National Defence Défense nationale

Canadian Forces College
Collège des Forces Canadiennes

ADDITIVE MANUFACTURING: SUPPORT TO CANADIAN ARMY SUSTAINMENT

Major Ryan Adams

JCSP 45

Service Paper

Disclaimer

Opinions expressed remain those of the author and do not represent Department of National Defence or Canadian Forces policy. This paper may not be used without written permission.

PCEMI 45

Étude militaire

Avertissement

Les opinons exprimées n'engagent que leurs auteurs et ne reflètent aucunement des politiques du Ministère de la Défense nationale ou des Forces canadiennes. Ce papier ne peut être reproduit sans autorisation écrite

Canada

CANADIAN FORCES COLLEGE/COLLÈGE DES FORCES CANADIENNES
JCSP 45/PCEMI 45
15 October 2018/15 Octobre 2018

DS545 COMPONENT CAPABILITIES
SERVICE PAPER

ADDITIVE MANUFACTURING: SUPPORT TO CANADIAN ARMY SUSTAINMENT

By Major Ryan Adams
Par le major Ryan Adams

Word Count: 2635

Nombre de mots: 2635

ADDITIVE MANUFACTURING: SUPPORT TO CANADIAN ARMY SUSTAINMENT

AIM

1. The aim of this service paper is to explore the potential of Additive Manufacturing (AM) technologies to contribute to the sustainment of Canadian Army (CA) vehicle and equipment fleets. While the CA is aware of '3D Printing' in general, its rapid evolution warrants increasingly frequent re-examination to determine its technological readiness to facilitate the transition of the sustain function "to a distribution-based system where supplies are held within a pipeline and delivered on as required basis[1]" as well as enhance the provision of specific health services. This paper seeks to examine the breadth of the AM opportunity space and its capacity to influence the sustainment of CA equipment.

INTRODUCTION

2. In order for the Canadian Armed Forces (CAF) to execute its core missions domestically and abroad, it must be able to sustain its forces. CA Sustain function "integrates strategic, operational and tactical levels of support to generate and maintain force capability. This function addresses issues of sustainment on the physical and moral planes. It integrates the provision of materiel and personnel support to ensure the sustainment of combat power[2]". The CA must be able to sustain its capabilities in a responsive and ideally cost effective manner. Additionally, successful support to the Adaptive Dispersed Operations envisioned in Land Operations 2021 will necessitate "a highly integrated, adaptive and flexible sustainment system[3]". Technological advances in AM represent an opportunity to reduce the strain on, or even revolutionize key aspects of the CA sustainment system.

3. This paper will first outline the context of sustainment of land forces. It will discuss present employment of AM systems, followed by an examination of near-term technological readiness and capabilities of the technology. Within this context, the paper will explore potential CA specific applications and analyze the AM sub-systems as part of a viable future CA sustainment capability.

DISCUSSION

Context

4. The CA's current approach to sustainment is founded upon a "supply-based support system, centred on stockpiling within echelons[4]". This system begins via initial centralized procurement of capital equipment which includes a package of 'two years' worth of initial spare parts. Those parts are then decentralized among the depots and units servicing and employing the corresponding equipment for training and operations.

5. Maintaining fleet readiness is perpetual challenge for the CA. First this multi-resource intensive approach requires upfront capital investment, stocking, repetitive shipping based on

---

[1] *B-GL-300-001/FP-001 Land Operations.* Ottawa: DND Canada, January 2008. Para 417.
[2] *B-GL-310-001/AG-001 Land Operations 2021.* Ottawa: DND Canada, 2007. 12.
[3] *Ibid*., 32.
[4] *B-GL-300-001/FP-001 Land Operations.* Ottawa: DND Canada, January 2008. Para 417.

readiness cycles, and long-term warehousing of parts; some of which are consumed early requiring subsequent, costly acquisition, while others are never used. Secondly, the bulk of the CA's support vehicle fleet (B-fleet) has reached or exceeded life-expectancy, making the sourcing and purchase of military specific replacement parts problematic and increasingly expensive. One illustration of this dynamic is cited in the Common Heavy Equipment Replacement (CHER) Project Business Case Analysis (BCA): "The current Heavy Support Equipment [HSE] contains mechanically fatigued machines up to thirty-three (33) years old; most have surpassed their service-life, and are technologically obsolete[5]". In order to "operate beyond economical life expectancy, [HSE] requires significant and recurring investments; many commonly required individual repair components are now obsolete and no longer in production[6]". This reality "increasingly forces maintenance personnel to conduct time consuming searches for used parts through equipment recyclers often times in the United States or broker one-off production of custom components from machine shops[7]". Therefore as fleet readiness becomes increasingly sensitive to budgetary and time implications, the CA must consider any means of adapting its sustainment strategy.

