total Cost of Manufacture (TCM) for 3D Printing, which may be much higher than expected. This can be attributed to the materials required to make support structures during the 3D Printing process, as well as the loss of material that could not be reused. This is particularly applicable for extrusion methods such as Fused Deposition Modelling (FDM), which require the use of support material. Therefore, when budgeting for 3D Printing, the TCM should be taken into consideration.[20]

Quality Standards

Quality certification is needed to ensure that the parts printed are up to standard. This is due to a lack of world certification standards currently on 3D Printing. There are many issues that 3D Printing is now facing with the quality of parts, such as geometrical deviations, porosity and surface roughness.

FRAMEWORK FOR 3D PRINTING

Capability Development Roadmap

While the technology for 3D Printing continues to mature, it is necessary to establish a build-up plan so as to effectively leverage on the available 3D Printing technologies. It would be necessary to firstly establish the capability for 3D Printing and subsequently to sustain the capability. A proposed capability development roadmap is shown as follows:

Enabling Phase: Building Up the Foundation

The first phase of the capability build-up will focus on establishing a baseline of knowledge and competency related to 3D Printing, as well as validating the outputs of 3D Printing:

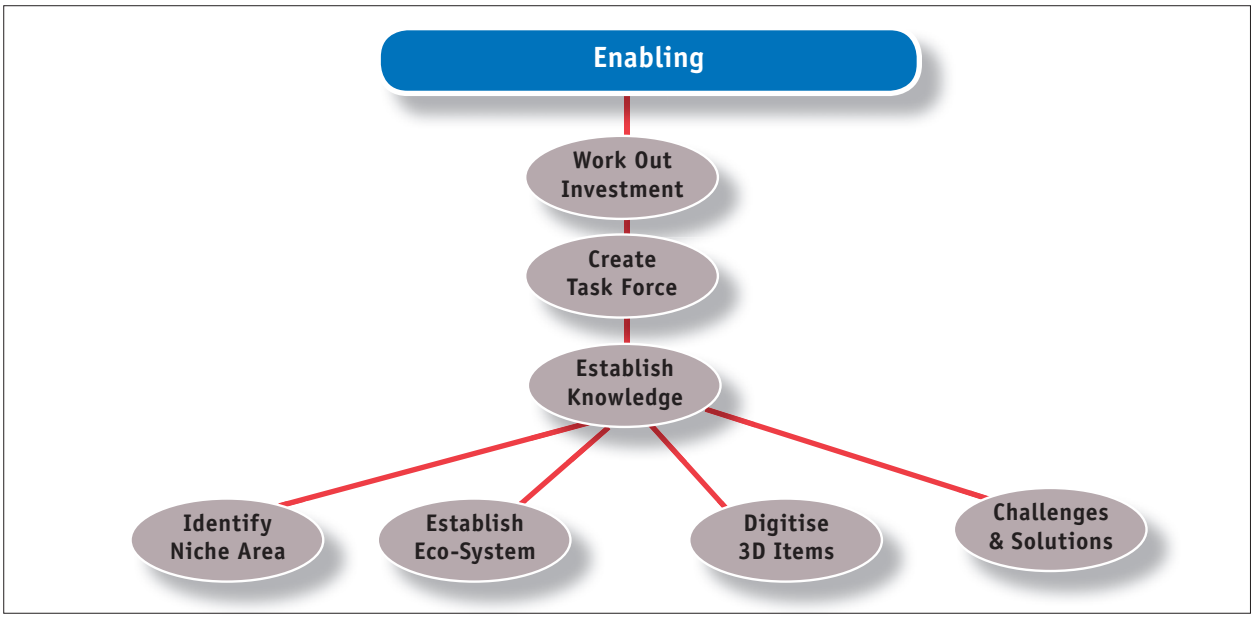

Figure 5: Enabling 3D Printing Capability.

