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3D PRINTING AND ITS IMPLICATIONS ON ARMY SUSTAINMENT

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AIM

1. The aim of this service paper is to examine the advantages and challenges of implementing three dimensional (3D) printing within deployed land forces. This informative piece shall consider multiple factors to determine how 3D printing will affect sustainment. This paper is meant to provide a tactical perspective to sustainment; therefore amendments to infrastructure, tooling and organisational structures are outside the scope of the research and would require further examination.

INTRODUCTION

2. Background. 3D printing also called additive manufacturing (AM) is the "classification of processes that create physical objects layer-by-layer with a machine, digitized design drawings, and some type of building material, such as powder, metal, or plastic."[1] With rapid advances in this technology, what started as a hobby for a niche group of amateurs has evolved into "one of the most promising disruptive technologies."[2] It has been integrated into the fields of manufacturing, automotive, medicine, aerospace and defence to name a few. This technology has the potential to drastically change the Canadian Armed Forces (CAF) sustainment concepts during deployed operations. By printing repair parts or assemblies as far forward as possible "when they are needed [will be] essential to reducing overall holdings and the sustainment

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[1] Nicholas A. Meisel, Christopher B. Williams, Kimberly P. Ellis, and Don Taylor, "Decision Support for Additive Manufacturing Deployment in Remote Or Austere Environments." *Journal of Manufacturing Technology Management 27*, no. 7 (2016): 898, https://search.proquest.com/docview/1844291805?accountid=9867.

[2] Department of National Defence, *Additive Manufacturing and Repair: Support & Distribution*. (Ottawa, Ont: Defence Research and Development Canada, 2018), i.

footprint."[3] Becoming more agile is one of the main characteristics of the Army of Tomorrow in adaptive dispersed operations (ADO).[4]

3. Director General Land Equipment Program Management (DGLEPM) is currently examining the developments in AM with a particular interest in its implementation within the land equipment management system (LEMS) on deployed operations. The bulk of this paper consists of the considerations relevant to the implementation of AM at the tactical level. Initially, the present and future opportunities brought forth by this new technology will be explored. Next, a thorough analysis of the existing challenges of deploying 3D printers in austere and contested environments will be presented before ending with recommendations on implementation.

DISCUSSION

Present and future advantages of AM

4. Additive manufacturing has evolved through advances in technology at an ever-increasing rate. As Moore's law predicts, the extraordinarily fast growth over time in the amount of computing hardware available for the same dollar of spending becomes exponentially more powerful every year or so.[5] While industry, academia and government continue to explore innovative ways to use 3D printing and invest significant funds in research and development, printing speeds, quality, size and versatility are ever increasing. These factors have yet to plateau

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[3] Department of National Defence, *Toward Land Operations 2021: Studies in Support of the Army of Tomorrow Force Employment Concept*. (Kingston, Ont: Directorate of Land Concepts and Design, 2009), 9-5.

[4] Department of National Defence, *Land Operations 2021: Adaptive Dispersed Operations: A Force Employment Concept for Canada's Army of Tomorrow* (Kingston, Ont: Directorate of Land Concepts and Doctrine, 2007), 32.

[5] Andrew McAfee and Erik Brynjolfsson, *Machine, Platform, Crowd: Harnessing Our Digital Future* (New York: W.W. Norton & Company, 2018), 35.

and therefore, "there is no reason to believe that the coming decades will not include breakthroughs in additive manufacturing that would astonish laypersons living today."[6] As with any new technology, with time, the cost of printers and their raw materials are inversely proportional to their performance. For this paper to be relevant for the next few years, the opportunities will be divided into what is possible now and what analysts predict will be possible in the decades to come.

5. The Canadian Army (CA) has minimal experience with AM. "The Land Engineering Support Centre (LESC) is mainly the only land institution using 3D printing for prototyping."[7] The few components that have been designed for armoured vehicles were printed using plastics to validate form and function before having the metal components manufactured by industry. At the moment, the Royal Canadian Navy (RCN) is leading the way within the CAF. A laser AM system has been purchased for use at the Fleet Maintenance Facility (FMF) Cape Scott. The equivalent of 202 Workshop Depot for the Navy, it uses the 3D metal printer to support its ageing fleets and prevent part obsolescence. Multiple components were repaired such as a fuel flow meter, some bearing surfaces, gear splines and cracked castings.[8] These repairs saved time and ensured the operational readiness of the ships. A 3D printer has recently been acquired and is currently deployed on ongoing operations aboard the HMCS VILLE DE QUEBEC with the RCN.

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[6] John M. Mattox, "Additive Manufacturing and its Implications for Military Ethics," *Journal of Military Ethics* 12, no. 3 (2013): 227.

[7] Department of National Defence*, Additive Manufacturing and Repair…,* 39.

[8] Ibid., 38.