6. "The relationship between technological advancement and adaptation is the critical starting point for considering the military implications of future scientific and technological evolution[8]". While military necessity has been a traditional driver of technological advancements, the CA is able to look to industry for innovative sustainment technologies. According to Strong, Secure, Engaged (SSE), "Canada's military must be agile, flexible and responsive in meeting the challenges and capturing the opportunities of our rapidly evolving world[9]". Having previously recognized the opportunity potential of AM technology to mitigate and/or enhance sustainment approaches [10](among the other operational functions) in 2014, the CA is now seeking greater situational awareness in regard to possible employment and management of such a capability.

Current Employment

7. First developed in 1983 for rapid production of new design prototypes using plastics[11], the technology now referred to as Additive Manufacturing has grown into a broad range of production techniques that construct an object by depositing layers of a given material based on a computer's digital model of that object. Envisioned in CAF Future Security Environment 2013-2040, "Additive manufacturing has the potential to dramatically change the sustainment function. The CAF could seek to reduce its logistical tail with the ability to build spare parts and other supplies in the joint operational area[12]."

8. The CAF has some, albeit isolated, experience with AM. Faced with the same type of challenge as that of the CA's B-Fleet, the Royal Canadian Navy (RCN) has yielded the most

---

[5] Business Case Analysis: Common Heavy Equipment Replacement Project. Directorate of Land Requirements. May 2017. Executive Summary.
[6] *Ibid*., 1.1.3.5.
[7] *Ibid*., 3.3.3.
[8] *The Future Security Environment, 2013-2040*. Winnipeg. Chief of Force Development DND Canada, 2014. 63.
[9] *Strong, Secure, Engaged: Canada's Defence Policy*. Ottawa: June 2017. 67.
[10]C. Bayley and M. Kopac. "The Implications of Additive Manufacturing on Canadian Armed Forces Operational Functions", *Canadian Military Journal*. Volume 18, No. 3 2018.
[11] *3D Printing History: The Free Beginner's Guide*. February 2016.
[12] *The Future Security Environment, 2013-2040*. Winnipeg. Chief of Force Development DND Canada, 2014. 69.

significant sustainment gains through its employment of AM to address equipment readiness. It equipped its Halifax Fleet Maintenance Facility (FMF) in 2012 with "the [AM] capability of not only defect rectification, but also manufacturing obsolete pieces, thereby ensuring [its] vessels are operational and are able to continue with missions[13]". Other elements' practical uses of 3D printing are focused on individual training. The Engineering Department of the Royal Military College (RMCC) has been using 3D printing since 2010 to "assist students in the design and evaluation of engineering projects, utilizing a tool-of-the-trade it considers essential for tomorrow's engineers[14]". The CA's Army Learning Support Center produces scale models to support leadership war-gaming, as well as replica tools and equipment components for technician training. In 2014, the Canadian Army Land Warfare Center (CALWC) in conjunction with Defence Research and Development Canada (DRDC) took a proactive step by sponsoring the Emerging Disruptive Technology workshop in which it "identified how AM could influence the Canadian Armed Forces operational functions[15]".

9. Comparatively, the United States (US) Army actively pursuing the incorporation of AM capabilities to support its operations. In 2014 it began developing policy and requirements, as well as conducting the BCA "to reduce logistical burden through point-of-use AM". It is also actively working on "requirements for in-theatre AM"[16]. Research & Development Command's (RDECOM) laboratory focuses "on research related to enhancing machine performance, material development, direct-write electronics and hybridization of processes", while the engineering centers "focus on applications in prototyping, discrete part manufacturing, low-cost tooling, repair of metallic components and rapid fielding"[17], and its depots and arsenals use "AM for repair…processes on Army systems"[18]

10. To promote technological innovation, SSE introduced the Innovation for Defence Excellence and Security (IDEaS) program[19]. Currently, the CAF is seeking an innovative approach to the Shield function through the application of AM to the fabrication and evaluation of armour systems for personnel and platforms[20].