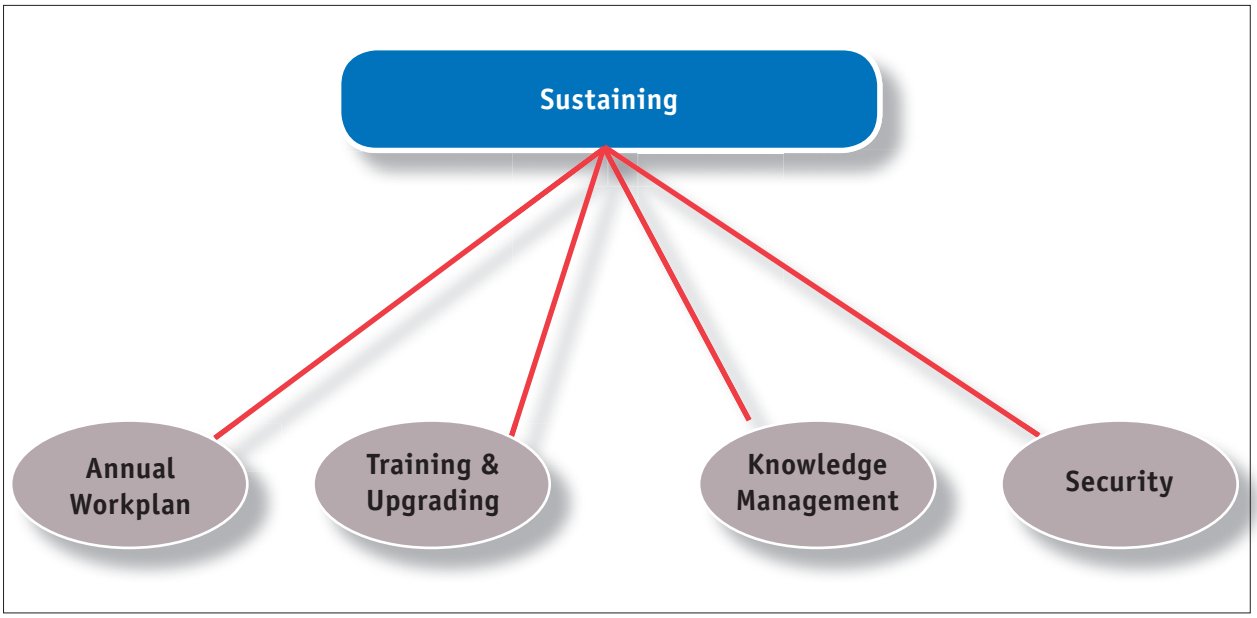

Figure 6: Sustaining 3D Printing Capability.

Work Out Return of Investment

There is firstly a need to consider and compute the return of investment that 3D Printing can bring versus current manufacturing methods. At the same time, cost computations may need to be done on the whole supply chain, as having just the technology is not enough. Considerations on the whole supply chain would need to be studied.

Create a 3D Printing Task Force

This team will identify the uses of 3D Printing and study its feasibility. As 3D Printing is progressing rapidly, the team would also need to be the eyes and ears for the military in keeping up to date with the current technology. It will also coordinate on the various levers of policies in relation to 3D Printing for the organisation.

Establish 3D Printing Knowledge & Competency

This will include sending personnel to courses and seminars (local or overseas) on 3D Printing or RP. The objectives would be to familiarise themselves with 3D Printing technologies and develop an understanding of possible 3D Printing strategies that can be adopted by the military. The knowledge gained can then be disseminated through pilot 3D Printing workshops.

Identify 3D Niche Areas

As it is not possible for everything to be 3D printed, there is a need to consider the niche areas that 3D Printing can be applicable, as well as to ensure non-infringements on printed items. The classification of items to be printed would therefore be necessary.

Establish 3D Printing Eco-system

As it may not be viable for the military to own and print their own items, it would be a necessity to establish a 3D Printing eco-system consisting of partners and suppliers. This would also be required for the long term sustenance of the technology.

Digitise 3D-Printable Items

To enable 3D Printing, the digital files of the part to be printed are essential. There would therefore be a need to digitise all the parts that have been classified to be 3D Printable. This would ensure that when the need arises, the items can be printed.

In theory, it should be possible to send a few 3D Printers to a warzone where they would use local materials to replicate themselves and then, based on digital images stored in their computers, produce an endless stream of military hardware.

Study Challenges and Derive Potential Solutions

As mentioned earlier, while 3D Printing holds many promises, there are many challenges which need to be overcome before it can reach full potential. There is therefore a need to study all the various challenges and derive potential solutions to overcome them.

Sustaining Phase: Ensuring Sustenance

With the setup of the 3D Printing task force and the initial groundwork on the feasibility of 3D Printing, the focus will shift towards operationalising the applications of 3D Printing for the military. Applications for both peacetime and operational uses should be considered. While it may be unlikely that the military print its own parts, a 3D Printer could still be purchased for experimentation and work on possible innovations.

CONCLUSION

This article has explored 3D Printing technology and its potential applications for the military. It has also highlighted its challenges and proposed a framework for the military to undertake 3D Printing. However, this is only the beginning. Future generations of 3D Printers could be made large enough to make parts for weapons systems, military vehicles or even aircraft. In theory, it should be possible to send a few 3D Printers to a warzone where they would use local materials to replicate themselves and then, based on digital images stored in their computers, produce an endless stream of military hardware. The applications of 3D Printing are therefore limited only to the imagination of the inventor. Indeed, with its many potential applications to the military, it is an invention that could be the 'mother of necessity' for the military.

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