6. The United States (US) Army, Navy and Marines are all developing additive manufacturing capabilities and are considered by members of the North Atlantic Treaty Organization (NATO) to be at the forefront of AM efforts.[9] The US Army has already implemented AM at the brigade combat team level on deployed operations. They have installed additive manufacturing laboratories in universal sea containers for ease and rapidity of strategic and tactical deployments. The Rapid Equipping Force has provided innovative solutions to complex problems, "including valve stem guards, M249 Squad Automatic Weapon bipod links, and handheld mine detector light mounts."[10] Other advances include small arms components, custom body armour, helmets, munitions, engine and missile components, tools and modular infrastructure. They have even designed, printed and assembled a complete drone.

7. Defence and security is not the only industry to invest heavily in additive manufacturing. The National Aeronautics and Space Administration (NASA) embraced the technology by sending a 3D printer to the International Space Station (ISS) as early as 2014. They have managed to produce tools in the zero-gravity environment. The advantages of producing critical components as needed in the confines of the station are quite obvious considering the isolated nature of space and the delay in shuttle replenishments. As space and weight restrictions will be critical on future missions to Mars, NASA has investigated the use of processed human waste to manufacture tools and components. Even though this concept might seem like science fiction, it's a lot closer to becoming a reality in the near future.[11]

[9] Ibid., 24.

[10] Daniel Kent and Maj Michael Carvelli, "Looking at 3-D Printing from all Sides Now: New Technology Offers Major Benefits for Army Maintenance," *Army 66*, no. 11 (11, 2016): 20, https://search.proquest.com/docview/1843276016?accountid=9867.

[11] Calgary Homestretch, "Students fly in 'Vomit Comet' to test 3D-printing tools with recycled astronaut poo," *CBC news Calgary*, 29 August 2018.

8. The Canadian Army may not need to go to such extremes as NASA, but the implementation of additive manufacturing will bring many advantages in the next 5-15 years. As Land Operations 2021 highlights, the advances in technology will "allow for a reduced logistics burden in terms of daily operational supply and forward stock holdings."[12] Printing repair parts as required in an isolated area with extended lines of communication has the potential to reduce the strategic lift necessary to deploy and the tactical lift to support the dispersed forces. By "increasing readiness rates and flexibility through decreased waiting times and by making thousands of parts versus packing and shipping tens of them,"[13] the deployed force becomes more agile and responsive. Reducing the logistic burden will provide more ground and air resources for the pointy end of the spear, the combat forces.

9. Whether you print one component or a hundred, AM doesn't offer economies of scale similar to traditional manufacturing. "With AM there is no minimum batch size, no cost for tooling and no cost for prototyping" This is an especially useful factor within the CA where small fleet sizes rarely provide enough incentive for industry to ramp up a production line unless significant funds are invested. Customization of small arms accessories, "body armour and other personal equipment such as boots could be tailor-made to conform to the soldier physiology as opposed to the soldier conforming to the configuration of the equipment."[14] Such endeavours would limit the stock holdings within the supply system and reduce wait times. Nike as already

[12] Department of National Defence, *Land Operations 2021: Adaptive Dispersed Operations…*, 32.
[13] Daniel Kent and Maj Michael Carvelli, *Looking at 3-D Printing from all Sides Now…*, 20.
[14] Department of National Defence, *Director General Land Equipment Program Management Report on Additive Manufacturing Capability Development (*Ottawa, Ont: Director General Land Equipment Program Management, 2017), 18.

started to 3D print running shoes by applying 3D scanning and producing a tailor-made upper that perfectly matches the client's feet.

10. Recent innovations have rendered 3D printing "capable of constructing infrastructure, including the building of base camps, and humanitarian efforts, or enclosing contaminated areas with limited exposure to personnel."[15] This aspect of AM could be greatly beneficial to the Disaster Assistance Response Team (DART), Canadian Joint Incident Response Unit (CJIRU) or theatre activation teams.

11. As AM matures new innovative materials such as ceramics, composites, resins and concrete are being used to produce articles. Even waste such as used water bottles, plastic cutlery, cardboard and broken parts could be recycled and used as the "ink" for a 3D printer. Further in the future, it could be envisioned that "If a truck is equipped with a diagnostics system, then that system could communicate with a 3D printer when it determines a part is near failing. That printer manufactures the part using a pre-existing technical data package."[16] As new vehicle fleets are procured the detailed technical data package (TDP) enabling additive manufacturing could be included in the lifetime support contract. Another option for technicians wanting to produce a repair part could be to access the Interactive Electronic Technical Manual (IETM) and print the components required.

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[15] Christopher Bayley and Michael Kopac, "The Implications of Additive Manufacturing on Canadian Armed Forces Operational Functions," *Canadian Military Journal* 18, no. 3 (2018): 48.

[16] Justin Katz, "3D PRINTING CHANGING KEY QUESTIONS AROUND WEAPON SYSTEMS ACQUISITIONS," *Inside the Pentagon's Inside the Navy* 30, no. 40 (Oct 09, 2017): 2, https://search.proquest.com/docview/1949020503?accountid=9867.