Technological Readiness

11. Today, industrial additive processes deliver "material integrity and consistency that are superior to casting and rival the properties of forgings[21]". As forging is the conventional production method for the majority of vehicle driveline, steering, engine, frame and suspension components, AM processes are now a viable manufacturing alternative. While there are many types of AM process, two common methods are Direct Metal Laser Sintering (DMLS) which is typically used to produce new parts from a bed of metal powder, while Direct Metal Disposition (DMD) which injects powdered metal into a laser beam, can be used for both new part

---

[13] "3D Printing Transforms the RCN", *The Navy News*. February 2016.
[14] S. Lachance. "Royal Military College engages its future engineers with 3D printer", *eVeritas*.
[15] C. Bayley and M. Kopac. "The Implications of Additive Manufacturing on Canadian Armed Forces Operational Functions", *Canadian Military Journal*. Volume 18, No. 3 2018.
[16] Clark Kerwien, S. *U.S. Army RDECOM Additive Manufacturing Plans & Activities.* US Army RDECOM-ARDEC. August 2014.
[17] *Ibid*.
[18] *Ibid*.
[19] *Strong, Secure, Engaged: Canada's Defence Policy*. Ottawa: June 2017. 77.
[20] *Additive Manufacturing for High Performance System.* Ottawa: ISEDC, May 2018.
[21] Zelinski, P. "The Possibilities of Electron Beam Additive Manufacturing". *Additive Manufacturing*. March 2016.

production, as well repair of damaged metal components. While these AM techniques are capable of making near-net-shape workpieces, these objects, like those made from forging, still require subsequent processing such as heat treating, machining, polishing and quality inspections in order to become end-useable parts. Presently each step in this whole process chain requires personnel with specific design, metallurgical, testing and machining expertise, as well as the specialized equipment and machinery to complete the finishing work. AM, as part of a whole process, is capable of producing the quality of sustainment components needed to contribute to the readiness of the CA's vehicle fleets.

Contributions to CA Sustain

12. According to DRDC, the most promising application for AM in the realm of sustainment is that of parts-on-demand, (followed by customized health care solutions)[22]. An integral capacity to produce replacement vehicle and equipment parts on an as needed basis, or reproduce those no longer commercially available, as well as repair of damaged components will primarily improve CA readiness by lowering the mean-time-to-repair of broken vehicles & equipment. AM methods and point of production would be typically subject to the complexity of the required parts, volume required, time sensitivity, and costing.

13. From an institutional perspective this capability would also serve to reduce Operations & Maintenance (O&M) expenses by lessening the need for vast warehousing of spare parts inventories and less frequent shipping of parts to end-users. It would also reduce overall demand on the Department's Investment Plan (IP), as the traditional practice of up-front investment of vast quantities of spare parts within each new capital equipment project would no longer be required on the same scale.

14. Intellectual Property law will prove to be a very significant consideration when deciding on which parts to internally produce rather than purchase.   In general, the implications of the law will depend on who holds the IP for a given part, what is the IP, and how long the IP is protected.   In Canada patents are held for 20 years, while copyrights are valid for the life of the creator and trademarks are forever as long it is in use. Only if the IP has expired, can the parts be reproduced without cost. Otherwise it will be necessary to purchase the license for the part[23].

AM Within a Greater Capability

15. A capability for the CA consists of equipment, personnel, and training.   On its own, the benefits of AM are limited. Rather it represents a sub-system within a whole process capable of taking an idea or concept through to production of an end-useable part.   This system of equipment includes storage of Original Equipment Manufacturer (OEM) design data (usually purchased), computer design and reverse engineering (for obsolete and modified parts), AM machine for printing the rough part, followed by a selection of finishing equipment such as heat treating oven, CNC machine, lathe & mill, and testing equipment as well as the shop floor itself. Mirroring industry, the specialized personnel required to produce, repair, or re-manufacture end-useable parts include design, materials, and manufacturing engineers & technicians, CNC

---

[22] C. Bayley and M. Kopac. "The Implications of Additive Manufacturing on Canadian Armed Forces Operational Functions", *Canadian Military Journal*. Volume 18, No. 3 2018.
[23] A/JAG. Email exchange with author. 04 October 2018

operators, and machinists. These expertise, are developed via post-secondary education at colleges and universities.

16. At present technology levels, this construct could be reasonably adopted by DND, as each element is supported by 3rd line engineering and workshop facilities to assist in fleet sustainment. In support of the CA, Director General Land Equipment Program Management (DGLEPM) operates Quality Engineering Test Establishment (QETE) and 202 Workshop Depot (202 WD). To fulfill their current assigned sustainment tasks, these organizations are generally populated with the requisite engineering and machining personnel and equipment – less the AM equipment and associated training. To integrate an AM capability, QETE would be responsible for developing a data base of parts, as well as end-part certification, while 202 WD equipped with AM machines, would be responsible for physical production. The Technical Authorities for each fleet would remain responsible for directing and funding the production of individual parts.

17. As the technology evolves, it is conceivable that AM machines capable of self-completing finishing work will be produced, reducing process steps and specialized personnel requirements. Paired with a sufficiently populated parts data base, it is at that point where the capability will become more viable for point-of-use production within a Forward Support Group (FSG) to sustain deployed operations.

CONCLUSION

18. With only a few integral examples of AM pursuits, DND has yet experience the magnitude of contributions possible with this technology as a defence capability. To date known CA investment has been limited to one focused study, and a unit level acquisition of a localized AM machine to assist in individual training. While this is not unreasonable given the evolving nature of AM, industry has brought the technology readiness level to the point where it is now capable of mitigating CA ground fleet readiness challenges, particularly in the realm of cost & time effective, centralized, small scale reproduction or repair of components for obsolete support vehicle fleets. As these fleets are re-capitalized over the next decade, the capability will also mature to include not just centralized production, but also deployable provision of end-useable parts, significantly off-setting the burden on the sustainment chain and CA O&M budget. As this capability becomes institutionalized, next horizon capital projects will be in a position to reduce requirements for up-front investment in spare parts and special tooling, lowering demands on the Department's IP.

RECOMMENDATIONS

19. The CA must appreciate that AM is no longer a novel technology in development. Rather, having experienced exponential growth in scale and capability, it is now a dependable production means within industry. In order to efficiently realize the benefits of AM for itself, the CA must become more proactive in its exploration and adopt a more deliberate approach to the development of AM capability within it's sustain functions. As Deputy Assistant Secretary of the US Navy stated in remarks at the Karles Invitational Conference in August 2016, "…we need to ensure that the fields are ploughed so when industry 'marketizes' a product, Defence is ready to accept this manufacturing method". Therefore the following recommendations are presented for CA consideration:

a. While CALWC previously examined how AM can influence CA operational functions, the CA should identify an additional, down-stream capability development representative - possibly within DLR - to maintain situational awareness of AM progress and practical opportunities for CA to leverage, through direct liaison with Allies, ADM(Materiel), R&D institutions and industry.

b. Stemming from this effort, the representative would also be in a position to support a Capability Based Planning process in conjunction with stakeholders such as CALWC and Director Land Force Development (DLFD). Subsequently undertake an initial PRICIE+G analysis, and identify possible High Level Mandatory Requirements (HLMRs) for a future 2nd line, deployable whole process chain capability for on-site production of end-useable vehicle components.

c. The manufacturing sector has successfully developed AM to assist in static production-line processes. Unlike manufacturers, the CA will in part benefit from a deployable (i.e. mobile) AM capability. Therefore the CA is uniquely situated to serve as a catalyst for our defence industry to 'marketize' such a capability as envisioned by SSE[24]. There is opportunity to further leverage the IDEaS initiative as well as continue to work with Public Services and Procurement Canada's (PSPC) Built in Canada Innovation Program (BCIP).

d. AM's current technological readiness level (TRL) makes it viable contributor for 3rd line sustainment operations. A BCA should be undertaken by DGLEPM to explore the development of an AM capability within QETE and 202 WD, to facilitate in-house reproduction and remanufacture of obsolete or damaged components that are currently out-sourced at significant expense and time. Subject to the state of expertise, initial focus could be on parts that do not have extensive verification/validation requirements.

e. As discussion of health care sustainment was outside the scope of this paper, AM's capabilities should be explored in detail by medical subject matter experts within Military Personnel Command (MPC) while coordinating efforts with the CA AM stakeholders.

f. In order to capitalize on the aforementioned efforts, be prepared to establish Minor Capital Projects (MCP) to acquire exploratory/trial AM systems with a view to refine requirements and concepts of employment for vehicle and soldier health care sustainment.

g. Determine the legal implications surrounding the employment of AM with regard to intellectual property rights by undertaking dialogue with experts from Judge Advocate General, ADM(Materiel), PSPC, and Innovation Science and Economic Development Canada (ISEDC).