Challenges of additive manufacturing

12. The arrival of AM technology has the potential to revolutionize the way we sustain deployed defence forces, however, the challenges faced in achieving this full potential are quite significant. One of these factors specific to tactical sustainment is the environment. The environmental conditions under which the printing takes place such as dust, ambient temperature fluctuation, and humidity can significantly affect the quality of the end product. The use of a clean room such as the 2nd line Electronic-Optronic (EO) maintenance shelters would be required. Another challenge in a deployed environment is the requirement for a continuous source of stable voltage. Any fluctuations during the printing process which can regularly take upwards of 12 hours could render the component useless.

13. Operator safety is a concern which needs to be factored. “Most 3D printers emit nanoparticles which are not necessarily safe since they can interact with the body’s systems, including the skin, lungs, nerves and the brain.”[17] Personal protective equipment is critical to prevent injuries resulting from electrocution, hot surfaces and ultraviolet radiation. Important to note that some “AM powders are potentially explosive and highly dangerous and they must be stored in a location which is separate from the production facility.”[18] Storage, transportation and handling of these dangerous goods can become quite complicated in austere environments.

14. With the premise of printing most of the repair parts in theatre, additive manufacturing is still relatively slow. It can take anywhere from an hour to over a day to manufacture a metal part, depending on its size and the quality of the printer. Even with multiple printers operating

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[17] Department of National Defence*, Additive Manufacturing and Repair…,* 18.
[18] Department of National Defence, *Director General Land Equipment Program Management Report …,* 43.

simultaneously, the requirements from a maintenance workshop could quickly run a backlog. New techniques are being discovered which could accelerate the printing speeds by tenfold and resolve this issue.

15. The land materials technicians (MAT TECH) would be the obvious choice in allocating the responsibility of additive manufacturing within the CA. Their training in sheet metal work, machining, fabrication, metallurgy, welding and manufacturing is an excellent complement to AM. However, Mat techs would still need further training to operate 3D printers safely. If technicians are to create the data packages to print components, formal training is required in Computer-Aided Design (CAD). As with any technician with a particular qualification, proper employment within this speciality and career limitations become a concern.

16. Land Material Assurance (LMA) is a critical factor in AM. The plethora of new 3D printing manufacturers has created a lack of universal standards of product quality and safety. “Obviously, components that bear dynamic forces or are load-bearing will need to meet higher standards than others.”[19] As AM cannot currently produce 3D metal parts with consistent quality, strength and reliability, a significant amount of risk would need to be accepted, or each individual part would need to be tested. The latter option may not be cost permissive.

17. Intellectual property (IP) infringement is a common risk with AM even if the OEM has stopped producing the vehicle fleet and its related parts. At the moment, DGLEPM doesn’t own

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[19] Department of National Defence, *Director General Land Equipment Program Management Report …*, 41.

most of the IP for the fleets they support. Since designing the component in CAD is a significant portion of the printing process, the cost of TDP and the related IP should not be underestimated.

18. As mentioned previously, the cost of AM technology has decreased over the last few years, however, it can still be quite significant. Most manufacturers of 3D printers require the use of their brand of raw materials which are purchased at a premium. In service support of this equipment such as calibration, preventive maintenance and repair are also to be considered. An in-depth economic analysis of implementing AM in the CA would be beneficial but require substantial research which would only remain valid for a short duration as the technology rapidly evolves, therefore it is considered outside the scope of this service paper.

CONCLUSION

19. This service paper examined the advantages and challenges of implementing three dimensional (3D) printing within deployed land forces. It is quite clear that the CA and the CAF will benefit from this new technology and its progression cannot be ignored. DGLEPM has a vested interest in understanding how AM will impact LEMS at levels in the short, medium and long term. The information presented in this paper is by no means a definitive analysis of all the factors that need to be considered before fielding this capability at the tactical level. It does, however, highlight significant challenges that would need to be resolved or mitigated in order to pursue this endeavour. At the moment, additive manufacturing is not mature enough for deployed land forces to significantly benefit from its opportunities.

RECOMMENDATIONS

20. Based on the information presented during this service paper, the following are recommendations concerning the implementation of additive manufacturing at the tactical level within the CA.

a. Continue to evaluate the technological advances of AM by collaborating with defence stakeholders such as the Material Group, Defence Research and Development Canada. Involve other groups such as other government departments, academia and industry;

b. Consider amending the policy of IP ownership when negotiating procurement options on future capital investments;

c. Postpone the implementation of 3D metal printing at the tactical level until the technology matures and LMA standards are established. A proof of concept could be planned using a low-cost polymer 3D printers fielded within Maintenance Companies throughout the CA as a Buy and Try; and

d. Participate in AM working groups to leverage opportunities for collaboration with our military allies.

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