---

[24] *Strong, Secure, Engaged: Canada's Defence Policy*. Ottawa: June 2017. 75.

h. Future capital projects should seek to incorporate licencing of intellectual property with priority to high cost and high wear parts and components.

BIBLIOGRAPHY

Canada. Department of National Defence. *Strong, Secure, Engaged: Canada's Defence Policy*. Ottawa: June 2017.

Canada. Department of National Defence. *B-GL-300-001/FP-001 Land Operations*. Ottawa: DND Canada, January 2008.

Canada. Department of National Defence. *B-GL-310-001/AG-001 Land Operations 2021*. Ottawa: DND Canada, 2007.

Canada. Department of National Defence. *Business Case Analysis: Common Heavy Equipment Replacement Project*. Ottawa: Directorate of Land Requirements, DND Canada. May 2017.

Canada. Department of National Defence. *The Future Security Environment, 2013-2040*. Winnipeg: Chief of Force Development, DND Canada. 2014.

Canada. Department of National Defence. "3D Printing Transforms the RCN", *The Navy News*. February 2016. http://www.navy-marine.forces.gc.ca/en/news-operations/news-view.page? doc=3d-printing-transforms-the-rcn/il3c32xa

Canada. Department of National Defence. "Five Eyes workshop explores 3D printing for deployed logistic operations", *The Maple Leaf,* May 2018.

Canada. Innovation, Science and Economic Development Canada. *Additive Manufacturing for High Performance System.* Ottawa: ISEDC, May 2018. https://www.ic.gc.ca/eic/site/101.nsf/eng/00025.html

Clark Kerwien, S. *U.S. Army RDECOM Additive Manufacturing Plans & Activities.* US Army RDECOM-ARDEC. August 2014.

Macpherson Brewer, M. "Make me a tank: 3D printing and computer animation leading the way in training the future Canadian Army", *Army News*. July 2015. http://www.army-armee.forces.gc.ca/en/news-publications/national-news-details-no-menu.page?doc=make-me-a-tank-3d-printing-and-computer-animation-leading-the-way-in-training-the-future-canadian-army/ib6au7mx

Dutta, B., Palaniswami, S., Choi, J., Mazumder, J. "Rapid Manufacturing and Remanufacturing of DoD Components Using Direct Metal Depositon", *The AMMTIAC Quarterly*, Volume

6, Number 2. https://pdfs.semanticscholar.org/c5ba/2cbc5ec3914c2b44d514f99e053839e6dab1.pdf

Zelinski, P. "The Possibilities of Electron Beam Additive Manufacturing". *Additive Manufacturing*. March 2016. https://www.additivemanufacturing.media/articles/the-possibilities-of-electron-beam-additive-manufacturing

C. Bayley and M. Kopac. "The Implications of Additive Manufacturing on Canadian Armed Forces Operational Functions", *Canadian Military Journal*. Volume 18, No. 3 2018. http://www.journal.forces.gc.ca/vol18/no3/eng/page47-eng.asp

S. Lachance. "Royal Military College engages its future engineers with 3D printer", *eVeritas*. August 2010. http://everitas.rmcclub.ca/rmc-engages-its-future-engineers-with-3d-printer/

3D Printing Industry. *3D Printing History: The Free Beginner's Guide*. February 2016. http://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/history/

Foskett, S. Defining Failure: What Is MTTR, MTTF, and MTBF? July 2011. https://blog.fosketts.net/2011/07/06/defining-failure-mttr-mttf-mtbf/

Manfredi, D., Calignano, F., Krishnan, M., Canali, R., Paola Ambrosio, E., Atzeni, E. "From Powders to Dense Metal Parts: Characterization of a Commercial AlSiMg Alloy Processed through Direct Metal Laser Sintering". *Materials.* March 2013. *https://www.mdpi.com/1996-1944/6/3/856/htm#B1-materials-06-00856*

Simchi, A., Petzoldt, F., Pohl, H. "On the development of direct metal laser sintering for rapid tooling". *Journal of Materials Processing Technology* Volume 141, Issue 3. November 2003. https://www.sciencedirect.com/science/article/pii/S0924013603002838

Zelinski, P. "Lockheed Martin: Importance of Closed-Loop Control in AM". *Additive Manufacturing*. August 2016. https://www.additivemanufacturing.media/articles/lockheed-martin-importance-of-closed-loop-control-in-am